[illegible] DATA SHEET

PN-AAJ-139

[illegible]

International Rice Research Institute; annual report, 1978

4. PERSONAL AUTHORS (100)

5. CORPORATE AUTHORS (101)

IRRI

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1979	789p.	633.18.I61a-1978

9. REFERENCE ORGANIZATION (130)

IRRI

10. SUPPLEMENTARY NOTES (500)

(Research summary)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Rice
Plant genetics
Plant general
[illegible]

Soil fertility
Yield
Technological change

13. PROJECT NUMBER (150)

14. CONTRACT NUMBER (140)

The International Rice Research Institute

Annual Report for 1978

PN-

The International Rice Research Institute

Annual Report for 1978

The International Rice Research Institute receives support from a number of donors, including The Ford Foundation, The Rockefeller Foundation, the European Economic Community, the United Nations Development Programme, the United Nations Environment Programme, the Asian Development Bank, the International Development Research Centre, the World Bank, and the international aid agencies of the following governments: USA, Canada, Japan, the United Kingdom, the Netherlands, Australia, the Federal Republic of Germany, Iran, Saudi Arabia, New Zealand, Belgium, Denmark, and Sweden.

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

ERRATA 1978 ANNUAL REPORT

Page 12. First column, 5th paragraph, 6th line: change 28,409 to 13,359. Table 1: change 28,409 of Total to 13,359.

Page 46. Replace Table 17 with the following:

Table 17. Grouping of Philippine races on the basis of reaction of key varieties. IRRI, 1978.

Variety	Reaction[a] to race group											
	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL
Kataktara DA-2	S	R	R	R	R	R	R	R	R	R	R	R
CI 5309	S	S	R	R	R	R	R	R	R	R	R	R
Chokoto	S	S	S	R	R	R	R	R	R	R	R	R
CO 26	S	S	S	S	R	R	R	R	R	R	R	R
Wagweg	S	S	S	S	S	R	R	R	R	R	R	R
Pai-kan-tao	S	S	S	S	S	S	R	R	R	R	R	R
Peta	S	S	S	S	S	S	S	R	R	R	R	R
Raminad str. 3	S	S	S	S	S	S	S	S	R	R	R	R
Taichung T.C.W.C.	S	S	S	S	S	S	S	S	S	R	R	R
Lacrosse	S	S	S	S	S	S	S	S	S	S	R	R
Sha-tiao-tsao(s)	S	S	S	S	S	S	S	S	S	S	S	R
KTH-17	S	S	S	S	S	S	S	S	S	S	S	S

[a]S = susceptible, R = resistant.

Page 126. Table 4: run a straight line across from under 8 in column Internode length (cm) to under 75 in column Cumulative length.

Page 135. First column, 4th paragraph: change Krang Serang 55 to read Karang Serang 55.

Page 193. Figure 12: change the title of the ordinate to read: Fertile eggs (cumulative no./100 m^2).
Figure 13, upper graph: change the title of the ordinate to read: Eggs laid (no./90 m^2 per 24 h).

Page 196. Table 30, column Predator fecundity (no. eggs/day): move the last 3 entries – 1.2 c, 4.8 b, and 7.6 a – to the right, in a separate column, to indicate 2 separate experiments.

Page 198. Table 32: remove asterisk (*) after –2 in column Difference.

PN-AAJ-139

The International Rice Research Institute

Annual Report for 1978

1979
THE INTERNATIONAL RICE RESEARCH INSTITUTE
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About this report

This 17th annual report covers research during 1978. The various sections deal with the interdisciplinary approach to problem areas. The department or departments that performed the research are identified in italics below the topic heading. For example:

EVALUATING DISEASE RESISTANCE OF BREEDING MATERIALS
Plant Pathology Department

In collaborative work, the department that did one phase of the research is identified in italics in parentheses following the subtopic. For example, the Agronomy and Plant Breeding Departments cooperate in the project VARIETAL SCREENING. Because the Agronomy Department bears responsibility for one phase of that work, its name follows the heading:

Dryland field screening (*Agronomy*).

This report is on a metric basis. The International System of Units (SI) is not, however, completely adopted for abbreviations. All monetary units are as U.S. dollars ($). Unless otherwise stated, *control* or *check* means an untreated control, grain yield is calculated as rough rice at 14% moisture, and protein content is calculated as a percentage of brown rice at 14% moisture. A single asterisk (*) means different at the 5% level of significance, and a double asterisk (**) means significantly different at the 1% level.

The report liberally uses abbreviations of names and terms often repeated within sections, e.g., BPH (brown planthopper), GLH (green leafhopper), DT (days after transplanting), DAT (days after treatment), etc. Such abbreviations are spelled out when first used.

Pedigrees are indicated by a slant bar (/) rather than by the multiplication sign (×). For example, IR32 × IR34 is now written IR32/IR34. The sequence of crosses is indicated by the number of slant bars: (IR32 × IR34) × Bg90-2 is now written IR32/IR34//Bg90-2. The third and further crosses are designated /3/,/4/,/5/, and so on. Backcrosses are indicated by a superscript numeral.

The report makes reference to three fundamental types of rice culture. Dryland (upland) culture means rice grown without irrigation in unbunded fields. Rainfed paddy culture means rice grown without irrigation but in fields that are bunded to impound water. Irrigated culture means rice grown with irrigation in bunded fields. A shift to use of the terms *dryland* (instead of upland) and *wetland* (instead of upland) as adjectives describing rice and rice-growing soils begins in this report.

A thumb index on the back cover provides quick access to each section. To use it, bend the book slightly and follow the margin index to the page with the black-edge marker.

Research highlights

AN INTERNATIONAL FOCUS ON FOOD PRODUCTION

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

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

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

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

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

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

New high of IRRI international activity

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

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

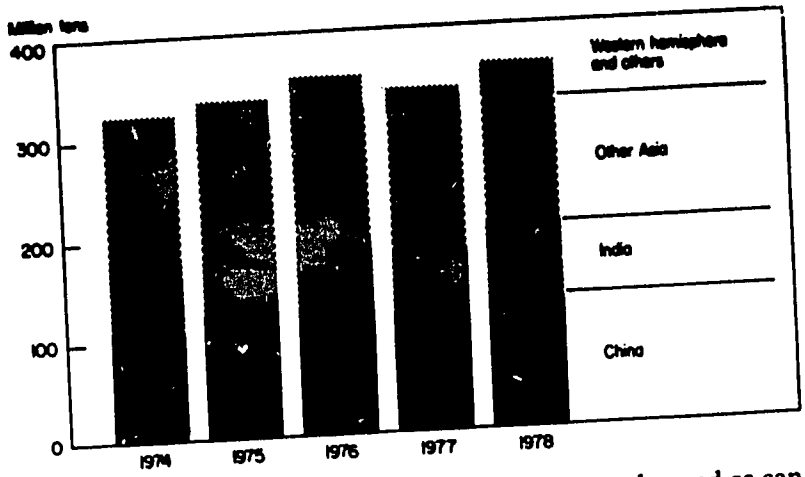
In 1978, four Chinese rice scientists spent nearly 8 months at IRRI. While there they participated in a 4-month GEU training course and had joint research projects with IRRI scientists. Several Chinese scientists participated in 1978 international conferences at IRRI.

Early in 1979, we formalized our working relationships with the Chinese Academy of Agricultural Sciences and developed a formal resumé of cooperation that includes the exchange of genetic materials and scientists. Among the other areas of mutual interest are genetic resource collection and storage, international rice testing, innovative breeding techniques, biological fixation of nitrogen, small-farm machinery development, and fertilizer efficiency.

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

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

The expanding cooperation with China can also be significant to that country. It gives Chinese scientists access to the world's largest collection of rice genetic resources. It will encourage an interaction with scientists from other rice-growing countries, and especially those from Asia. Breeding lines with host resistance to major insects and



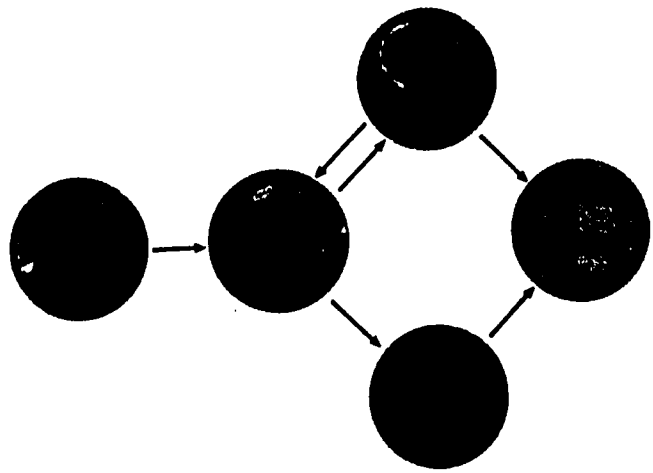
1. World rice production for 1974–78. China produced nearly 35% of the total in 1978.

diseases – a major concern in South China – can be exchanged as can scientists among cooperating countries. Already plans are under way for a jointly sponsored conference-cum-monitoring tour to be held in South China in October 1979. Scientists from other Asian countries and from IRRI will participate along with their Chinese counterparts.

Major achievements

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

The flow chart in Figure 2 shows how IRTP assures the dissemination and testing of the world's best rice breeding materials. Entries in



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

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

Region, country	Designation	Origin	Name given
Southeast Asia			
Burma	BG90-2	Sri Lanka	Sinthiri
	BR51-91-6	Bangladesh	Sintheingi
	IR34	IRRI	Sinshwethwe
Vietnam	IR2071-625-1	IRRI	NN 3A
	Jaya	India	
	Pelita I-1	Indonesia	
	Biplab	Bangladesh	
South Asia			
Bangladesh	IR2061-214-3-8-2	IRRI	BR6
	IR2053-87-3-1	IRRI	BR7
India[a]	BR51-46-C1	Bangladesh	–
	IR30	IRRI	IR30
	IR34	IRRI	IR34
	IR36	IRRI	IR36
Nepal	BG90-2	Sri Lanka	Janaki
	IET2938	India	Durga
	IR2061-628-1-6-4-3	IRRI	Laxami
	IR2071-124-6-4	IRRI	Sabitri
Sub-Sahara Africa			
Ivory Coast	Jaya	India	–
Sierra Leone	Cica 4//IR665/Tetep	CIAT	ROK 11
	Cica 4//IR665/Tetep	CIAT	ROK 12
Latin America			
Bolivia	IR1529-430-3	IRRI	V5
Cuba	IR1529-430-3	IRRI	IR1529

[a]Named in certain states.

the IRTP nurseries that perform well in the country of testing are either included as parents in the national breeding programs or tested further directly in national yield trials. IRTP has been in operation long enough to show that the system works and that national scientists are making effective use of the genetic materials that IRTP is helping to disseminate. Table 1 lists the rices from IRTP nurseries that have been released or recommended for release in 9 countries around the world.

The computerization of data handling and the timely publication of performance data from the nurseries add greatly to the value of the IRTP. From these data, varieties or lines with unusual performance stability are identified. The seven entries in the replicated yield trial for early-maturing rices shown in Table 2 illustrate this point. When grown in environments varying from the dry hot climate of Egypt to the relatively cooler and moist climate of Taiwan, these varieties generally performed well. They yielded as well as the locally adapted check in two-thirds of the trials.

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

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

Monitoring and planning conferences

We utilize IRTP for further interaction among scientists from national programs. At the April 1977 International Rice Research Conference attended by nearly 125 scientists, general plans for the 1978 and 1979 research years were made. The plans included a record number of monitoring tours in 1978. Four such tours focused on regional research activities, six were concerned with research problem areas.

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

Incorporation of insect and disease resistance

We have succeeded in markedly increasing the degree of host plant resistance to major rice diseases and insect pests. Traditional varieties are susceptible to most of the major rice pests (Table 3). By screening

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

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

varieties in the germplasm bank we were able to select the few traditional cultivars that are resistant to or tolerant of the major rice pests. They were used as parents in our GEU program to incorporate the desired trait into lines with other superior characteristics.

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

Biochemical basis of insect resistance

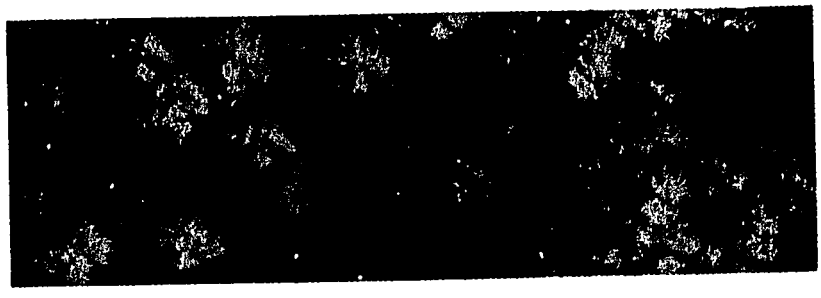
We continued studies to determine the biochemical basis for resistance of rice varieties to insect pests. In one study we learned that naturally occurring chemicals in the resistant varieties are likely responsible for their resistance. Extracts from varieties resistant to gravid striped borer moths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

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

Lines with short growth duration

Widespread interest in methods of increasing cropping intensity has focused attention on rices with short growth duration. IR36, which matures in 110–115 days from seeding, has become popular in the Philippines and has been released to farmers in Indonesia, India, and Vietnam.

Research to develop high yielding, pest-resistant rices with even shorter growth duration than IR36 began a few years ago. In our 1978 replicated yield trials breeding lines with a growth duration of 90–100 days were evaluated. These lines inherit this trait from the



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

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

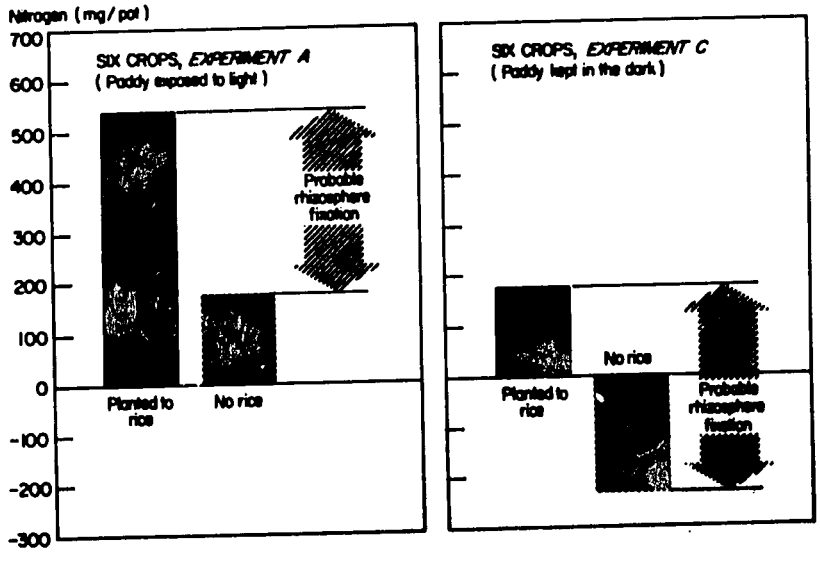
Line	Parents	Growth duration (days)	Yield t/ha	Yield kg/day
IR10154-23-3-3	ADT4/IR747B$_2$-6//IR747B$_2$-6	90	5.3	59
IR10176-24-6-2	IR747B$_2$-6-3/29Lu 1/IR747B$_2$-6	90	5.4	60
IR10179-2-3-1	IR747B$_2$-6-3/Ai-nan tsao 1/IR747B$_2$-6	92	6.1	66
IR10179-23-1-3	IR747B$_2$-6-3/Ai-nan tsao 1/IR747B$_2$-6	90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

early-maturing Indian varieties ADT 4 and Cauvery and the Chinese varieties Ai-nan-Tsao 1 and 29 Lu 1. Yields from the new lines were from 5.2 to 6.3 t/ha. IR36, which requires 10 to 20 days longer to mature, yielded 6.8 t/ha in the same tests (Table 4).

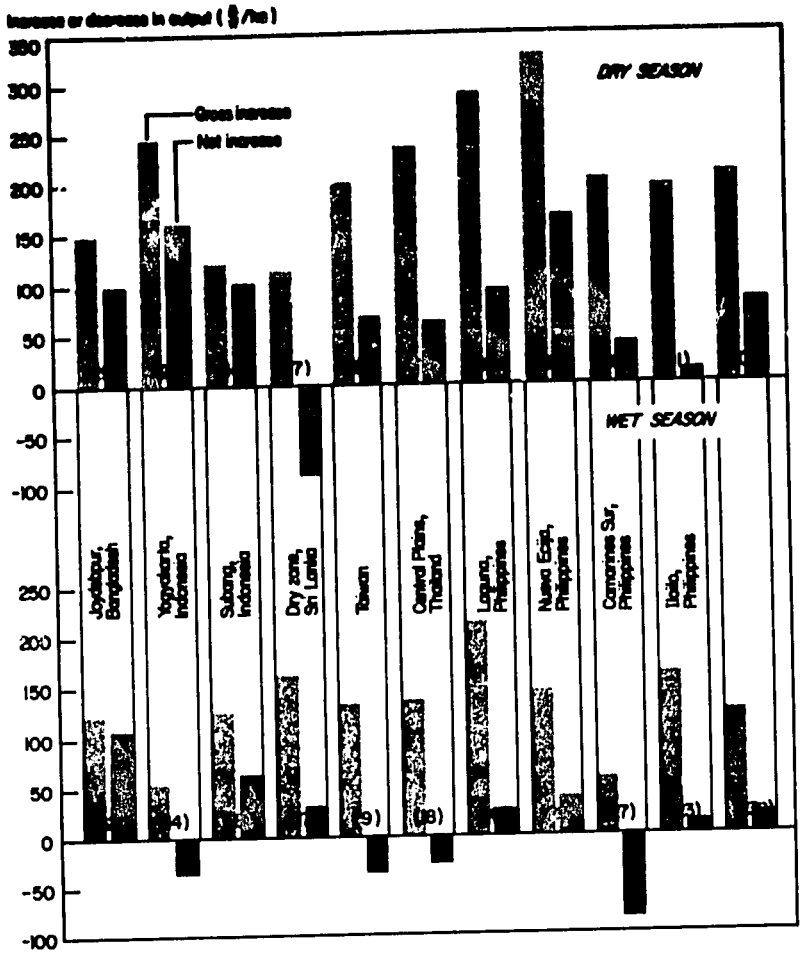
Nitrogen fixation

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

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



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



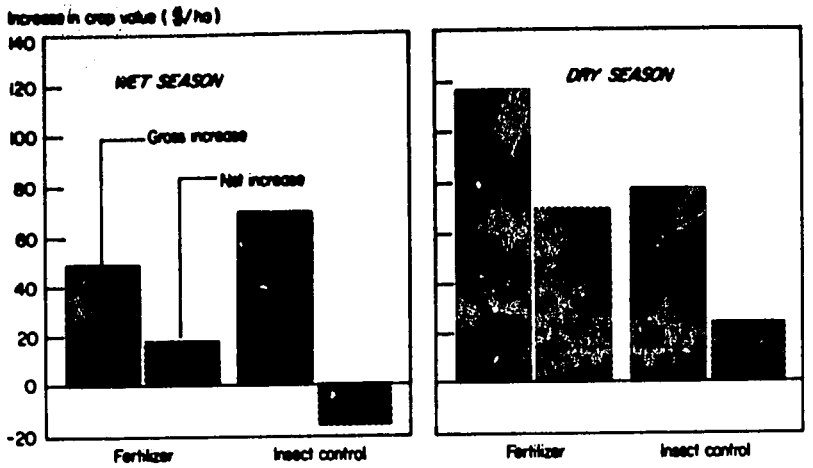
5. Average increases in gross and net returns from test inputs were higher than those from inputs used by farmers. The number of trials for each location is shown by numbers in parentheses. Note that the higher inputs were generally profitable during the dry season but gave low net returns or even losses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

heterotrophic organisms and by light-dependent blue-green algae occur simultaneously in the rice paddy.

Constraints on rice production

Farmers do not automatically obtain economic benefits when they produce more food. Four years' data from experiments in six Asian countries on factors constraining rice yields on farmers' fields were summarized in 1978. We found that technology inputs higher than those used by the farmers generally gave good returns in the dry season. But in the wet season the costs of added inputs negated most of the production gains and in some cases resulted in losses from the higher inputs (Fig. 5).

Levels of fertilizer application higher than those used by farmers gave profitable increases especially during the dry season. In contrast, high input levels for insect control gave discouragingly low net increases in the dry season, and resulted in losses in wet-season trials



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

(Fig. 6). These findings provide a challenge to scientists concerned with pest management. They also explain the reluctance of many farmers to use insecticides unless the pest threat to their crop is obvious.

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

Computer-based data management

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

• *GEU.* The germplasm computer data bank (GB) now contains 1,314,870 records (representing information on variety name and origin; and data on 38 morphoagronomic characters and 37 GEU traits) for 38,535 registered accessions of *O. sativa.* The breeding records of 25,066 crosses are stored, and can be used in tracing the family tree of any desired crosses. We also keep the inventory of all selected lines from IRRI crosses. The GB information retrieval system (developed and completed in late 1976) is used frequently by our GEU scientists and other rice researchers. It provides instant access to – and retrieval of – desired information from the germplasm data bank.

• *Cropping systems.* The Cropping Pattern Monitoring (CPM) project is an undertaking of the Asian Cropping Systems Network. So far, only data for 3 years (1975–78) from the Philippine sites

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

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

(Pangasinan and Iloilo) are in our computer files.

The Farm Record Keeping (FRK) data files are farmers' daily records of production operations on their farms.

• *Networks.* The data for the IRAEN and INFER are computerized and are easily accessible to scientists throughout the two networks.

Genetic evaluation and utilization (GEU) program

Genetic resources program

Plant Breeding Department

FIELD COLLECTION 12
INSTITUTIONAL EXCHANGES 12
SEED INCREASE, REJUVENATION, AND DISTRIBUTION 13
INVENTORY, CHARACTERIZATION, AND DATA PROCESSING 13
SEED STORAGE 14
TRAINING OF GENETIC STOCK OFFICERS 14
INTERNATIONAL AND INTERINSTITUTIONAL COLLABORATION 14

FIELD COLLECTION

After the 1977 Workshop on the Genetic Conservation of Rice, IRRI communicated with major rice-producing countries to systematically develop and implement field collection operations. In 1978 IRRI collaborated with Asian countries in assembling indigenous varieties from areas where they were being replaced by improved varieties. Such replacement had become so advanced in irrigated areas of the Philippines, Indonesia, Sri Lanka, and other countries that canvassing netted only few seed samples.

IRRI staff members collected 364 seed samples in Sri Lanka during 2 major crop seasons. Local extension workers sent in 16 more samples. Collaborative assemblage in eastern Bangladesh netted 233 samples; extension workers sent in 43 more.

IRRI staff members joined coworkers from the Philippine Bureau of Agricultural Extension in canvassing the northern Luzon countryside for traditional types; 448 seed samples were collected. Extension workers sent in 25 other samples. The Bureau of Plant Industry collected 347 samples from different Philippine islands.

A visit to Kalimantan, Indonesia, netted 89 seed samples. Extension workers who were previously contacted sent in 501 samples from Java.

IRRI participated directly in the collection of 1,134 seed samples in the 1978 field trips. Local efforts added 1,171 samples. Since the initiation of such collaborative efforts in 1972, 9,152 samples have been collected with direct IRRI input. Another 28,409 samples (Table 1) were collected by local extension workers, rice breeders, peace corps workers, college professors, anthropologists, missionaries, and other collaborators in 14 countries.

IRRI also helped plan a massive field collection in 16 Indian states. The project, which was launched in 1978, was coordinated and funded by the Indian Council for Agricultural Research. Rice workers in Thailand canvassed the north, the northeast, and the central plain and collected about 700 samples.

The International Board for Plant Genetic Resources (IBPGR) provided IRRI a grant to assist collaborative efforts. The funds were mostly used to assist national centers to collect local rices and ship seed samples to IRRI.

Table 1. Indigenous rice varieties collected with IRRI's direct or indirect participation in 14 collaborating Asian countries, 1971 to 1978.

Country	Years	Indigenous varieties collected (no.) with IRRI's	
		Direct participation	Indirect participation
Bangladesh	1973–78	2,130	2,347
Bhutan	1975–76	—	121
Burma	1973–74, 1978	225	406
India	1978	—	
Indonesia	1972–76, 1978	4,455	3,880
Cambodia	1973	280	—
Laos	1972–73	—	899
Malaysia	1973–76	—	859
Nepal	1971–72	—	952
Pakistan	1972–73, 1978	—	771
Philippines	1973–76, 1977–78	510	1,481
Sri Lanka	1972, 1975–76, 1978	1,444	399
Thailand	1973, 1975–76, 1978	—	746
Vietnam	1972–75	108	649
Total		9,152	28, 409

INSTITUTIONAL EXCHANGES

Indian germplasm was transferred to IRRI through continuing communication with and visits to national and state organizations in India. In 1978 the IRRI germplasm bank received 1,309 seed samples from Tamil Nadu Agricultural University; 937 from Pattambi Rice Research Station, Kerala; 88 from Patna Rice Research Station, Bihar, and 156 from the Agricultural University, Gujarat.

Vietnam donated 100 winter rices to the germplasm bank; Cuba, 22 samples; the USSR, 313; Hungary, 20. Donors provided 54 samples to replace dead accessions.

Six hundred and forty-two diverse entries that national centers entered in the International Rice Testing Program were deposited in the bank in 1978. Similarly, promising materials from the IRRI GEU program were entered and preserved.

The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) provided 350 strains of African rice (*O. glaberrima*).

SEED INCREASE, REJUVENATION, AND DISTRIBUTION

Field space for seed increase, characterization, and rejuvenation was expanded to 5 ha in 1978. At 4 seeding dates, 4,725 plots were planted for seed multiplication; 3,491, for systematic characterization; and 2,603, for rejuvenation.

Initial seed increase of strongly photoperiod-sensitive accessions must be under short day length. In November, 2,000 plots were planted to meet that need. About 2,000 rows were grown for seed increase of exotic varieties, mutants, genetic testers, *O. glaberrima* strains, and wild species.

In the wet season, *O. glaberrima* accessions were grown in 294 plots in an irrigated field; 15 more accessions were planted in a fertile, hydromorphic soil in an upland area. The African rices on the hydromorphic soil grew almost as well as those under irrigation. Upland fields generally have fewer insects and diseases than lowland fields and upland planting offers promise for growing planthopper- and virus-susceptible African rices.

Seed distribution continued to be a principal service of the germplasm bank: 7,316 Asian rice samples and 331 samples of African rices and wild taxa were furnished to 159 researchers in foreign countries. Within IRRI 31,941 samples of Asian rices and 911 samples of other species were provided to GEU scientists on 198 occasions (Table 2).

Since intensive field collection began in different collaborating countries in 1972, IRRI staff members have devoted much effort to the canvassing of germplasm in areas of specific stresses caused by climatic, edaphic, or hydrologic constraints. By late 1978, about 7,000 samples with reputed tolerance for one or more such specialized problems had been assembled. But many such special types are poor seed producers. An extra cycle of seed increase was often needed to produce sufficient seed for evaluation. In 1978, accessions were offered to various IRRI GEU scientists for evaluation; 309 for cold tolerance, 262 for elongation ability, 194 for alkali tolerance, 158 for iron toxicity, and 540 deepwater rices for drought testing.

Table 2. Progress of the IRRI Genetic Resources Program in field collection, preservation, and distribution of seed of *Oryza sativa* cultivars, 1973–78.

Year	Samples collected in Asia (no.)	Distinct accessions in germplasm bank (no.)	Samples distributed (no.)	
			Inside IRRI	National programs
1973	1,405	24,162	8,275	9,777
1974	2,982	26,818	19,236	2,603
1975	566	30,332	22,155	4,043
1976	1,466	34,229	40,200	4,819
1977	696	36,956	49,778	4,089
1978	1,134	40,768[a]	31,941	7,316

[a]About 13,098 recently received seed samples are yet to be registered; 4,061 duplicate accessions and 2,790 nonviable seed samples were removed from the registry during 1973–78.

INVENTORY, CHARACTERIZATION, AND DATA PROCESSING

In 1978 IRRI received 7,728 seed samples from institutions, scientists, missionaries, and international service volunteers. Experiment stations replaced another 54 nonviable samples of *O. sativa* received earlier.

At the end of 1978, the IRRI germplasm bank had 40,768 registered accessions of *O. sativa*, 1,891 accessions of *O. glaberrima*, 886 populations of wild species or taxa, and 637 genetic testers and mutants. Another 13,183 *O. sativa* seed samples that were recently received must be planted and compared with plants with identical varietal names so that those identified as new accessions can be registered (Table 2).

Of the *O. sativa* accessions, 33,945 have been characterized for 38 morphoagronomic characters; another 3,491 accessions have been completely characterized in the field, but laboratory measurements on 8 remaining items are still to be recorded.

In the 1960s, different strains of wild *Oryza* species were simply grown for seed increase and for reidentification after seed receipt. The taxonomy and nomenclature of taxa in the genus *Oryza* was in a state of flux, and the seed stocks were gradually exhausted. During a recent program of systematic seed rejuvenation, a comprehensive characterization scheme to cover all species in the genus was developed. The present array of 95 taxonomic and agronomic characters exceeds in coverage the

38-descriptor morphoagronomic set for the cultivars but will be fully compatible with the existing data system of cultivated rices. During 1978, 173 samples of wild relatives of *O. sativa* and 30 of wild relatives of *O. glaberrima* were grown and scored.

SEED STORAGE

In early 1978, the seed stocks in the old seed laboratory were moved into the fumigated short-term storage area of the new Rice Genetic Resources Laboratory (RGRL). A fire in December destroyed the old seed laboratory but did not affect the adjacent medium-term storeroom where 20,000 accessions were stored in glass jars.

Steel shelves for the short-, medium-, and long-term seed storage areas had been installed in the RGRL by the end of 1978. In the short-term storeroom, seeds of recently harvested (up to 4-year shelf life) accessions were kept in paper bags and stacked in plastic trays. The expected seed longevity is 4 to 5 years.

For medium-term storage, 28,993 accessions are stored in glass jars at 2 sites. New seed-drying and packing equipment will allow fresh seed to be packed in aluminum cans under partial vacuum. The medium- and long-term rooms can each accommodate more than 120,000 accessions.

Negotiations with the germplasm staff of the U.S. Department of Agriculture were renewed in 1978, allowing IRRI to continue to deposit duplicate sets of conserved stock in the improved facilities at the U.S. National Seed Storage Laboratory, Ft. Collins, Colorado. The Laboratory has stored 18,780 accessions for IRRI since the mid-1960s.

TRAINING OF GENETIC STOCK OFFICERS

IRRI provided 2-month resident training for genetic stock officers of the Bangladesh Rice Research Institute and the South China Agricultural College, Kwangtung province, China. IRRI also supplied materials for a training course conducted by the National Bureau of Plant Genetic Resources, India.

INTERNATIONAL AND INTERINSTITUTIONAL COLLABORATION

IRRI staff members advised several national centers on the planning of field collection operations and the construction or improvement of seed storage facilities. Such technical assistance has increased in recent years as more centers initiate or expand genetic conservation measures.

IRRI continued to serve as the principal depository for the world's rice (base collection). Institutions in India, the USSR, and West Africa sent in thousands of samples from their collections for preservation at IRRI.

IRRI began to systematically exchange accession lists and characterized data with major national genetic resources centers and seed banks. Such exchange will not only reduce redundancy in conserved stocks but also ensure that no accession is overlooked and discarded when comparing inventories and discarding duplicates.

At a November meeting at the Beltsville Agricultural Research Center, USA, the IBPGR-IRRI Rice Advisory Committee developed a uniform set of descriptors and descriptor-states to be used in rice genetic resources programs. The committee's action will appear in a joint bulletin.

Genetic evaluation and utilization (GEU) program

Agronomic characteristics

Agronomy, Plant Breeding, and Plant Physiology Departments

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GROWTH DURATION

Plant Breeding Department

The proportion of breeding materials with short growth duration increased greatly in 1978. Many new crosses with extremely early maturing varieties were made and a large proportion of breeding materials grown in the pedigree nurseries matured in 100–110 days. There was a corresponding increase in early maturing entries in the replicated yield trials, which for the first time, had entries with a growth duration of less than 96 days. As the data in Table 1 show, 70.7% of the entries in the 1978 wet-season replicated yield trials matured in less than 116 days. Only 16.9% of the entries grown in the 1969 wet-season replicated yield trials matured in less than 116 days.

GRAIN SIZE AND SHORT GROWTH DURATION

Plant Physiology Department

Vigorous early growth is a desirable character because it not only shortens the growth duration but also overcomes weeds. IRRI experiments showed that grain size affects early growth. Figure 1 shows the relationship between 1,000-grain weight and seedling dry weight on the 10th day after sowing for 10 selected rice varieties of different grain size, from Bomdia (13.1 g) to Khao Luong (46.2 g). Larger grain size is clearly advantageous for establishing large seedlings earlier.

Figure 2 shows relative growth rate (RGR) between 10 and 20 days after sowing for the varieties in Figure 1. The difference in RGR among the varieties is not great, although some IR varieties showed a slightly higher rate. Thus, the difference among varieties in early growth (10th day) is maintained during further growth. Larger grain size is clearly advantageous for early growth, as well as for grain filling and yield (1976 Annual Report).

YIELD PERFORMANCE AND NITROGEN RESPONSE

Agronomy Department

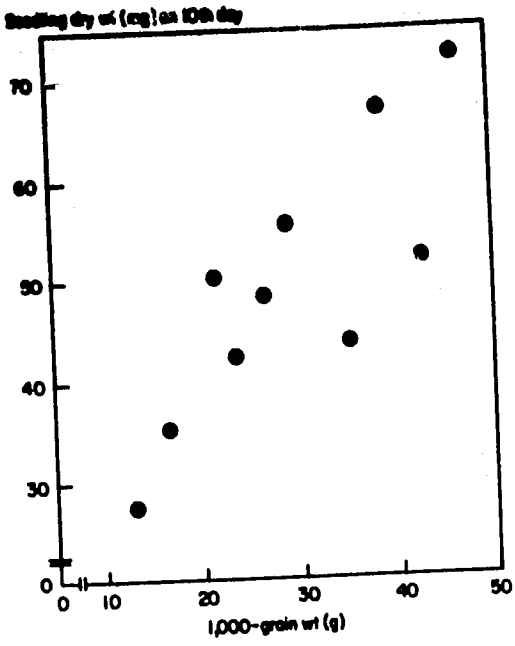
Irrigated rice. The performance of promising breeding lines and established varieties was evaluated during the dry and wet seasons at IRRI, at Philippine Bureau of Plant Industry (BPI) stations, and in farmers' fields.

IRRI. Table 2 shows the yield of established varieties and selected promising lines. As in previous seasons, IR42 had the most stable yield. It outyielded all the other entries in the wet season. But in the dry season, it was outyielded by two breeding lines, IR4568-86-1-3-2 and IR4570-83-3-3-2, at most of the nitrogen levels. Other promising lines with good performance were IR2058-78-1-3-2 (named IR46 in the Philippines) and IR4432-52-6-4. Among the early maturing group, IR9129-457-1 and IR9224-117-2 yielded more than IR36 during both seasons.

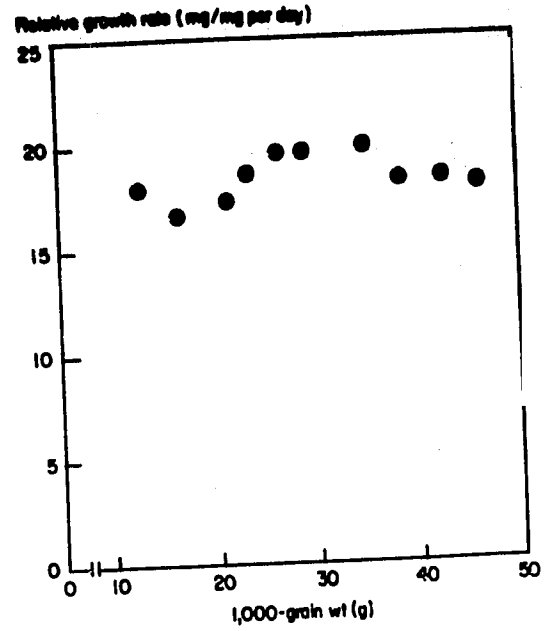
BPI stations. The grain yield of 18 varieties and breeding lines was evaluated in Nueva Ecija, Bicol, and Visayas during the wet season and during the dry season only in Nueva Ecija and Bicol.

Table 1. Change in the frequency of entries in different growth duration groups in the IRRI replicated yield trials grown during the wet season of 1969–78.

Year	Frequency of entries (% of total)						Entries (total no.)
	<96 d	96–105 d	106–115 d	116–125 d	126–135 d	>135 d	
1969	0	2.1	14.8	34.9	39.1	9.0	189
1970	0	2.1	16.4	51.8	25.4	4.2	189
1971	0	3.7	6.1	43.8	31.4	14.8	162
1972	0	0.5	7.5	35.0	51.5	5.5	200
1973	0	2.0	35.6	41.6	18.4	2.4	250
1974	0	4.5	28.0	43.0	21.5	3.0	200
1975	0	1.7	26.3	54.6	17.0	0.3	300
1976	0	4.0	15.2	62.5	16.0	2.2	275
1977	0	20.7	17.3	31.0	30.0	1.0	300
1978	2.2	28.0	40.5	18.7	9.0	1.5	400



1. Relationship between 1,000-grain weight and seedling dry weight on 10th day after sowing in selected rice varieties. IRRI, 1978.



2. Relative growth rate of selected rice varieties between 10 and 20 days after sowing. IRRI, 1978.

Table 2. Yields of some varieties and promising lines at 5 levels of nitrogen[a] (av of 3 replications). IRRI, 1978.

Variety or line	Maturity (days)	Dry season yield[b] (t/ha)					Maturity (days)	Wet season yield[b] (t/ha)				
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	128	1.5	1.6	1.3	1.1	1.0	130	2.2	2.8	3.1	3.4	2.8
IR42	129	3.2	5.0	5.9	5.9	6.2	139	2.9	3.2	3.8	2.9	3.6
IR2058-78-1-3-2	120	3.6	5.0	5.5	6.3	5.6	133	2.3	3.0	3.4	3.7	2.8
IR2863-38-1	126	2.7	4.1	5.4	5.4	5.9	133	2.1	3.0	3.5	2.9	2.6
IR4219-35-3-3	129	3.0	3.8	3.2	3.1	3.3	—	—	—	—	—	—
IR4432-52-6-4	126	3.5	5.0	5.2	5.1	4.9	133	2.7	3.0	3.5	3.1	3.0
IR4568-86-1-3-2	118	3.7	5.6	6.4	6.4	6.5	128	1.6	3.6	3.2	3.4	3.0
IR4570-83-3-3-2	133	3.8	5.2	6.5	6.4	6.6	139	2.6	3.0	3.5	2.6	3.2
IR4570-117-2-1-2	133	3.2	5.3	5.8	6.3	6.4	139	2.4	3.5	3.6	2.9	3.2
IR5853-118-5	118	3.1	5.0	5.0	5.9	6.2	118	2.1	3.3	3.3	2.9	3.4
IR5853-162-1-2-3	119	3.7	4.6	5.8	5.7	6.3	126	2.5	3.4	2.7	3.1	2.9
IR9129-209-2-2	—	—	—	—	—	—	108	2.2	3.2	2.8	3.0	3.3
IR9129-457-1	106	2.4	3.4	4.7	5.5	5.3	108	2.7	3.4	3.4	3.3	4.0
IR9224-117-2	106	3.0	4.7	5.0	5.9	5.9	111	3.3	3.3	3.1	3.4	2.6
IR9761-19-1	—	—	—	—	—	—	108	3.1	3.1	3.8	3.4	3.5
Peta	136	2.0	2.7	1.7	1.8	1.5	142	2.0	2.0	1.7	1.4	1.5

[a]The treatments, except 0 kg N/ha, include 30 kg N/ha in dry season and 20 kg N/ha in wet season, topdressed at panicle initiation stage.

	Dry season		Wet season	
	LSD (5%)	LSD (1%)	LSD (5%)	LSD (1%)
[b]To compare 2 N means of same or different V—	1.20	1.60	0.88	1.17
To compare 2 V means at same or different N —	1.17	1.54	0.87	1.15

In the dry season IR42, IR2058-78-1-3-2, and IR4568-86-1-3-2 gave the most stable yields at all nitrogen levels and outyielded the other entries (Table 3). In the early maturing group, IR9129-457-1 gave a yield comparable with that of IR36 at all fertility levels; however, it is 5–7 days earlier than IR36.

The yield differences during the wet season were not so great (Table 4). IR2058-78-1-3-2 and IR4568-86-1-3-2 again outyielded the other entries. In the early maturing group, IR9224-117-2 outyielded IR36 at all the nitrogen levels except 150 kg N.

Farmers' fields. Three varieties and four breeding lines were evaluated in both seasons in irrigated farmers' fields in Laguna province (Table 5).

During the dry season IR2058-78-1-3-2 produced the high yield of 5.1 t/ha at 150 kg N and outyielded all others at the 50-kg N level. During the wet season, the IR42 yield of 4.6 t/ha with no nitrogen was impressive and consistent with the previous year's results.

Rainfed wetland rice. The performance of

Table 3. Yield of some varieties and promising lines at 6 levels of nitrogen[a] at 2 locations: Maligaya Rice Research and Training Center and Bicol Rice and Corn Experiment Station, Philippines, 1978 dry season.

Variety or line	Maturity (days)	Yield[b] (t/ha)					
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha	180 kg N/ha
IR8	134	3.2	5.0	6.1	5.7	6.1	4.8
IR42	135	3.1	4.4	5.6	6.1	6.6	5.1
IR2058-78-1-3-2	122	3.2	5.6	6.3	5.8	5.8	5.7
IR2307-247-2-2-3	120	2.9	4.2	4.9	5.3	5.4	4.7
IR2863-38-1	134	2.6	4.0	5.4	4.9	4.9	4.7
IR4219-35-3-3	132	3.6	3.6	4.9	4.4	4.3	3.6
IR4432-52-6-4	132	3.2	4.4	5.6	5.4	4.8	4.4
IR4568-86-1-3-2	119	3.0	5.0	5.9	5.8	5.7	5.1
IR4570-83-3-3-2	140	3.1	4.8	5.7	6.1	5.1	4.2
IR5863-118-5	118	2.8	4.3	5.0	5.6	5.4	4.4
IR7546-27-3-2	133	3.7	3.8	5.6	5.5	5.4	4.6
IR9129-457-1	105	2.1	3.2	4.4	4.0	4.6	4.4
IR9209-26-2	105	2.2	3.5	3.5	3.1	3.7	3.5
Peta	143	2.4	3.6	2.1	2.2	1.9	1.5

[a]The treatments, except 0 kg N/ha, include 20 kg N/ha topdressed at panicle initiation. [b]Av of 2 locations, each with 3 replications, LSD 5% 0.9.

Table 4. Yields of some varieties and promising lines at 6 levels of nitrogen[a] at Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines, 1978 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha)					
		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha
IR8	123	2.1	2.7	3.1	2.6	2.8	2.3
IR42	140	3.1	3.2	4.1	4.2	3.7	4.1
IR2058-78-1-3-2	121	2.6	4.0	3.4	3.4	3.3	2.6
IR2863-38-1	117	3.1	3.4	3.9	4.0	3.4	3.1
IR4432-52-6-4	118	2.9	3.6	3.9	3.4	3.0	2.5
IR4568-86-1-3-2	118	2.8	3.7	4.0	4.0	3.9	3.9
IR4570-83-3-3-2	133	3.2	4.0	3.9	3.6	3.1	3.2
IR5863-118-5	114	2.8	3.5	4.1	3.8	3.5	3.4
IR5863-162-1-2-3	119	2.9	3.7	3.5	3.8	3.1	3.2
IR9129-209-2-2	105	2.8	3.6	3.9	3.8	3.8	3.5
IR9129-457-1	107	2.6	3.5	3.8	3.7	3.5	3.4
IR9224-117-2	110	3.3	4.1	4.1	4.1	3.5	2.9
IR9761-19-1	108	2.5	3.9	3.6	3.5	3.3	3.1
Peta	135	3.3	3.1	2.6	2.3	2.1	2.0

[a]The treatments, except 0 kg N/ha, include 20 kg N/ha topdressed at panicle initiation. [b]Av of 3 locations, each with 3 replications, LSD (5%) 0.5.

Table 5. Yield of some varieties and promising lines at 4 levels of nitrogen[a] (av of 3 replications), Irrigated farmers' fields, Laguna, Philippines, 1978 dry and wet seasons.

Variety or line	Maturity (days)	Dry-season yield[b] (t/ha) 0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha	Maturity (days)	Wet-season yield[b] (t/ha) 0 kg N/ha	40 kg N/ha	80 kg N/kg	120 kg N/ha
IR8	123	2.0	2.3	2.5	3.8	132	4.4	3.7	4.0	3.9
IR26	106	2.1	3.3	4.9	4.3	106	2.4	3.0	2.2	2.9
IR42	123	2.7	2.0	3.8	3.7	145	4.6	4.0	4.6	4.4
IR2058-78-1-3-2	120	2.6	4.6	5.2	5.1	130	4.4	3.4	4.1	4.1
IR2863-38-1	120	2.3	2.4	4.7	4.1	140	3.7	3.1	3.1	3.1
IR4432-52-6-4	120	1.8	2.6	2.2	4.3	140	4.2	3.0	3.2	3.2
IR4570-83-3-3-2	123	2.9	3.9	3.9	4.2	115	4.2	3.6	4.4	4.1

[a]The treatments, except 0 kg N/ha, include 20 kg N/ha topdressed at panicle initiation in both seasons. [b]LSD (5%) 1.3, LSD (1%) 1.7 for the dry season and LSD (5%) 0.8, LSD (1%) 1.0 for the wet season.

Table 6. Effect of nitrogen[a] levels on the grain yield (av of 3 replications) of rice varieties and promising lines as a rainfed crop. IRRI, 1978 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha) 0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR5	134	2.9	2.8	3.2	3.1	3.1
IR34	119	1.2	2.1	2.4	2.3	2.4
IR36	120	1.0	1.5	1.2	1.7	1.9
IR42	134	1.6	2.8	3.1	3.4	3.1
IR2058-78-1-3-2	125	2.0	2.5	2.5	3.0	3.1
IR2307-247-2-2-3	120	1.8	2.1	2.4	2.3	2.8
IR2863-38-1	134	2.0	2.4	2.6	2.9	2.7
IR3880-13-5	125	1.4	1.0	1.6	1.9	1.6
IR4219-35-3-3	139	1.8	2.3	2.3	2.3	2.4
IR4570-83-3-3-2	139	2.0	2.2	2.5	3.0	2.9
IR5853-118-5	120	1.6	1.9	2.5	2.4	2.8
Mahsuri	139	1.8	2.0	2.1	2.1	2.3

[a]The treatments, except 0 kg N/ha, include 20 kg N/ha topdressed at panicle initiation. [b]LSD (5%) 0.7, LSD (1%) 0.9.

Table 7. Effect of nitrogen[a] levels on yield of rice varieties and promising lines (av of 3 replications) as a rainfed crop in farmers' fields in Laguna province, Philippines, 1978 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha) 0 kg N/ha	40 kg N/ha	80 kg N/ha	100 kg N/ha
IR8	129	4.4	4.1	4.1	4.1
IR26	129	3.9	3.5	4.1	3.7
IR36	105	3.6	3.2	3.6	3.6
IR42	141	5.0	4.2	5.1	4.4
IR2058-78-1-3-2	129	4.4	4.4	4.1	3.6
IR2863-38-1	141	4.2	3.3	8.3	3.4
IR4570-83-3-3-2	141	4.4	4.2	3.9	3.8
IR5853-118-5	116	3.6	3.4	4.0	3.2

[a]The treatments, except 0 kg N/ha, include 20 kg N/ha topdressed at panicle initiation in both seasons. [b]LSD (5%) 0.7, LSD (1%) 1.0.

seven promising lines and five varieties as a wet-season rainfed crop was evaluated at IRRI. Four varieties and four breeding lines were evaluated as a rainfed crop in farmers' fields.

IRRI. IR5, IR42, and IR2058-78-1-3-2 were the best performers at IRRI (Table 6). Disease and insect incidence was extremely low in 1978 and IR5 yielded well. IR2058-78-1-3-2, which as IR46 was recommended by the Philippine Seed Board for rainfed wetland conditions, performed well.

Farmers' fields. IR42 produced the highest yield with no nitrogen fertilizer added and outyielded the seven other entries at all levels of

nitrogen application (Table 7). IR2058-78-1-3-2 and IR4570-83-3-3 performed well. IR8 yielded well at all levels of nitrogen because diseases and insects did not depress yields.

SOURCES OF SEMIDWARFISM

Plant Breeding Department

The search continued for sources of semidwarfism that would differ from the principal source derived from Dee-geo-woo-gen of Taiwan, which has been extensively used by the rice breeders of Asia. During the last 2 years Indian and American researchers submitted a number of semidwarfs or *dwarfs* that came from induced mutations, crosses involving an induced mutant, or wide crosses. In 1978, 24 crosses were made, and 28 crosses grown for F_2 seeds. Ten F_2 populations of eight test-crosses, each involving the recessive semidwarfing gene of Dee-geo-woo-gen and one of the new sources, were grown.

The wide range of segregation for height in the F_2 populations suggests the following sources have different plant height genes:

1. D66, an induced mutant from Calrose, developed by the USDA and the University of California at Davis, USA. It has the 'd_2' gene.
2. CI9858, a hybrid selection from RRU-RR250/Bluebelle, developed by USDA and Louisiana State University, USA. It has the 'd_3' gene.
3. Double Dwarf 1 (CI 11036), a hybrid progeny from Calrose 76/D66, selected by the USDA and the University of California at Davis. It has the 'd_1' and 'd_2' genes.
4. Double Dwarf 3 (CI 11038), a hybrid progeny from CI9858/D66, selected by the USDA and the University of California at Davis. It has the 'd_2' and 'd_3' genes.
5. M7, a selection from Calrose 76/CS-M3, developed by the California Cooperative Rice Research Foundation, University of California at Davis, and the USDA.

Although several short-statured selections from California were called *dwarf* or *double dwarf*, their plant height did not differ much from that of IR36. Therefore, they belong to the semidwarf category.

Crm 13-3241, furnished by the Central Rice Research Institute of India, has the same semidwarfing gene as Dee-geo-woo-gen.

In the F_2 populations of two other crosses, a few tall segregates were observed. But the extremely low or low frequency of the tall plants indicates that such sources may share a portion of the compound semidwarfing locus, or the two loci are closely linked. Sources belonging to this category are:

1. P-3 dwarf, a spontaneous mutant isolated from Basmati Dehradun by the Krishinagar Farm, Madhya Pradesh state, India.
2. Double Dwarf 2 (CI 11037), a selection from CI 9858/Calrose 76 developed by the USDA and the University of California at Davis. It has the 'd_1' and 'd_3' genes.

All the above sources lack the early growth vigor and tillering ability of the Dee-geo-woo-gen type. However, the semidwarfs from California are distinctly earlier in maturity than IR36 and could be useful in developing short-duration selections. P-3 dwarf has slightly greater growth vigor and tillering ability than the *dwarfs* from California.

Other nonallelic sources of semidwarfism revealed by studies in previous years are the CP231/SLO-17 line of USA, K8 mutant of Sri Lanka, CN242-d_3 of Taiwan, Culture 854 and Culture 956 of India, Fanny Dwarf of France, and Intermediate Dwarf of USA.

In recent years a number of short-statured cultivars, similar to IR8 when grown in the dry season, were found in rices from Indonesia. However, these accessions more closely resemble IR5 in height and maturity when grown in the wet season or in long days. Such accessions — Djamadi, Lembat, Sirinit, and Sipilian — could serve as a useful source of intermediate plant stature.

GENETIC STUDY OF WETLAND-DRYLAND CROSSES

Plant Breeding Department

Difficulty in obtaining the desired progenies was encountered when single crosses between traditional dryland varieties and semidwarf wetland varieties were made and tested. An earlier study

indicated that partial hybrid sterility and atypical F_2 segregation of three marker-genes showed up in such wide crosses (1975 Annual Report).

Reciprocal crosses between two wetland varieties and two large-grained dryland varieties were studied further to ascertain if aberrant segregation of plant stature and grain characters also occurred in such crosses. One of the lowland varieties was semidwarf IR20; the other was intermediate-statured BPI-76. In two tall × semidwarf crosses, the F_2 populations failed to produce the typical segregation pattern of 3 (tall and moderately tall): 1 (semidwarf). The F_2 distributions were continuous and the moderately tall progenies predominated in one cross. With respect to grain characteristics, the F_2 populations tended to show an excess of F_2 plants with shorter and lighter grains. But in terms of grain shape, F_2 plants with bolder grains were slightly in excess in one cross and were deficient in another cross.

This study confirms that complex gene interactions, along with partial hybrid sterility, could explain the atypical segregation of several traits in dryland-wetland crosses and the difficulty of obtaining certain desired recombinants.

Genetic evaluation and utilization (GEU) program

Grain quality

Chemistry and Plant Breeding Departments

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BREEDING PROGRAM

Plant Breeding and Chemistry Departments

High total and head rice yields, translucent and medium-long to long, slender grains, intermediate amylose content, and soft gel consistency continued to be the objectives of the breeding program. Some aromatic rices are also being developed.

Many of the intermediate-amylose lines in the breeding program have either C4-63G or BPI-121-407 as an intermediate-amylose parent. Texture studies (Instron food tester) indicated that BPI-121-407 and its lines had about 1 kg harder cooked rice than C4-63G and its lines (Table 1). Filipinos prefer intermediate-amylose rices to high-amylose rices. To verify the actual preference for cooked-rice texture in intermediate-amylose rices, a cooperative consumer evaluation of C4-63G, BPI-121-407, and promising intermediate-amylose rices was formalized with the Institute of Human Ecology, University of the Philippines at Los Baños. The lines evaluated had similar gel consistency but retained the gelatinization temperature (alkali spreading) class of their parents. Some of the lines, such as IR4570-83-3 and IR9129-209-2, are in advanced yield trials.

WORKSHOP ON RICE GRAIN QUALITY

Chemistry and Plant Breeding Departments

A workshop at IRRI in October reviewed the present knowledge on grain quality, country reports, and methodology for measurement of rice quality. The participants included 28 breeders and chemists from 11 countries and IRRI. Areas recommended for research priority were characters of cooked rice and inheritance of characteristics influencing grain quality. Five cooperative test groups were recommended for 1979 — degree of milling, alkali test, amylose determination, gel consistency, and instrument methods for cooked-rice texture.

FACTORS THAT AFFECT GRAIN QUALITY

Chemistry Department

Starch properties of world rice collection. Among cultivated varieties, amylose content and gelatinization temperature (as measured by alkali digestibility) are considered independent properties of rice endosperm starch. However, milled rices with high gelatinization temperature (>74°C) among the intermediate-amylose (20–25%) and high-amylose (>25%) types, and rices with intermediate gelatinization temperature (70–74°C) among the waxy (0–2%), low-amylose (9–20%), and very low-amylose (3–9%) types are rare. These combinations were identified from 10,517 rices analyzed for alkali digestibility in 1978. The correlation coefficient between amylose content and alkali digestibility was negative, indicating that waxy rices tend to have low gelatinization temperature (Table 2). Amylose content was negatively correlated with

Table 1. Properties of intermediate-amylose IRRI lines and of intermediate-amylose parents BPI-121-407 and C4-63G. IRRI, 1978.

Parents and lines	IRRI crop	Alkali spreading value	Gel consistency (mm)	Instron cooked rice	
				Hardness (kg)	Stickiness (g·cm)
BPI-121-407	1977 dry	6.9	96	7.6	117
BPI-121-407	1977 wet	6.9	68	7.2	68
BPI-121-407	1978 dry	7.0	70	6.6	99
BPI-121-407 lines (3)	1977 dry	6.9–7.0	73–94	7.2–7.9	75–90
BPI-121-407 lines (3)	1977 wet	7.0	38–73	6.8–8.0	51–68
Mean		7.0	72	7.3	80
C4-63G	1977 dry	2.0	92	5.9	78
C4-63G	1977 wet	3.0	79	6.6	80
C4-63G	1978 dry	4.0	94	5.7	89
C4-63G lines (3)	1977 dry	2.5	80–100	5.5–6.4	84–122
C4-63G lines (4)	1977 wet	3.1–5.3	78–100	5.8–6.5	75–107
Mean		3.4	90	6.0	93

Table 2. Linear correlation coefficients among amylose content, alkali digestibility, and protein content of 10,517 germplasm bank entries. IRRI, 1978.

Property	Alkali digestibility	Protein content: Dry season (n = 5,422)	Protein content: Wet season (n = 5,282)
Amylose	−0.39**	−0.20**	−0.13**
Alkali digestibility	1.00	0.23**	0.13**
Protein content, dry season		1.00	0.36***

*n = 736.

protein content, but alkali digestibility showed the opposite trend.

The distribution of defatted brown-rice amylose content in 14,261 rices classified in the germplasm bank was 11.6% waxy (0–2%), 2.9% very low (3–9%), 15.6% low (10–19%), 39.5% intermediate (20–24%), and 30.4% high (>24%). Slightly different amylose ranges were assigned to the various amylose type in brown rice because its starch content is lower than that of milled rice.

Survey of world rice varieties. As part of the periodic survey of world rice varieties, samples from 15 countries were analyzed. Protein and starch properties varied widely (Table 3). The predominant amylose type for each country reflected the region's preference for cooked-rice texture. Soft or medium gel was preferred to hard gel in all countries. The low-gelatinization-temperature types was predominant; it was followed by the intermediate-gelatinization-temperature type.

The set of Korean varieties differed from Tongil in that they were identical to the check, japonica varieties Jinheung and Akibare in alkali spreading value, gel and amylograph consistency, and hardness and stickiness of cooked rice. Evidently the newer varieties had become quite similar to japonica rices in eating quality and could not be readily distinguished from each other by physicochemical means.

A compilation of quality characteristics of milled rice grown in 38 countries and periodically analyzed in the Chemistry Department since 1963 was published.

Refinement of amylose test. Because reproducible results are difficult to obtain at alkaline pH, the amylose analysis of check milled-rice samples was tried at pH 4.5–4.8. Defatted purified starches and defatted milled rices were used. Potato amylose was a suitable amylose standard but commercial amylopectin samples were inferior to waxy rice starch in terms of low amylose impurity. A standard curve was prepared with amylose and waxy rice starch mixtures containing 90 mg starch/100 ml dispersion based on 90% starch in milled rice (dry weight). Weights of 10, 20, 25, and 30 mg amylose were combined with waxy starch to a total starch weight of 90 mg. Results for 100 mg defatted milled rice flour and 90 mg defatted starch were comparable. Values for undefatted flour averaged 2.6 percentage points lower than those of defatted flour.

Table 3. Range of physicochemical properties of milled rice from 15 countries. IRRI, 1978.

Source	Milled rices (no.)	Protein (%)	Apparent amylose type[a]	Gel consistency type[b]	Gelatinization temp. type[c]
Australia	10	6–8	L>I>Wx	S	I>L
Bangladesh	19	5–11	H>I	S>H>M	L>I
Bulgaria	8	6–8	I>L	S>M	L
Colombia	6	8–11	H>I	M>S>H	L
Egypt	10	6–9	I>L>H	S>M	L
Hungary	12	6–8	I	M>S	L
Italy	10	6–8	I>L	S	L
Korea	10	7–9	L	L	L
Philippines	10	6–10	H>I>Wx	S>H	I>L>H
Portugal	10	5–7	I>L	S	L
Spain	4	6–7	I>L	S	L
Sri Lanka	10	6–10	H>I	S	I>L
Taiwan	9	4–11	L>H>I, Wx	S>H>M	L>H
USA	8	5–8	L>I>H	S>M	I, HI>L
USSR	8	6–8	I>L	S	L, I

[a]Wx = waxy (0–2%); L = low (10-20%); I = intermediate (20-25%); H = high (≥25%). [b]S = soft, 61-100 mm; M = medium, 41-60 mm; H = hard, 26-40 mm. [c]Based on alkali digestibility: L = low, 6-7; I = intermediate, 4-5; HI = high-intermediate, 3; H = high, 1-2.

Both amylopectin and amylose had higher starch-iodine absorbance at pH 4.5 than at pH 10. Amylose and starch absorbance were maximum at 610–620 nm, but amylopectin absorbance peaked at 550 nm.

Milled-rice flour standing in 1 N NaOH at 25°C for 24 hours gelatinized as effectively as that heated in a boiling water bath for 10 minutes. An incubation temperature of 40°C gave essentially the same amylose values for the samples as did 25°C.

Usually only the check samples whose absolute amylose contents are to be determined are defatted using refluxing 95% ethanol. Indian workers claimed that defatting of the alkaline rice dispersion once with petroleum ether and then carbon tetrachloride effectively removed the milled rice lipids. IRRI results, however, showed that although the amylose values thereby obtained were higher than those for undefatted samples, they were lower than the values for flour defatted with refluxing ethanol. Defatting with refluxing ethanol requires less operator time than defatting of the rice dispersions.

Starch amylose content is usually determined colorimetrically, but iodine complexing with amylose may also be determined by potentiometric and amperometric titration. A comparison of the various methods used with six rices indicated fairly good proportionality except that amperometric titration gave values about 25% lower than colorimetry (Table 4). With another set of 4 samples, mean amylose based on amperometric titration was only 71% of the mean value based on colorimetry. The end point of amperometric titration was sharper than that of potentiometric titration.

Cooking methods and texture of rice. In most tropical countries, milled rice is cooked in the amount of water it will absorb. In others, rice is cooked in excess water and the excess broth discarded. In the former method, relatively good cooked rice was produced by adjusting the cooking water to a predetermined optimum level based on amylose content, boiling for 20 minutes in an automatic rice cooker with excess water in the outer pot, and leaving it undisturbed for 10 minutes after turning off the heat.

With excess water, the boiling time required for the center of the rice grain to gelatinize (become translucent) varied from 16 to 26 minutes among varieties. Attempts were made to standardize the procedure by presoaking the raw rice in water for 10 minutes and then boiling for 16 minutes. With that method, the cooked rice of IR32 was harder than that of IR42; the reverse was true with the rice cooker method. In rices that show extreme elongation on cooking, lengthwise expansion of the grain seemed preferable to girthwise expansion when cooking water was limiting. The cooking method requires further refinement.

Improvement of texture determination using the Instron food tester continued. Values for stickiness tended to increase with increasing clearance (>0.4 mm) during flattening of the cooked-rice sample. The greater clearance values probably represented the combined contribution of adhesiveness and cohesiveness of the rice and were probably affected by the relative surface area of the cooked grains.

Hardness is now measured by extrusion in a modified Ottawa Texture Measuring System (OTMS) cell. Back extrusion using a cell with 10-mm annular gap may also be employed to

Table 4. Comparison of 3 iodometric methods of determining amylose of starch, IRRI, 1965 and 1978.

Sample	Amylose content (% of milled rice dry wt)			
	Potentiometric titration[a]		Amperometric titration[b]	Colorimetry[c] ($A_{620\ nm}$)
	$CaCl_2$	KI		
Malagkit Sungsong	0.9	0.4	1.0	1.0
Early Prolific	12.4	—	9.0	11.3
Khao Dawk Mali 105	15.2	—	11.7	17.9
Bengawan	22.4	21.3	—	29.5
Nahng Mon S-4	26.0	—	18.7	27.8
Peta	29.1	26.3	24.9	29.1

[a]1965 data based on iodine-binding capacity of 19% for rice amylose. [b]Based on IBC of 18.4% for potato amylose. [c]Based on a blue value of 1.144 Absorbance for potato amylose.

measure hardness, but it requires a load cell (the same as that required by the OTMS cell) different from the one used for the stickiness test.

The use of a texture profile from a double-bite method with the Instron unit, to simulate the Texturometer, was tried using five grains or a pellet or mold. The double-bite method required the plunger to travel to a fixed proportion (2/3) of the thickness of the rice grain. Molds tended to crumble, giving erroneous hardness values, particularly for high-amylose rice, but cohesiveness readings were satisfactory. Hardness data were better when five grains were used but clearance had to be changed to allow for differences in grain thickness among varieties.

Hardness is usually measured 1 hour after cooking, because cooked rice, particularly high-amylose rice, hardens progressively. A minimum of three samples were cooked for each test because cooked rice was softer with only one or two samples per cooker (7.9 kg vs 7.3 kg for a sample of IR8). Acetic acid (0.5%) — used in Japan to preserve the texture of cooked rice — was not effective on high-amylose rice, whose hardness increased (from 6.6 kg to 7.8 kg) after overnight standing at 25°C.

The secondary effect of differences in protein content on the texture of cooked rice was demonstrated in two crops of waxy rices (Table 5). Hardness and stickiness of cooked rice of wet and dry season samples of each variety varied. In some instances, the higher-protein sample even had the softer cooked rice.

Parboiling had little effect on the hardness and stickiness of waxy rice, but it increased the hardness of a low-amylose and an intermediate-amylose rice and reduced the stickiness of two high-amylose rices. Parboiled rice was presoaked for 45 minutes before cooking for the same 20 minutes and with the same amount of cooking water as nonparboiled rice.

Digestibility of waxy starch in infants. Cooked waxy rice is known to cause indigestion, particularly in children. In a cooperative study with the Instituto de Investigacíon Nutricional, Lima, Peru, a cooked waxy rice (IR29) and two cooked nonwaxy (IR480-5-9 and IR32) rices were compared for starch digestibility in eight Peruvian weaned infants. The rices were prepared as a liquid homogenate. Fecal carbohydrate analysis showed identical high starch digestibility in cooked waxy and nonwaxy rice. The results agree with the comparative enzymic digestibility of amylopectin and amylose. The higher bulk density of the cooked rice, which often results in overconsumption is the suggested cause of the poorer digestion of waxy rice. The more compact structure and more sticky texture of cooked waxy rice are related factors. The reported poorer digestibility of cooked freshly harvested rice, compared with that of cooked aged or stored rice, can be similarly explained.

Freeze-thaw of amylopectin gels. Starch chemists have reported that waxy rice 5% gels subjected to successive freezing (−20°C) and thawing (25°C) are much more stable than waxy corn and sorghum starches. Varietal difference in freeze-thaw stability among rice amylopectins was investigated. Waxy corn starch showed liquid separation by the second thawing whereas waxy rice starches were stable for 2 to 6 freeze-thaw cycles, and rice amylopectins were stable for 3 to 14 cycles. In three pairs of isogenic lines, waxy amylopectin was stable for

Table 5. Hardness and stickiness of cooked milled rice of 2 1977 crops of 4 waxy rices. IRRI, 1978.

Sample	Protein (%)		Instron cooked rice: Hardness (kg)		Instron cooked rice: Stickiness (g·cm)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
IR3464-75-1	5.6	8.0	4.2	4.0	430	430
IR4427-51-6	6.9	7.3	4.7	3.8	410	450
IR4427-58-5	5.8	7.2	3.7	3.6	490	450
IR4445-63-1	6.8	7.6	4.9	3.9	410	410
Mean	6.3	7.5	4.4	3.8	435	435

6 to 14 cycles; nonwaxy amylopectin was stable for only 3 to 6 cycles. Although they have the same mean chain length, the waxy amylopectins had relatively smaller molecular size based on intrinsic viscosity. The amylopectin of waxy rices with low gelatinization temperature tended to be more stable to freeze-thaw treatment than the amylopectin of waxy rices with high gelatinization temperature. The latter had relatively greater molecular size.

Factors affecting gel consistency. The variation in gel consistency values among samples of the same variety was caused mainly by bran lipid contamination, as determined by degree of milling. All nonwaxy brown-rice samples had hard gel, but after being defatted with refluxing 95% ethanol, they all gave soft gel readings, regardless of the gel consistency of the milled rice. Similarly, defatted milled rices had soft gels. For example, a sample of IR8 with gel consistency of 30 mm had a value of 50 mm after petroleum ether defatting, and 84 mm on 95% ethanol refluxing. The extracted lipid (0.7%) had a neutral lipids-glycolipids-phospholipids ratio of 65:15:20. Palmitic acid (0.4–0.7%) added to defatted milled rice restored the gel consistency to the original value (Table 6). Because neither defatting nor palmitic acid addition affected the gel consistency of waxy milled rice, the interference must have involved fatty acid-amylose complexing.

Most high-amylose rices with low gelatinization temperature (high alkali digestibility) have a hard gel. The correlation equation for 308 elite samples from 5 seasons was $y = 114.95 - 9.12x$ ($r = -0.41$**), where y is gel consistency and x is alkali digestibility. The correlation coefficients for the 5 crops ranged from −0.33** to −0.55** (n = 53 to 67).

Differences in the consistency of alkaline gels of milled rice seemed to relate to differences in amylograph consistency (viscosity on cooling to 50°C minus final viscosity at 94°C) of 10% pastes (wet basis) for high-amylose rices. The amylograph measures the changes in viscosity of the rice paste during heating at 1.5°C/minute from 30° to 94°C, 20 minutes cooking at 94°C and cooling at 1.5°C/minute to 50°C. This paste level did not effectively differentiate among lower amylose nonwaxy rices, which had previously been shown in the gel consistency test. With 10% gels, the correlation coefficient between gel consistency and amylograph consistency was −0.70** (n = 29) for high-amylose milled rice and −0.76** (n = 88) for intermediate- and low-amylose rices. At paste concentrations of 12%, differences in amylograph consistency were more apparent among intermediate- and low-amylose rices. Proportionately higher gel concentrations (6% vs 5%) were also required for differentiating among the samples in the gel consistency test.

The use of one paste concentration (10%) for amylography has been criticized by some rice chemists who suggested that samples be compared at the same peak viscosity. However, because water absorption during cooking is identical in samples of similar amylose contents, a paste concentration of 10% was found to be optimum for high-amylose rices and about 12% was optimum for both intermediate- and high-amylose rices for amylograph consistency differentiation. With these conditions, the high-

Table 6. Effect of defatting with refluxing 95% ethanol and addition of palmitic acid to the defatted rice on the neutral gel consistency of waxy milled rice and on the alkaline gel consistency of nonwaxy rices. IRRI, 1978.

Variety or line	Amylose type	Solvent	Gel concn (mg/2 ml)	Gel consistency (mm)		
				Undefatted	Defatted	Defatted + palmitic acid[a]
Malagkit Sungsong	Waxy	0.15 N KOAc	150	63	60	68 (1.0 mg)
Panpet 63	Waxy	0.15 N KOAc	150	45	45	42 (1.0 mg)
IR34	Low	0.2 N KOH	120	37	88	36 (0.8 mg)
C4-63G	Intermediate	0.2 N KOH	110	62	100	60 (0.4 mg)
IR32	High	0.2 N KOH	100	94	100	93 (0.5 mg)
IR42	High	0.2 N KOH	100	31	92	32 (0.4 mg)

[a]Values in parentheses are amounts of added palmitic acid.

Table 7. Comparison of amylograph consistency among nonwaxy rices of similar amylose contents at similar paste concentrations and at 1000 B.U. peak viscosity. IRRI, 1978.

Variety	Amylose type	Paste concn (% at 12% H_2O)	Amylograph viscosity (Brabender units)				
			Peak	Final at 94°C	Cooled to 50°C	Setback	Consistency
IR5	High	10.0	580	360	745	185	385
IR8	High	10.0	915	780	1525	610	795
Rojolele	Intermediate	12.0	1365	600	1010	−355	410
Bengawan	Intermediate	12.0	1675	680	1180	−495	530
Jinheung	Low	12.0	1215	540	830	−385	290
Tongil	Low	12.0	1235	520	995	−250	425
IR5	High	13.0	1000	565	1230	230	670
IR8	High	10.3	1000	800	1600	800	800
Rojolele	Intermediate	10.6	1000	540	790	−210	250
Bengawan	Intermediate	10.2	1000	520	840	−160	320
Jinheung	Low	11.5	1000	460	730	−270	250
Tongil	Low	11.4	1000	490	820	−180	330

amylose and intermediate-amylose rices differed in peak viscosity, hot paste viscosity at 94°C, and cold paste viscosity, but low-amylose rices differed mainly in cold paste viscosity (Table 7). Comparison at similar peak viscosities (1,000 B.U.) had no advantage over comparison at similar paste concentrations. At a similar peak viscosity, the better quality rices, such as IR5, Rojolele, and Jinheung, had lower setback and consistency viscosity than the poorer quality samples. Setback viscosity is the difference between viscosity cooled to 50°C and peak viscosity. The correlation coefficient between gel consistency and amylograph setback of 10% gels was −0.44** (n = 41) for high-amylose rices and −0.64** (n = 88) for intermediate- and low-amylose rices.

Gel consistency correlated negatively with viscosity (determined with a Wells-Brookfield cone-plate microviscometer) in both nonwaxy milled rice 5.0% gels (r = −0.69**, n = 61) and purified nonwaxy starch 6.75% gels (r = −0.82**, n = 63).

The relationship between gel consistency and hot-water soluble starch of milled rice was reviewed using rice flour samples. Soluble amylopectin (and starch) at 100°C was highest in soft-gel, high-amylose rices, such as IR32 — much higher than in waxy rices UPLB-Ri-1 and C441-4 (Table 8). In contrast, starch fractions in hard-gel, high-amylose rices, such as IR42, had lower solubility in hot water. Defatting with refluxing 95% ethanol had little effect on the solubility of the starch in hot water. In hot water, amylopectin was actually much less soluble than amylose in the high-amylose, hard-gel rice than in the high-amylose, softer gel sample. The flour of nonwaxy milled rice had more soluble starch than the flour of waxy milled rice.

Substances associated with rice starch granules. Unlike nitrogen content (0.01–0.06% dry basis), which increased prog-

Table 8. Solubility of amylose and amylopectin in boiling water bath, as affected by amylose content and gel consistency of starch. IRRI, 1978.

Variety or line	Gel consistency type	Amylose[a] (%)		Hot-water soluble amylopectin[a] (%)
		Total	Hot-water soluble	
UPLB-Ri-1	Soft	1.4	0.4 (29)	9.8 (9)
C441-4	Soft	5.4	1.6 (30)	11.2 (13)
IR2071-137-5	Soft	13.3	9.3 (70)	4.5 (8)
IR2061-38-3	Soft	16.6	9.5 (57)	9.0 (12)
Kuban	Soft	18.4	10.6 (58)	10.8 (15)
BPI-121-407	Soft	24.1	14.0 (58)	8.7 (14)
C4-63G	Soft	23.8	14.5 (61)	8.2 (12)
IR32	Soft	27.1	16.5 (61)	20.5 (33)
IR42	Hard	26.7	11.2 (42)	4.8 (9)

[a]Milled-rice dry basis. Values in parentheses are percentages of solubility of amylose or amylopectin in a boiling water bath.

reasively with amylose content of rice starch (1.7–30.3% dry basis), bound lipids extracted with water-saturated butanol at room temperature from 8 rice starches prepared by dodecylbenzene sulfonate (DoBS) removal of protein ranged from 0.03 to 0.44%, but were highest in intermediate-amylose rices, not in high-amylose starches. The lipid fractions were present in an approximate ratio of 1:1:1. The residual lipid (25%) had essentially the same composition as the extracted lipid. Thin-layer chromatography revealed that neutral lipids were mainly free fatty acids, glycolipids were di- and monoglycosyl di- and monoglycerides, and lysophosphatidyl choline and lysophosphatidyl ethanolamine were the major phospholipids. The major fatty acids of these fractions, determined by gas liquid chromatography of their methyl esters, were linoleic and palmitic with variable levels of oleic acid, plus smaller amounts of myristic, stearic, and linolenic acids. In waxy starch, bound lipids (0.12%) were mainly free fatty acids.

Water-saturated-butanol-defatted starch had slightly higher amylose value, 1° to 3°C lower gelatinization temperature, and 0 to 0.07 N lower gelatinization normality in the alkali viscogram, slightly greater susceptibility to lintnerization loss in 2.2 N HCl at 35°C, and reduced gel viscosity and softer gel consistency compared with undefatted starch. However, residual nitrogen was not affected and less than 50% of the bound phosphorus was removed on defatting. The phosphorus content of waxy starches was not reduced by defatting. Changes in hot-water-soluble amylose and starch and alkali viscogram viscosity from defatting were not consistent with starch properties. Bound nitrogen consisted mainly of protein and phospholipid nitrogen. Bound phosphorus was mainly phospholipids and organic phosphate esters.

The use of 1.2% sodium DoBS to purify rice starch resulted in a partial loss in bound lipids (mainly phospholipids) and an increase in glycolipid fraction, without any effect on the rheological properties of the starch. Evidently, residual DoBS had the same solubility as glycolipids. Sodium dodecyl sulfate (0.5%)–0.6% β-mercaptoethanol was more effective than DoBS in reducing bound lipid of starch and also reduced the gelatinization temperature of IR480-5-9 starch. Sodium hydroxide (0.1 or 0.2%) effectively removed protein but also reduced bound lipids drastically. The preferred method of preparing starch for lipid studies was wet milling in a Waring blendor, sonication, and treatment with alkaline protease at pH 10 at 50°C. Digestion of protein bodies by the protease probably also effectively removed the lipids associated with the protein bodies, particularly glycolipids.

The bound protein from purified waxy and nonwaxy rice starch granules was extremely difficult to remove in a pure form from the granules (0.007–0.08% N). SDS-polyacrylamide gel electrophoresis indicated more protein bands in nonwaxy starch than in waxy starch.

LIPIDS OF MATURE AND DEVELOPING GRAIN

Chemistry Department

Lipids of milling fractions of brown rice. Fat or lipids may be classified into readily extractable or free lipids, and alcohol-water soluble or bound lipids. Free lipids were extracted with chloroform-methanol (2:1) for 8 hours and with water-saturated butanol (WSB) for 0.1–1 hour. Bound lipids were then extracted for 24 hours with WSB. The 0.1–1 hour WSB extraction effectively removed most (>90%) of the remaining lipids of protein bodies after chloroform-methanol extraction. Bound lipids were mainly associated with starch granules and occurred in milled rice in the same amount as free lipids associated with protein bodies.

Fat-by-hydrolysis determined by hydrochloric acid hydrolysis of chloroform-methanol-defatted sample had essentially the same fatty acid composition as bound lipids. WSB at room temperature effectively extracted 75% of fat-by-hydrolysis. Hot extraction can remove most of the residual lipids. Fat-by-hydrolysis, or the fatty acid fraction, constituted 48% of the dry weight of bound lipids.

The free lipids were concentrated in the embryo and bran-polish fractions, whereas bound lipids were mainly in the milled-rice or

Table 9. Comparative composition of free and bound lipids* of milled rice of 3 rices differing in amylose content. IRRI, 1978.

Property	IR4445-63-1	IR480-5-9	IR42
Amylose type	Waxy	Intermediate	High
Free lipids (% dry basis)	0.8	0.4	0.4
Bound lipids (% dry basis)	0.1	0.6	0.5
Neutral lipids:			
glycolipids:phospholipids in			
Free lipids	76:12:12	66:17:17	66:18:16
Bound lipids	47:29:24	25:15:29	27:17:56

*Extracted with chloroform:methanol (2:1 vol/vol) and with water-saturated butanol from 95% milled rice.

endosperm fraction. Free fatty acids were also concentrated in milled rice.

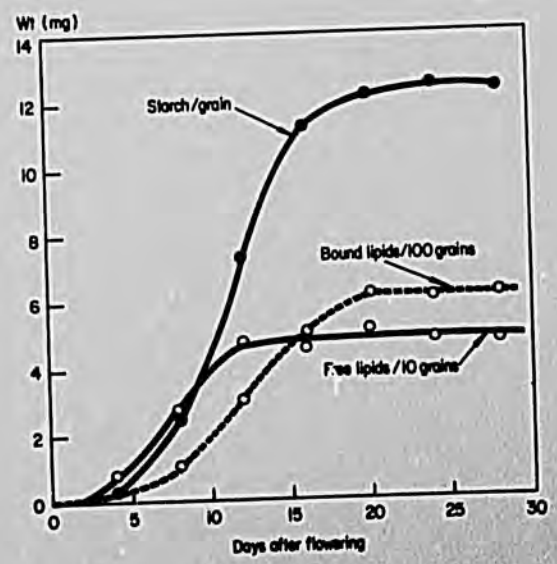
Fractionation of lipids by silicic acid chromatography revealed that neutral lipids were the major fraction of brown-rice free lipids, plus 4–5% glycolipids and 8–9% phospholipids. Bound lipids had larger proportions of phospholipids and glycolipids. Endosperm lipids tended to contain more glycolipids.

The amylose-amylopectin ratio of starch, as indexed by amylose content, affected lipid composition (Table 9). A waxy milled rice (1–2% amylose) had more free lipids and less bound lipids than two nonwaxy milled rices. In addition, its bound lipids had more neutral lipids (fatty acids) and glycolipids and less phospholipids than the bound lipids of nonwaxy rice. An intermediate-amylose rice (IR480-5-9) had slightly more bound lipids than a high-amylose rice (IR42).

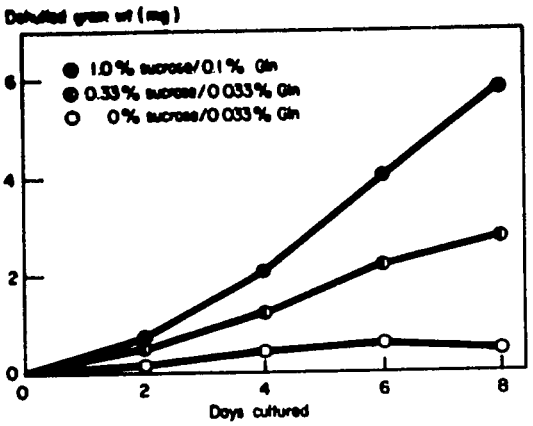
The composition of the lipid fractions of brown rice was determined by silica gel thin-layer chromatography and confirmed by the Department of Agricultural Chemistry, Obihiro University, Japan. The neutral fraction of the free lipids was mainly triglycerides, free fatty acids, sterol esters, and 4-monomethyl sterols with minor amounts of diglycerides and terpene alcohols. The neutral fraction of the bound lipids had the same compunds but free fatty acids instead of triglycerides predominated. Glycolipids of both free and bound lipids were acyl sterol glycolipids, monoglycosyl diglycerides, ceramide sterol glycosides, ceramide glycosides, monoglycosyl monoglycerides, diglycosyl diglycerides, and diglycosyl monoglycerides. Three unknown spots detected for bound glycolipids may be free sugars.

The phospholipids of the free lipids were phosphatidyl choline, phosphatidyl ethanolamine, and phosphatidyl *myo*-inositol, together with acyl phosphatidyl ethanolamine, phosphatidyl glycine, lysophosphatidyl ethanolamine, and lysophosphatidyl choline. In the bound lipids, lysophosphatidyl choline and lysophosphatidyl ethanolamine predominated together with phosphatidyl choline.

In terms of fatty acid composition, free lipids of three brown rices had mainly 36–40% linoleic acid, 32–37% oleic acid, and 23–24% palmitic acid, whereas bound lipids had 43–48% palmitic acid, 29–40% linoleic acid, and 12–17% oleic acid. The minor fatty acids were 0–3% myristic, 2–4% stearic, and 1–2% linolenic acids. The three fractions of free lipids had a fatty acid composition similar to that of



1. Accumulation of free and bound lipids and starch in developing IR42 rice caryopsis. IRRI, 1978.



2. Dry matter accumulation in developing IR42 grain from detached panicles in liquid culture of varying sucrose and glutamine (Gln) concentrations. Initial age of grains was 1–2 days after flowering. IRRI, 1978.

the total free lipids, but the fractions of bound lipids varied more in composition from the total bound lipids.

Lipids of developing IR42 rice grain. Free lipids accumulated within the first 12 days after flowering (DF) and fat-by-hydrolysis or bound lipids as long as 20 DF (Fig. 1). Glycolipids and phospholipids were synthesized faster than neutral lipids. The major fatty acids were palmitic, oleic, and linoleic, and there was an increase in oleic acid and a decrease in linoleic acid during grain development. Fat-by-hydrolysis contained more palmitic acid but less oleic acid than free lipids.

The earlier accumulation of free lipids relative to starch (and protein) is consistent with the earlier development of the bran layers in developing rice grain. Protein accumulated during the same period as starch during grain ripening. Fat-by-hydrolysis tended to follow closely dry matter accumulation, which supports the view that this lipid fraction is associated with starch granules. Free fatty acids increased slightly during grain desiccation in the field. Lipase and lipoxygenase activities in developing grain were low.

DRY MATTER ACCUMULATION IN DETACHED PANICLES

Chemistry Department

A time-sequence study was made to determine the curve of dry matter accumulation as a function of sucrose-glutamine level in the medium in which detached panicles are incubated. Results indicate that the lag period is 1 day or less for grains 1 to 2 DF (Fig. 2). Dry matter accumulation closely followed the level of substrates, sucrose, and glutamine.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments

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EVALUATING DISEASE RESISTANCE OF BREEDING MATERIALS

Plant Pathology Department

Multiple disease resistance. Promising elite breeding lines and selected IRRI varieties were evaluated for resistance to several fungal, bacterial, and viral diseases (Table 1). Results of field screening tests for blast, sheath blight, and *Cercospora* leaf spot resistance were inconsistent, indicating that pathogen virulence varies from test to test. Many lines were resistant to three or more diseases, but none were resistant to the ragged stunt virus. Frequent afternoon rains in the wet season adversely affected field inoculations for *Cercospora;* only dry-season reactions were therefore evaluated. Sheath rot evaluations were based on natural infection early in the wet season.

Table 1. Average disease reactions of elite IRRI breeding lines and varieties (1 to 5 trials). IRRI, 1978.

Designation	Diseases[a] reaction[b]									
	LS	CLS	SHB	SHR	BST	BB	BLS	RTV	GS	RS
IR8	MS	MS	MS	MS	S	S	MR	M	R	S
IR20	MR	MS	M	VS	S	R	MR	M	R	S
IR26	MS	MS	M	MS	S	R	MR	M	R	S
IR29	S	—	M	—	R-S	R	MR	R	R	S
IR32	S	M	M	M	R-M	R	S	M	R	M
IR34	S	M	M	MS	R[c]-S	R	S	M	—	S
IR36	S	MR	MS	M	R[c]-M	R	MS	S	R	S
IR38	—	MS	M	M	R	—	—	M	R	M
IR42	S	M	M	M	R[c]-S	R	S	S	R	S
IR1529-430	MS	—	M	—	S[c]-R	R	MS	M	R	S
IR1529-430-3	M	—	M	—	S	—	—	M	R	S
IR1754-F5-B22	MR	—	M	—	S-M	R-S	MS	S	R	S
IR2035-108-2	M	VS	M	—	R	—	—	M	M	S
IR2035-242	S	—	M	—	R-S	MS	M	M	R	S
IR2058-78-1-3-2-3	MR	MR	M	M	R[c]-S	MR	MS	M	R	S
IR2061-522-6-9	MS	—	M	—	S[c]-R	R	S	M	R	S
IR2071-176-1-2-1	S	—	M	—	R[c]-S	R	M	M	R	S
IR2071-686-3-5-4-3	S	M	MR	—	R[c]-S	R	MS	S	R	S
IR2307-247-2-2-3	S	M	M	M	R[d]-S	R	M	M	R	S
IR2797-105-2-2-3	S	MR	M	M	R[c]-S	R	MS	M	R	S
IR2797-125-3-2-2-2	S	MR	M	M	R[d]-S	R	S	M	R	S
IR2823-103-5-1	—	MS	M	—	R	—	—	R	M	S
IR2863-38-1	S	M	M	M	R[c]-S	R	S	S	R	S
IR2863-38-1-2	—	M	M	—	R	—	—	M	M	M
IR3351-38-3-1	MS	M	M	—	R[d]-S	R	M	S	R	S
IR3397-44-1-4-3	—	MS	M	—	R	—	—	M	R	S
IR3464-75-1-1	MS	M	M	—	S[c]-R	R	MS	M	M	S
IR3464-96-3-3-1-3-1	MS	MR	M	—	R-S	R	MS	M	R	S
IR3464-126-1-3	—	MS	M	—	S	—	—	R	R	S
IR3518-96-2-2-2	S	R	M	VS	R[d]-M	R	S	M	R	S
IR3646-9-1-1	S	M	M	—	S	—	—	S	R	—
IR3646-9-2-1	S	—	M	—	M[c]-S	S	—	S	R	S
IR3646-9-3-1	MS	—	M	—	S[c]-R	S	MS	S	R	S
IR3648-1-1-1	MS	—	M	—	M[c]-S	S	MR	S	R	S
IR3839-1	—	M	M	—	M	—	—	M	R	S
IR3880-10	MR	MS	M	—	R[c]-S[c]	S	MS	M	R	S
IR3880-13	MR	MR	M	—	M[c]-S	R	S	S	R	S
IR3880-13-5	S	MS	M	—	M[c]-S[c]	R	M	M	R	M
IR3880-13-7	S	—	M	—	M[c]-S	R	M	M	R	S
IR3880-13-10	MS	—	M	—	R-S	MS	R	M	R	S
IR3880-13-17	—	MR	—	—	S	—	—	—	—	—
IR3880-17	—	MR	M	—	S	—	—	M	R	S
IR4215-409-2-2	—	MS	M	—	S	—	—	R	R	—
IR4219-36-3-3	—	MS	M	M	S	—	—	R	R	S
IR4227-28-3-2	MS	S	MS	—	R[c]-S	R	MR	M	R	S
IR4417-179-1-5-2	—	M	M	—	R	—	—	R	R	S
IR4422-6-2-3-1	—	R	M	—	S	—	—	M	M	S
IR4422-51-1-1-2	—	M	M	—	S	—	—	M	R	S
IR4422-143-2-1	—	M	M	—	S	—	—	M	R	S
IR4422-480-2-3-3	MS	MR	M	M	S	R-S	MS	M	R	S

Continued on opposite page

Table 1 continued

IR4422-61-6-3	S	S	M	—	R[4]-S	R	MR	M	R	S
IR4427-59-5-2	MR	M	M	—	R[c]-M[c]	R	MR	M	R	S
IR4427-316-3-3	—	S	M	—	R	—	—	R	R	S
IR4722-39-6	S	MR	M	M	R[4]-S	MR	S	M	R	S
IR4422-39-6-5	—	M	M	—	R	—	—	M	R	—
IR4422-52-6-4	MS	M	M	MS	R[4]-S	R	M	M	R	S
IR4422-169-6-4	—	MS	M	—	R	—	—	M	R	S
IR4445-53-1-2-2	MS	M	M	—	S[4]-R	R	MR	M	R	S
IR4553-53-1-3-6	—	MS	M	MR	M	—	—	M	R	S
IR4553-56-1-3-2	MS	MR	M	M	R[c]-M	R	MR	M	R	S
IR4569-225-3-2	—	MS	M	—	S	—	—	M	R	S
IR4570-53-3-3-2	MR	MR	MR	MS	R[c]-S	R	MR	M	R	M
IR4570-117-2-1-2	MR	MR	M	—	R[4]-S	MR	MR	M	R	M
IR4613-54-5	—	VS	M	—	S	—	—	S	R	S
IR4625-219-2-2	MS	M	M	—	S	R	MR	M	R	S
IR4693-54-2-2-3	—	M	M	—	S	—	—	R	R	S
IR4693-54-2-2-2-3	MS	—	M	—	S	R	MS	R	S	—
IR4707-123-3	—	M	M	—	S	—	—	R	M	S
IR4707-225-2-3	—	S	M	—	S	—	—	R	R	S
IR4744-295-2-3	—	M	M	M	M	—	—	R	M	S
IR4816-70-1	MS	M	M	—	S	R	S	M	M	S
IR4819-77-3-2	—	M	M	—	S	—	—	M	M	S
IR4870-15-1-1	MS	R	M	—	M[4]-S	R	M	M	R	S
IR5105-80-3-3-2	MR	R	M	—	S	R		S	R	M
IR5105-93-2-2	—	M	M	—	S	—	M	R	S	S
IR5178-1-1-3	MS	—	M	—	R	MR	R	M	R	S
IR5716-18-1	MR	MS	M	—	R[c]-S	R-S	MS	M	R	S
IR5785-37-1	—	M	M	—	M	—	—	R	M	—
IR5863-118-5	MS	MS	M	M	R	R	MR	S	R	S
IR5863-162-1-2	MS	VS	M	—	R[4]-M	R	—	S	M	S
IR5863-162-1-2-3	MR	M	MR	MR	R[4]-M	R	MR	S	M	S
IR5863-165-1	—	M	M	—	R	—	—	R	M	S
IR5863-165-1-1-2	—	—	M	—	R[c]-M	R	MR	M	R	S
IR5863-198-1-2	MS	M	M	M	M[c]-R	R	MR	M	R	S
IR5982-7-6-1	MS	—	M	—	S	R-S	—	S	R	S
IR6115-1-1-1	S	VS	M	—	R[4]-M	R	MS	S	R	S
IR6503-24-3-1	S	R	M	—	R[c]-S	R	MR	S	R	M
IR7545-27-3-2	MS	M	MR	—	R-S	R	M	S	R	S
IR7760-4-8-2	—	VS	M	M	R	—	—	R	R	—
IR7805-22-3-1	—	M	M	—	R	—	—	S	R	—
IR8192-31-2-1-2	MS	VS	MR	—	R-S	R	M	R	R	S
IR8192-166-2-2-3	S	MS	MR	—	M[c]-S	R	—	S	M	S
IR8192-200-3-31	S	M	M	—	R-S	R	M	R	R	S
IR8608-189-2-2	MR	M	M	—	S[c]-R	R	MR	M	R	M
IR8608-298-3-1	MS	MR	M	—	S	R	—	M	R	S
IR9129-136-2	S	M	M	—	R[c]-S	R	MS	S	R	S
IR9129-209-2-2	S	R	M	M	M[c]-S	R	MR	M	R	S
IR9129-457-1	S	M	M	—	M[4]-S	R	M	M	R	S
IR9209-26-2	MS	MR	MS	—	M[c]-S	R	MR	S	—	S
IR9209-181-2	—	MR	VS	—	R	—	M	S	M	—
IR9209-181-2-2	S	M	M	—	R[c]-S	R	—	S	R	S
IR9209-181-3	S	M	M	MS	R[c]-S	R	MR	M	R	S
IR9209-262-3	—	—	VS	MS	R	—	—	M	M	—
IR9209-262-3-6	MS	M	M	—	R-S	R	M	S	R	S
IR9224-117-2	S	MS	MS	—	R-M[c]	R	MR	R	R	S
IR9250-40-2	—	M	MS	—	R	—	—	R	M	—
IR9575-(BPI-76[b]/Dawn)	—	MR	M	—	M	—	—	S	M	S
IR9732-119-3	S	M	M	—	M[c]-S	R	MR	S	R	S
IR9761-19-1	S	—	M	—	R[c]-S	R	M	S	R	S
IR9761-47-3	MS	—	M	—	R[c]-M	R	MS	S	R	S
IR9761-75-3	MR	—	M	—	R[c]-S	R	MR	S	R	S
IR9788-19-2	MR	M	M	—	R[c]-M	R	S	M	R	S
IR9802-10-3	MR	—	MR	—	R-M	R	M	M	R	S
IR9805-78-2	MS	M	M	—	R	MS	M	M	R	S
IR9805-97-1	S	M	M	—	R-M	R	MR	M	R	S
IR9814-6-3	S	M	M	—	R[c]-S	R	R	M	R	S
IR11287-158-3	S	—	M	—	R-S	R	MR	M	R	S
BR51-91-6	S	—	MR	—	S[c]-M	R	M	M	R	S
IR8846-215-3	—	M	M	—	—	R	—	—	—	—

[a]LS = leaf scald, CLS = *Cercospora* leaf spot, SHB = sheath blight, SHR = sheath rot, BST = blast, BB = bacterial blight (PXO 61), BLS = bacterial leaf streak, RTV = rice tungro virus, GS = grassy stunt, RS = ragged stunt. [b]S = susceptible, R = resistant, M = moderately resistant, MS = moderately susceptible, VS = very susceptible. [c]2 cases. [d]3 cases.

Table 2. Summary of blast screening results. IRRI, 1978.

Source	Entries (no.)		
	Resistant	Intermediate	Susceptible
Elite breeding lines[a]	134	73	112
World collection[a]	3,342	2,162	2,834
Pedigree lines	16,148	8,908	13,320
Observational yield trial[a]	1,148	442	284
Replicated yield trial[a]	736	199	90
Hybridization block[a]	276	120	122
Korean material	128	336	2,759
Plant pathology lines	1,790	767	2,441
Brown planthopper material	480	81	31
Indonesian lines	12	5	16
Australian lines	28	60	9
Colombia lines	22	1	1
IRRN seedlist (78[a])	1,121	364	586
International Rice Arid Region Observational Nursery	41	23	71
International Upland Rice Observational Nursery	59	33	99
International Rice Cold Tolerance Nursery	53	24	156
International Rainfed Lowland Rice Observational Nursery	93	19	142
International Rice Observational Nursery	120	19	246
Total (no.)	25,714	13,596	23,328
Total (%)	41.06	21.71	37.24

[a]Tested 2 to 4 times.

SCREENING VARIETIES AGAINST MAJOR DISEASES

Plant Pathology Department

Fungal diseases. *Blast.* In 1978, 62,637 varieties and breeding lines were evaluated in the field for reaction to leaf blast. Forty-four percent of the test materials were pedigree lines, 13% were from IRRI's world collection, and 8% were plant pathology breeding lines. Forty-one percent of the entries were resistant, 22% were intermediate, and 37% were susceptible (Table 2).

After the first 10,000 IRRI germplasm accessions were screened for blast resistance, the screening of 10,286 more entries was initiated in 1974. About 11% were resistant. The varieties were retested 4 times in the IRRI blast nursery; only 50% remained resistant but many became susceptible to other races that were not present in the preliminary screening (Table 3). The resistant varieties, among which G378, JK689, RT1095-326, Belisiyan, and Tukad (Table 4), will be multiplied and included in the International Rice Blast Nursery to determine if they have a broad spectrum of blast resistance and can be used as donor parents.

Cercospora *leaf spot.* In the 1978 dry season, 437 elite breeding lines and entries in replicated yield trials were screened for resistance to *Cercospora* leaf spot.

Plants were inoculated late in the afternoon at an adjusted spore density of 45-50 spores/microscopic field of low magnification. Disease readings were taken from the flag leaves when plants reached the ripening stage (Table 5).

The wet-season screening and a preliminary yield-loss study were lost to October typhoons.

Leaf scald. The 1,208 varieties from the world collection that were previously observed as resistant to leaf scald in the field were artificially inoculated in the 1978 wet season to confirm their reactions. Plants at the maximum tillering stage were inoculated with a spore suspension of *Rhynchosporium oryzae* by the clipping method. Also inoculated were 337 entries from the 1978 wet-season elite lines and from the hybridization block. Varietal resistance was evaluated 21 to 30 days after inoculation with lesion length as the criterion. No variety was immune, but 3.8% of the entries were rated

Table 3. Retesting of blast-resistant varieties in blast nursery. IRRI, 1978.

Test no.	Date of seeding	Entries rated as						Entries tested (total no.)
		Resistant		Intermediate		Susceptible		
		No.	(%)	No.	(%)	No.	(%)	
1	4 Apr 1978	811	74.1	139	12.7	144	13.2	1094
2	13 Jun 1978	655	60.3	209	19.3	222	20.4	1086
3	20 Sep 1978	593	56.80	223	21.4	228	21.8	1044
4	9 Nov 1978	467	49.9	306	32.7	163	17.4	936

Table 4. Some rice varieties that remained resistant after 5 tests in the blast nursery. IRRI, 1979.

Variety	Accession no.	Country of origin
G378	11082	India
JX289	11085	India
Murungakayan 387	11086	Sri Lanka
CI-7767	11108	USA
Makee White	11146	Papua New Guinea
Redin Bisa	11138	Malaysia
RT1986-326	11154	Senegal
Bellahyan	11191	Philippines
Tulasi	11212	Philippines
Redio Anaise (PI 368812)	14798	Surinam
6-C	14807	Liberia
10-A	14812	Liberia
11-A	14813	Liberia
19-D	14814	Liberia
47-A	14818	Liberia
7-EB	14823	Liberia
8-EA	14826	Liberia
20-A	14838	Liberia
24-A	14843	Liberia
29-D	14845	Liberia
46-A	14852	Liberia
46-C	14853	Liberia
1-EB	14854	Liberia
29-E	14876	Liberia
DM	14879	Liberia
377	14880	Liberia
423	14881	Liberia
434	14882	Liberia
561	14889	Liberia
257	14912	Liberia
279	14916	Liberia
280	14917	Liberia
430	14922	Liberia
466	14922	Liberia
482	14924	Liberia
487	14926	Liberia
548	14931	Liberia
549	14933	Liberia
552	14936	Liberia
554	14938	Liberia
562	14943	Liberia
Lac 3	14946	Liberia
Lac 7	14947	Liberia
Lac 45	14963	Liberia
Lac 50	14964	Liberia
Ku 9	14981	Thailand
Ku 91	15031	Thailand
Ku 93	15032	Thailand
R53-157	15073	Belgian Congo
R54	15074	Belgian Congo
R75	15076	Belgian Congo

resistant and 56.1%, susceptible (Table 6). Varieties rated as resistant included ARC6563, ARC10654, Bhusuri Sali Paddy, CR179-1-177, and IR4744-295-2-3. After their resistance has been reconfirmed, those varieties can be used as sources of resistance to leaf scald.

In a field survey of the natural occurrence of leaf scald on 808 varieties in the plant breeding seed multiplication plot, 688 varieties were

Table 5. Screening for resistance to Cercospora leaf spot. IRRI, 1978 dry season.

Source	Entries (no.)	Entries (no.) with disease reaction		
		R	M	VS
Elite breeding lines	71	5	57	9
Replicated yield trial	366	31	321	4
Total	437	36	378	13
%		8.2	86.8	3.0

*R = resistant, M = moderate reaction, VS = very susceptible.

rated resistant and only 2 (0.25%) were rated susceptible. The others were rated moderately resistant and moderately susceptible. The resistant and moderately resistant varieties will be artificially inoculated to confirm their reactions.

Sheath blight. In the 1978 dry season, 7,090 entries from various sources were screened for resistance to sheath blight. No entry was highly resistant; about 2% were moderately resistant; 93.4%, intermediate; 3.2%, moderately susceptible; 0.8%, susceptible; and 0.6%, very susceptible.

Another group of 3,629 materials from the same sources was tested in the 1978 wet season. Again, no entry was resistant; about 2.5% were moderately resistant; 91.7%, intermediate; 4.9%, moderately susceptible; 0.9%, susceptible; and 0.2%, very susceptible.

Table 7 summarizes the 1978 sheath blight screening.

Sheath rot. Varieties and breeding lines were infected with sheath rot caused by *Acrocylindrium oryzae* at varying degrees of severity in the 1978 wet season. The standard evaluation system (SES) for scoring disease intensity was used. Few (about 1.2%) of the 244 entries were resistant; a large number (54.4%) were intermediate (Fig. 1).

The entries rated as resistant were IR4570-124-3-2-2-2, IR9129-204-1-2, and IR3259-PP5-160-1.

Virus diseases. In 1978, 46,099 varieties, elite lines, and pedigrees were scored for reaction to natural infection by rice tungro disease. On the international standard system scale of 1-9 (1 = less than 1% infected hills, 9 = about 100% infected hills), 89% were scored 3 or less; 8%, 4 to 6; and 3%, 7 or higher. Similarly, the reactions of 39,520 entries to ragged stunt were

Table 6. Summary of screening for resistance to leaf scald. IRRI, 1978.

Source	Entries (no.) with disease reaction[a]			
	Resistant (1-2)	Moderately resistant (3)	Moderately susceptible (4)	Susceptible (5-9)
World collection	8	115	324	761
Elite lines	0	15	32	35
Hybridization block	49	48	86	72
Total (no.)	57	178	442	868
Total (%)	3.8	11.5	28.6	56.1

[a]Disease reaction was based on the following scale: 1 = lesions 0-1 cm long, 2 = 1.1-2 cm, 3 = 2.1-3 cm, 4 = 3.1-4 cm, 5 = 4.1-5 cm, 6 = 5.1-6 cm, 7 = 6.1-7 cm, 8 = 7.1-8 cm, 9 = longer than 8 cm.

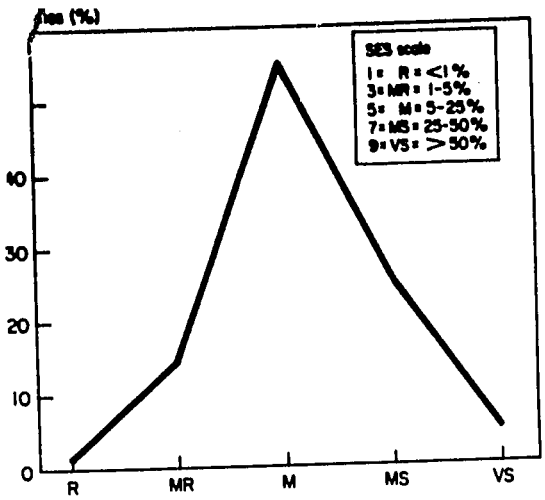
scored. Thirty percent were scored 3 or less; 43%, 4 to 6; and 27%, 7 or higher.

In the greenhouse, 13,436 entries of 3,136 varieties and lines were tested for reaction to tungro. Among the resistant rices, Basmati consistently had a low percentage of infection. Five thousand seven hundred fifty-one entries of 2,218 varieties and lines were inoculated to test

Table 7. Summary of sheath blight screening results. IRRI, 1978.

Source	Entries (total no.)	Entries (no.) with disease reaction[a]					
		R	MR	M	MS	S	VS
Elite breeding lines	154	0	17	122	9	3	3
Replicated yield trial (lowland)	1000	0	13	871	99	16	1
Replicated yield trial (upland)	160	0	1	148	7	2	2
Observational yield trial (lowland)	1485	0	21	1370	81	13	0
Observational yield trial (upland)	1171	0	1	1131	31	4	4
Hybridization block	579	0	2	524	35	13	5
5th International Rice Sheath Blight Nursery (2d set)	154	0	14	130	8	1	0
Plant pathology lines	370	0	23	297	33	13	4
Korean breeding lines	3165	0	59	3045	26	11	25
Collaborative sheath blight screening materials	151	0	15	135	1	0	0
Stress-resistant donors	20	0	5	15	0	0	0
Germplasm bank	2089	0	11	1986	69	14	9
Confirmation test							
Elite breeding lines	1	0	0	1	0	0	0
Replicated yield trial (lowland)	7	0	1	6	0	0	0
Observational yield trial (lowland)	43	0	9	32	2	0	0
Plant pathology lines	23	0	5	18	0	0	0
Korean breeding lines	57	0	2	55	0	0	0
5th International Rice Sheath Blight Nursery	30	0	13	16	1	0	0
International Rice Blast Nursery	12	0	7	5	0	0	0
International Rice Observational Nursery	18	0	3	14	1	0	0
International Rice Yield Nursery	15	0	2	12	1	0	0
Germplasm bank	15	0	0	14	1	0	0
Total	10,719	0	224	9947	405	90	53
%		0	2.1	92.8	3.8	0.8	0.5

[a]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, S = susceptible, VS = very susceptible.



1. Sheath rot reactions under natural infection of 244 varieties and breeding lines in the hybridization block. IRRI, 1978 wet season.

their reactions to grassy stunt disease. Similarly, 1,746 varieties and lines were tested by the newly developed mass-screening method for ragged stunt resistance. Of those, 82% had 61% infection or higher; 15%, 31 to 60% infection; and 3%, less than 30% infection. Varieties with low infection included: PTB 21 (acc. no. 6113), Molaga Samba (6114), PTB 21 (11053), Murungakayan 104 (12078), Hathili (15200), Mawee (15219), Mawee (15296), Mahamawee (15322), Chembaralgi Samba (15452), CR57-29 (15775), and PTB 33 (19325).

Bacterial diseases. More than 78,500 rice entries were screened, evaluated, and tested for bacterial blight resistance (Table 8). Both strains PXO 86 of pathotype 2 and PXO 61 of pathotype 1 of *Xanthomonas oryzae* were used in the screening program to determine the breeding materials with specific resistance conditioned by either *Xa 4* or *xa 5*.

FURTHER INCORPORATION OF DISEASE RESISTANCE

Plant Breeding Department

Blast. Rice blast is not a major threat in most tropical irrigated rice fields. Philippine farmers have widely accepted some IRRI varieties (e.g. IR26 and IR36) with only moderate resistance. Blast is rarely serious at IRRI, which indicates that it is a poor location for a strong breeding and field screening project for blast resistance. Although some use is made of sources of blast resistance in general breeding, more emphasis has been placed on analyzing the situation of varietal resistance through results from the IRBN and on collaborating with national breeders.

Breeding for resistance. Selection for resistance only in IRRI's blast nursery is inadequate in retaining some types of resistance that would be effective against a wide spectrum of blast races. Therefore, all breeding lines with some resistance potential are being tested in another blast nursery in Leyte, Philippines.

The present donors of resistance in advanced breeding lines are several lines from IR2588 (IR24/Tetep///Sigadis*2/TN1//IR24), IR2793 (Peta*4/TN1//Tetep*4/Peta*3/TN1//HR2///IR20/TKM 6), and IR2053 (Peta/TN1//Tetep///IR22/C4-63). All derive from Tetep, but their resistance differs from that of Tetep, which continues to be effective. Recent analysis indicated that the lines are occasionally susceptible at Leyte.

Further analysis indicated that many lines have a resistance similar to that of Tetep or Zenith (these two resistance sources are difficult to distinguish and separate in the present field-testing program). To recover Tetep's type of

Table 8. Screening of 6 groups of lines and varieties for bacterial blight resistance. IRRI, 1978.

Material screened	Entries tested (no.)		Resistant or moderately resistant (%)
Pedigree nurseries		67,181	82
F_3	36,927		72
with *Xa 4*	34,882		
with *xa 5*	2,045		
F_4	20,624		95
with *Xa 4*	20,102		
with *xa 5*	522		
F_5	6,510		91
with *Xa 4*	6,017		
with *xa 5*	493		
Hybridization block		538	45
Germplasm bank		6,216	15
Replicated yield trial		956	94
Observational yield trial		3,006	59
Elite lines		162	81
Total		78,086	

resistance, IR1905-81-3-1, some IR5533 lines, and IR9669 progeny have been crossed with rainfed wetland or dryland rices. The progeny will be screened simultaneously at IRRI and Leyte, to recover more improved lines with Tetep's type of resistance.

Analysis of prevailing host resistance. Data from the Leyte blast nursery have helped differentiate various types of host resistance at 1976. Some resistance donors often react to u[illegible] races at IRRI and those of Leyte in a distinct[illegible] different manner although the races at both sit[illegible] vary from season to season. Therefore, clas[illegible]sification of the types of host resistance has proceeded on the assumption that if a number of races in one group behave uniformly through

Table 8. Lines or varieties representing each blast resistance group. IRRI, 1978.

Group	IRSN entry no.	Subgroup	Line or variety	Entries (no.)	Reaction to blast (1 = resistant, 9 = susceptible)										
					Basic criteria				Secondary criteria						
					Philippines				Malaysia B. Lima		Indonesia	Thailand	Nepal	Indonesia	Colombia
					IRRI		Leyte								
					1976	1977	1976	1977	1976	1977	1976	1976	1976	1977	1977
1			*Major group*	81											
	146	Tetep 1a	IR1905-81-3-1	49	1	1	1	2	2	1	1	1	1	3	3
	99	Zenith 1b	IR4547-6-2-5	10	1	1	1	1	1	2	1	1	5	3	3
	350	Carreon 1c	Colombia I	12	1	1	1	2	1	2	2	3	7	3	2
	326	M-302 1d	IR946-33-2-2-2-2	6	1	1	1	3	4	5	5	5	5	7	4
		Miscellaneous		4											
2				28											
		O. nivara													
	165	2a	IR2588-2-3-3	25	1	1	8	1	5	2	1	1	1	2	5
	415	2b	74-5499 or	3	1	1	5	1	2	4	2	1	9	3	4
	416	2b	74-5507		1	1	6	1	4	4	1	1	9	3	4
3				67											
	169	3a	IR2793-18-5	53	1	1	8	4	4	2	1	1	1	4	4
	141	3b	IR34	12	1	3	8	8	5	4	7	2	4	4	3
		Unclassified		2											
4				26											
	332	4a	IR1529-680-3	17	1	9	8	6	8	4	8	4	1	7	7
	192	4b	IR3454-80-2-1	5	1	3	8	8	6	4	7	3	2	5	4
	161	4c	IR2071-588-5-4-3	4	1	7	8	4	4	8	5	3	1	9	7
5			*Minor group*	21											
	353	5a	Dawn	17	6	4	1	1	3	2	2	1	6	2	7
	58	5b	Ru 369-7-2-1-4	2	7	4	3	1	9	2	4	3	1	6	4
		Miscellaneous		2											
6				17											
	82	6a	IR3271-PP134-68-3-1	4	6	1	1	1	4	3	1	1	4	3	3
	333	6b	IR1544-38-2-2	6	6	3	6	1	9	4	2	3	1	4	3
	171	6c	IR2793-80-1	3	6	1	7	4	4	1	1	1	1	2	3
	269	6d	BW 246-10	4	5	1	5	1	3	4	6	7	1	9	5
7				3											
	60		TOS 2259/7-3-2-9-B2		1	9	4	1	8	7	3	2	7	3	2
	293		Hahng Yi 71		1	6	1	1	4	3	1	4	3	2	1
8				4											
	230		IR4432-29-6		5	1	8	7	7	4	9	3	1	4	7
				4											
	306		CI 5309		8	5	5	1	9	9	3	2	7	2	8
10	137		IR26	10	8	8	9	8	9	8	6	8	5	9	8
			Total	261											

other tests, their genotype may be similar.

From 397 IRBN entries tested at Los Baños and Leyte in 1976 and 1977, 261 entries were tentatively classified into 10 major resistant groups (Table 9). Subgroups were assigned to each major type, on the basis of reactions outside the Philippines. Table 10 shows two examples of the relative homogeneity of the reactions within each group.

The first four groups in the classification seem to represent the host resistance in the present breeding program. All are probably related to Tetep, Zenith, *Oryza nivara*, a segregant of an *Oryza nivara* cross, or Sigadis. A minor group of varieties reacts similarly to Dawn, but includes few IRRI lines because Dawn tends to be susceptible at IRRI. That type of resistance has not been selected at IRRI.

The results indicate that a tentative set of differential breeding lines can be selected to monitor races in blast nurseries (Table 11). IRRI is testing some races against this set. But the proposed set seems to have some inadequacies. First, it would not separate races that might distinguish Zenith from Tetep. Second, it does not include host resistance similar to that of Dawn. The tentative differentials may serve, however, as a guide to a more complete set for use in routine screening.

Hybridizations have been made to generate materials for genetic analysis. In 1978, 41 F_2 populations with different types of resistance were produced.

Collaborative development of race indicators. In reconstructing the resistance found in Tetep and Carreon into an improved agronomic background, breeding lines should be tested simultaneously at diverse locations. In addition, some race indicators appear necessary. In anticipation of the discovery of some race indicators with components of Tetep's resistance, sets of 100 F_5 lines each from

Table 10. Classification of resistant varieties in the International Rice Blast Nursery, IRRI, 1978.

Line, variety	Reaction to blast (1 = resistant, 9 = susceptible)										
	Basic criteria				Secondary criteria						
	Philippines										
	IRRI		Leyte		Malaysia Bumbong Lima		Indonesia	Thailand	Nepal	Indonesia	Colombia
	1976	1977	1976	1977	1976	1977	1976	1976	1976	1977	1977
Tetep Group (I), Carreon Subgroup											
Carreon	1	1	1	2	1	2	2	1	6	4	2
Colombia I	1	1	1	2	1	2	2	3	7	3	2
HR6674-4-8-1-2	3	1	3	1	—	2	2	1	7	1	4
CT2011-1	1	1	1	3	3	2	2	1	9	2	1
Colombia II	3	1	3	1	3	2	4	3	8	3	2
Diesi Hatif	3	1	1	1	1	2	2	1	8	3	2
El Gopher	3	1	3	1	2	2	2	1	6	3	5
818-3 BR 9	3	1	1	1	3	2	2	1	9	2	7
JKW S20	3	1	1	1	2	2	2	1	7	4	2
Ramgarh	1	3	3	1	4	3	2	1	7	—	5
Ram Tulasi	1	1	3	1	3	2	1	1	8	3	2
Ram Tulasi (Sel.)	1	1	1	1	3	2	1	1	7	3	3
Sigadis Group											
Sigadis											
IR1529-680-3	1	9	8	6	8	4	8	4	1	7	7
BRJ51-26-12	1	7	8	6	4	5	4	2	5	6	8
IR4532-10045-3-2	3	7	8	7	9	6	3	5	1	9	9
IR4534-10102-4-3	1	6	8	7	4	5	5	3	1	9	8
IR9671-8-3-1-1	1	8	8	8	8	4	8	3	4	8	7
IR3449-172-2-1	1	7	9	7	8	5	8	3	4	9	3
IR3464-35-2-1	1	7	8	7	6	4	7	4	4	6	4
IR3494-29-3-1	1	8	8	8	4	4	6	1	1	6	1
IR3494-128-1-3	1	7	8	8	4	4	7	4	3	5	1
IR3494-149-3-2	1	8	8	8	6	4	8	4	3	7	2

Table 11. A tentative list of differentials representing some large groups of blast resistance. IRRI, 1978.

Race group found in IRBN	Reaction (R = resistant, S = susceptible)				
	IR1905-61-3-1	IR2058-2-3-3	IR34	IR1529-680-3	IR26
A (IRRI 1976)	R	R	R	R	S
B (IRRI 1977)	R	R	R	S	S
C (Leyte 1976)	R	R	S	S	S
D (Leyte 1977)	R	S	S	S	S

Tetep/IR30 and IR30/Tetep//IR30 were tested in many countries. By late 1978, data from three Latin American locations obtained through an arrangement with the Centro Internacional de Agricultura Tropical, as well as data from Malaysia, Nepal, the Philippines (Leyte), and Sri Lanka had been compiled. Dr. S. Kiyosawa tested all 300 entries against 6 standard isolates in Japan.

If the various segregants of Tetep's resistance can be grouped, the types may reflect major genes in Tetep, although current data appear inadequate for such comparisons. A major limitation is a lack of the fungal races that may distinguish the types of resistance in the check varieties, as well as the fluctuation in the reactions in one genotype. Tetep, Zenith, and Carreon behave similarly; Dawn is not clearly separated from them (Table 12). The only way to overcome such difficulties appears to be the development of facilities for controlled inoculation of known races that will differentiate resistance types. Testing natural infection, even with

Table 12. Reactions of check varieties in collaborative testings of blast resistance. IRRI, 1978.

Entry	Reaction[a]							
	CIAT[b]			Malaysia[c]		Nepal	Philippines[d]	Sri Lanka[e]
	A	B	C	1st	2d	Khumaltar	Leyte	
Tetep	1	2	1	0	0(S)	2	1(3)	1–3
	5	1	1	0(R)	0(R)	1	1(3)	0
Carreon	1	2	1	0	0(R)	1	1(3,4)	1
	4	2	1	0(R)	0(R)	2	2	1
Zenith	1	2	1	0	5	1	1(3)	2 PS
	3	4	1	0	0(M)	2	1(3)	2–3
Dawn	1	2	1	0	0(S)	1	4	4
	6	3	1	0(R)	0(R)	1	8	5
IR34	1	1	1	3	7	1	4–5	1
	6	2	2	4	2	1	4(5)	1
Sigadis	4	8	9	8	11	1	8	1
	5	8	9	9	8	1	7	2
Dular	4	4	6	2	5	7	—	4
	1	5	5	3	5	2	—	4
Kataktara	4	3	3	2	6	7	8	3–4
	6	2	2	2	2	1	3	3
Peta	6	7	9	6	9	1	—	PS
	2	8	9	7	7	—	—	1
IR8	4	8	9	2	9	1	4	2–3
	3	8	9	5	6	1	3	2 PS
TN1	1–4	7	9	5	10	1	7	7
	5	8	9	6	5	1	5	6
KTH-17	3	7	8	4	9	1	7	1
	2	6	8	7	6	4	4	2–3
Straw	1	7	9	4	9	9	8	9
	6	8	9	4	8	9	7	9
IR30	3	8	6	6	7	1	—	1
	4	8	6	3	6	1	7	2 PS
	1–3	6	9	3	5	1	7	3–4
	1	6	9	3	8	1	8	5
	1–4	8	8	3	4	1	7	4
	1	8	8	4	3	4	8	3
	3–4	8	9	—	2	1	6–7	1
	4	7	7	5	4	1	4	3
	3	8	8	3	3	4	1	4
	3	7	7	3	8	1	7	4

[a]On a scale of 1–9: 1 = none to small brown specks of pinhead size, 9 = about 100% of leaf area infected. [b]A, B, and C under CIAT denote Panama, ICD-Palmira, and LD-Libertad. [c]1 = resistant, 12 = most susceptible. [d]Numbers in parentheses are the rating for the most severely affected spots in each plot. [e]PS = poor standing.

many collaborative nurseries, does not seem to be a good substitute. Reactions against six isolates in Japan indicated that some progeny lines had no resistance genes in the loci of *Pi-a, k, ta, z, z', b,* and *t*, while others appeared to have resistance genes in the loci of *pi-ta, z, b,* and *t*. The inadequacy of Japanese standard isolates in distinguishing many resistant host genotypes indicates a need to develop standard isolates for tropical rices.

DISEASE RESISTANCE STUDIES

Plant Pathology Department

Blast. *Pathogen variability.* Pathogen variability and lack of adequate differential varieties are most pronounced with the two major fungus diseases blast and sheath blight (Table 13). With respect to blast resistance the varietal genotype also greatly influenced the fungus races that prevailed in an area. From 1963 to 1977, Tjeremas was used as the susceptible check and as the spreader variety in the blast nursery. Its reaction to blast in the nursery ranged from 6 to 9 on the 1976 Standard Evaluation System for rice. Azucena and Bluebonnet 50 were also susceptible. Since 1977, IR442-2-58 has been used as the spreader and check variety. As a result, the prevailing fungus races in the blast nursery have changed. The resistance of the previously susceptible varieties Tjeremas, Azucena, and Bluebonnet 50 indicates the variability and high adaptability of *Pyricularia oryzae*.

Determining resistance by measuring rate of disease development on dryland varieties. Rice blast develops slowly in dryland varieties, which have horizontal resistance. In a test for determining the rate of development and spread of the disease, 39 dryland varieties from different countries were planted separately in 2- × 2- m fertilized plots. The plots were inoculated with isolates from naturally infected IR442 seedlings placed at the center of the plots 20 days after seeding (DS). At night the plots were covered with polyethylene plastic to make conditions favorable for blast development. The lesions on 5 plants/row were counted 1 week after inoculation. Nine subsequent readings were made at 2- to 4-day intervals.

The disease was severe on IR442-2-58 but less severe on such varieties as Bluebonnet and Azucena (Fig. 2).

The rate of disease development was calculated by regression analysis. Representative samples of *r* values were high in the susceptible varieties IR442, Goma 318, Taichung Sen 44195, and B9C-Md-3-3, but low in Azucena, Bluebonnet, C22, and others (Table 14). The varieties with low *r* values were susceptible to blast in previous tests. Whether the varieties had low *r* values because of horizontal resistance should be further investigated by using the isolates attacking them.

Reaction of Japanese field-resistant varieties to Philippine blast isolates. Some Japanese varietal groups are known to have low or slow blast infection, although they do not seem to possess

Table 13. Reaction of different varieties and lines to fungal diseases. IRRI, 1978.

Variety	Reaction[a] to				
	Blast	Sheath blight	Leaf scald	*Cercospora* leaf spot	Sheath rot
IR20	M-S-S-S	M-M-M-M	MR	VS	VS
IR26	S-S-M-S	M-M-M-M	MS	MS	MS
IR28	R	—	M	S	M
IR29	R-M-S	M	S	S	—
IR30	M	M	S	—	MS
IR32	M-R-R-S	M-MR	S	M	M
IR34	R-S	M	S	M	MS
IR36	R-R-M	S-MS-M	S	M	M
IR38	R-R	M	MS	MS	M
IR40	R	M-M	S	—	M
IR42	R-R-R-S	M-M-MR	S	M	M
IR2863-38-1-2	R	M-M	MS	M	—

[a]In various screening tests. Letters separated by a hyphen (-) denote reactions in different tests. R = resistant, S = susceptible, M = moderate, MR = moderately resistant, MS = moderately susceptible, VS = very susceptible.

Table 14. Rate of blast disease development on upland rice varieties. IRRI, 1978.

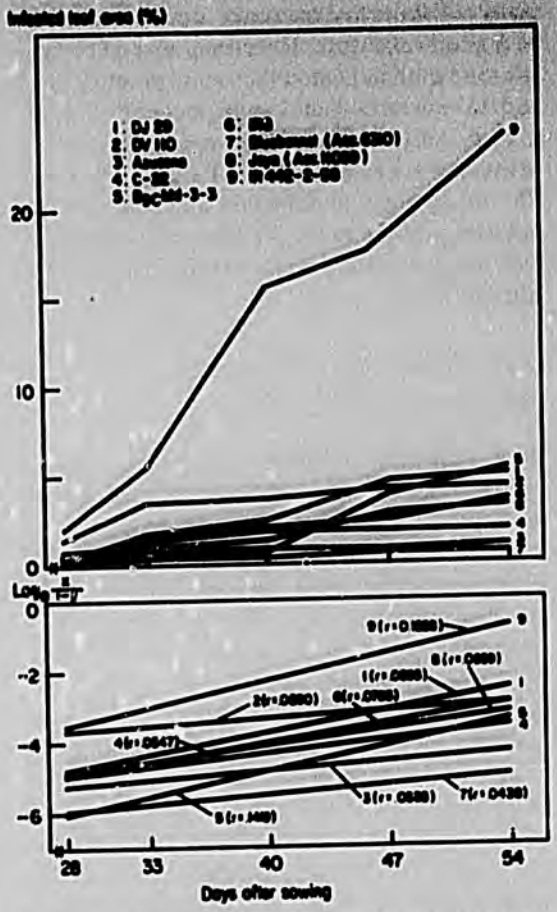
Variety	r[a]	Variety	r
Aus	—	Bluebonnet (Acc. 1709)	.03849
Ctg 1516	—	Bluebonnet (Acc. 6310)	.04378
DJ 29	—	Acc. 7	[illegible]
Sunjamukhi	—	DZ-41	[illegible]
Porto	—	FH 109	.05451
Chandarhat	—	C22	[illegible]
Binaniso	—	Jaya (Acc. 11099)	[illegible]
M1-48	—	KN 381-1-8-6	[illegible]
Sakamukhi	—	KN-88	[illegible]
Speed 70	—	IR8	.07632
DZ 392 G	—	A6-10-37	.07653
Thin Hull	—	Murungewee	[illegible]
IRAT 13	—	NET	[illegible]
F891-22-11-2-6-1	—	DJ29	[illegible]
Sampopay	—	B541b/KN/19/3/4	.11795
ARC 16872	.02776	IR442-2-58	.12282
DV 110	[illegible]	Gema 318	.12423
Kinandang Patong	.03182	Taichung Sen 44186	.12980
Siontelay	.03489	B9C-Md-3-3	.14169
Azucena	.03982		

[a]A dash indicates that the variety had no lesions or only a few, which did not develop.

the major gene or genes effective against Japanese isolates. In IRRI blast nursery tests their reactions differed remarkably, varying from moderately resistant to highly susceptible (Table 15). To determine if such variability was caused by differences in specificity to isolates, nine varieties were artificially inoculated with different monoconidial isolates (Table 16). None of the varieties were susceptible to the isolates. Cultivar Ou 247 appeared resistant to many isolates, and Suzuhara-mochi was susceptible to many.

That indicates the presence of a resistance gene or genes not clearly effective against Japanese isolates but effective against Philippine isolates. Consequently, varietal differences among Japanese rices were caused by differences in spectrums of resistance to specific isolates. It is not yet known whether the same factors responsible for the resistant reaction to Philippine isolates also operate, but in a different mode, as a component of field resistance in Japan.

To determine if a field-resistant variety has a certain character that slows disease development, the variety Suzuhara-mochi (SM), which is susceptible to many isolates, and KTH and Tetep were planted in 1-m² plots. Three isolates were inoculated separately on the different



2. Rate of blast development (r value) on 9 dryland rice varieties. IRRI, 1978. 1: DJ 29, 2: DV 110, 3: Azucena, 4: C-22, 5: B9C-Md-3-3, 6: IR8, 7: Bluebonnet (Acc. 6310), 8: Jaya (Acc. 11099), 9: IR442-2-58.

Table 15. Reaction of "Ou'-resistant" varieties from Japan in IRRI blast nursery tests. IRRI, 1978.

Code no.	Variety	Genotype known in Japan[a]	Field resistance[b] (Japan)	Reaction[c] in blast nursery, Philippines June	Nov.
F1	Chiyohikari	+	rr-r	m	m
F2	Ou 247	+	rr	m	rr
F3	Tokai 28	+	rr	m	m
F4	San-in 63	+	rr	s	rr
F5	Harima	+	rr	m	rr
F7	Suzuhara-mochi	+	rr	ss	ss
F10	Sensho	+	rr	s	m
F18	Tangin Sanu	+	r	s	m
F22	Kogane-masari	+	r	s	m

[a]+ means no true resistance gene known and not major gene. [b]rr = highly resistant, r = resistant, rr(-1) = highly resistant, r(-2) = resistant, m(-3 & 4) = moderately resistant, s(-5 & 6) = susceptible, ss(-7, 8 & 9) = very susceptible. [c]Scales are the numerical scale 1 to 9, adapted for international testing.

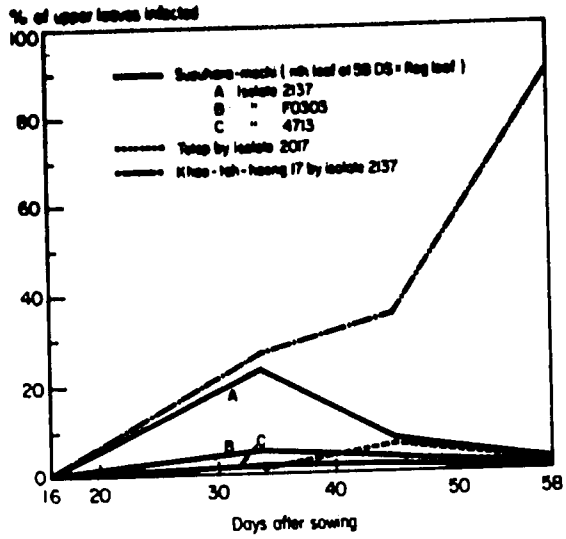
plots on the 12th day after sowing. At night the plots were covered with plastic to prolong the dew period. The lesions on the two upper leaves were counted and expressed as percentage of infected area (Fig. 3). The infected areas caused by isolates F0303 and 4713 on Suzuhara-mochi increased slowly, but lesions caused by isolate 2137 on both SM and KTH increased rapidly. After 34 days, the lesions on SM began to decrease to the same level as those on Tetep inoculated with 2017, while the lesions on KTH continued to increase. A certain resistance factor that is expressed in later growth stages could be involved. Further study is needed to determine 1) if such factor is isolate-specific, and 2) the degree of varietal differences as an aspect of the expression of resistance.

Standardization of Philippine race numbers of P. oryzae. The races in IRBN tests need to be classified on the basis of the reaction of Philippine differentials in various geographic regions. Requests from national programs for seed of Philippine and international differential varieties made it clear that Philippine race numbers should be standardized by predesignating the pathogenicity patterns of all theoretical races.

Table 18. Reaction of "field-resistant" varieties[a] in Japan to Philippine isolates of *Pyricularia oryzae*. IRRI, 1978.

Isolate	Reaction[b] of								
	F2	F1	F4	F22	F10	F5	F18	F3	F7
2137	S	S	S	S	S	S	S	S	S
4709	S	S	S	S	S	S	S	S	S
F0402	S	S	—	S	—	—	—	S	—
4702	S	S	—	S	S	S	R	—	S
F1201	R	S	—	R	R	S	S	S	S
4713	R	S	S	S	S	S	S	S	S
1506	R	S	R	S	S	S	R	S	S
0306	R	S	R	R	R	—	R	S	S
1204	—	—	S	R	R	R	S	S	S
2314	—	R	S	S	R	S	R	R	S
1602	R	R	S	R	R	R	R	S	R
F0303	R	R	R	S	S	R	S	S	S
2126	R	R	—	S	R	R	S	—	S
1513	R	R	R	S	R	R	—	R	—
F0201	—	—	—	R	R	—	—	S	—
7601	—	—	—	—	R	—	—	S	—
1602	—	—	R	—	—	—	—	R	R
3409	R	—	R	R	—	—	R	R	S
F0101	R	R	R	R	S	R	S	S	S
F0301	R	R	R	R	S	R	R	S	S
1202	R	R	—	R	—	R	S	S	S
8601	R	—	R	—	S	R	S	R	S
8603	R	R	R	R	S	—	S	R	S
4704	R	R	R	R	R	R	R	R	R
1627	R	R	R	R	S	—	R	S	S
F0401	R	R	—	R	—	—	—	—	—
3411	R	R	—	—	—	—	—	—	—
1509	R	R	—	R	—	R	—	R	S
4612	R	R	R	R	—	R	R	S	S
2026	R	R	R	R	R	R	R	S	S
1839	R	R	R	R	—	R	R	S	S
2027	R	R	R	—	R	R	—	S	S
3403	R	R	—	R	—	—	R	S	S
4708	R	R	R	R	R	R	R	S	S
1837	R	R	R	R	R	R	R	R	S
3402	R	R	R	R	—	—	—	R	S
2015	R	R	R	R	R	R	R	R	S
2133	R	R	R	R	R	R	R	R	R
3414	R	—	R	R	R	—	R	R	—
0803	R	R	R	R	R	—	—	R	R
2021	R	R	R	R	R	—	—	R	—
2126	R	R	—	R	—	—	—	R	—
F0801	R	R	—	R	—	—	—	R	—

[a]F1 = Chiyohikari, F2 = Ou 247, F3 = Tokai 26, F4 = San-in 63, F5 = Harima, F7 = Suzuhara-mochi, F10 = Sensho, F18 = Tenjin Bamu, F22 = Kogane-masari. [b]R = resistant, S = susceptible. — = no available data.



3. Blast development on 2 upper leaves of rice varieties. Positions of leaves at 34, 45, and 58 DS are *n*-1, *n*-2, and *n*, respectively, where *n* is the uppermost fully expanded leaf.

The system consists of a dichotomous or binary arrangement of susceptible and resistant reactions of the differential varieties.

The races are grouped according to reactions of the key Philippine differential varieties, designated by the prefix P (to distinguish them from international races), followed by the consecutive capital letters A through L. If Kataktara DA-2 is susceptible to a certain *P. oryzae* isolate, the isolate is automatically classified as the race PA, regardless of its reaction combinations in other varieties. If Kataktara DA-2 is resistant to a certain isolate and CI 5309 is susceptible, the isolate is classified as race PB. If both varieties are resistant to certain races but a third variety is susceptible, the race belongs to PC regardless of the reaction of the other varieties (Table 17). If KTH 17 is susceptible to a specific isolate and 11 other different varieties are resistant, the race is classified in the PL group.

On the basis of the reactions of the 12 differential varieties, 4,096 races could theoretically be obtained. For groups PA, PB, PC, PD, PE, PF, PG, PH, PI, PJ, PK, and PL, the corresponding number of races is 2,048, 1,024, 412, 256, 128, 64, 32, 16, 8, 4, 2, and 1, respectively. Group PM-1, which has resistant reactions on all differential varieties, should be added to complete the total number of races.

In race determination, one could number the races, without looking at the computerized table, by simply adding the values of the squares (equivalent to race number) that belong to each group, assuming that susceptible reaction = 0 and resistant reaction = 1 (Table 18). The values of squares are added and then 1 is added after each determination whether the reaction of the last variety is R or S (because no race group starts with 0). For example, if all varieties react as susceptible, the race group is PA-0 because all values of susceptible = 0, but if 1 is added, it is PA-1. If the reaction pattern is S, S, S, R, R, R, R, S, R, R, S, R, it is race PA-494, obtained by adding the values of squares of 256 (PD), 128 (PE), 64 (PF), 32 (PG), 8 (PI), 4 (PJ), 1 (PL), and 1. The method is similar for all race groups and also applies to international races.

Table 17. Grouping of Philippine races on the basis of reaction of key varieties. IRRI, 1978.

Variety	Reaction[a] to race group											
	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL
Kataktara DA-2	S	S	S	S	S	S	S	S	S	S	S	S
CI 5309	R	S	S	S	S	S	S	S	S	S	S	S
Chokoto	R	R	S	S	S	S	S	S	S	S	S	S
CO 25	R	R	R	S	S	S	S	S	S	S	S	S
Wagwag	R	R	R	R	S	S	S	S	S	S	S	S
Pai-kan-tao	R	R	R	R	R	S	S	S	S	S	S	S
Peta	R	R	R	R	R	R	S	S	S	S	S	S
Raminad str. 3	R	R	R	R	R	R	R	S	S	S	S	S
Taichung T.C.W.C.	R	R	R	R	R	R	R	R	S	S	S	S
Lacrosse	R	R	R	R	R	R	R	R	R	S	S	S
Sha-tiao-tsao(a)	R	R	R	R	R	R	R	R	R	R	S	S
KTH 17	R	R	R	R	R	R	R	R	R	R	R	S

[a]S = susceptible, R = resistant.

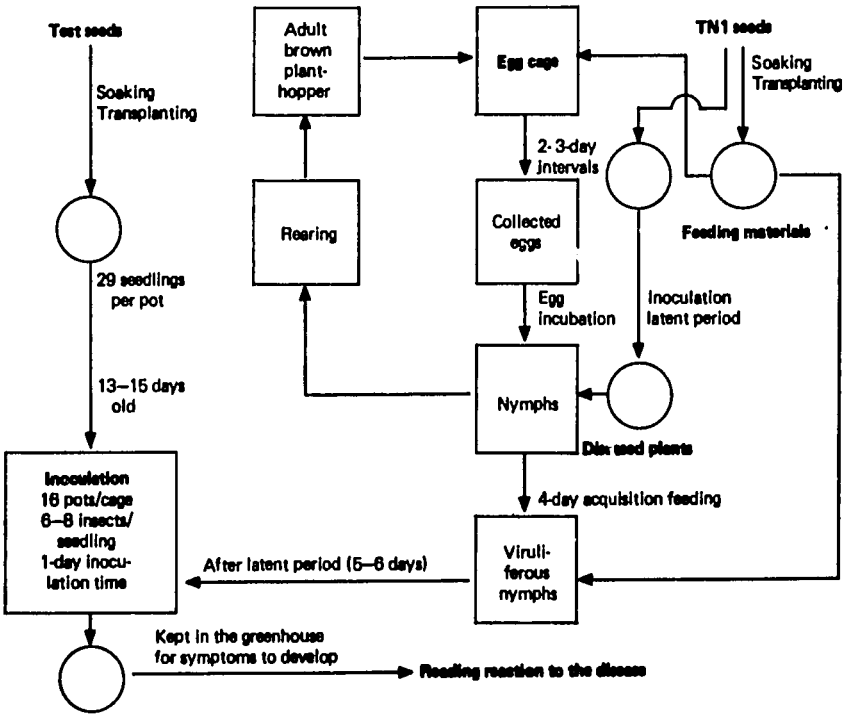
Table 18. Theoretical number of races under each group. IRRI, 1978.

Differential variety	Philippine race group	Base and exponents	Value of squares
Ketekara DA-2	PA	1×2^{11}	2048
CI 5309	PB	1×2^{10}	1024
Chokoto	PC	1×2^{9}	512
CO 26	PD	1×2^{8}	256
Wagwag	PE	1×2^{7}	128
Pai-kan-tao	PF	1×2^{6}	64
Peta	PG	1×2^{5}	32
Raminad str. 3	PH	$1 - 2^{4}$	16
Taichung T.C.W.C.	PI	1×2^{3}	8
Lacroase	PJ	1×2^{2}	4
Sha-tiao-tsao(s)	PK	1×2^{1}	2
KTH-17	PL	1×2^{0}	1

Since race studies were initiated in 1963, races have been numbered as P_1, P_2, P_3, and so on as they were identified, with no consideration of grouping based on reaction of key varieties. By 1976, 290 pathogenic races had been identified and classified by the old system. The previous race numbers have been revised (Table 18).

Ragged stunt. A mass-screening method for testing varietal resistance to rice ragged stunt disease in the greenhouse was developed. The method (Fig. 4) involves 1) rearing brown planthoppers (BPH) for inoculation, of healthy TN1 plants for insect feeding, and of diseased plants for insect acquisition feeding; 2) preparing viruliferous insects by providing the BPH at the nymphal stage with diseased plants and allowing them to pass the latent period before they are used for inoculation; 3) preparing seedlings of rice varieties or lines to be tested by transplanting germinated seeds at 29 seedlings/pot and inoculating the plants at 13 to 15 days old; 4) inoculating the test seedlings by confining them with viruliferous insects in inoculation cages at 6 to 8 insects/seedling for 1 day; and 5) scoring varietal reactions by examining the seedlings after symptoms develop.

The seedling mortality and seedling infection increased with the increase in number of insects inoculated per seedling. The mortality was 18, 22, 22, 19, 41, 46, 64 and 89%, and infection



4. A diagram of the mass-screening method used in testing varieties for resistance to rice ragged stunt disease. IRRI, 1978.

Table 19. Varietal reaction to rice ragged stunt disease as tested by the mass-screening method and to brown planthopper, the vector of the disease. IRRI, 1978.

Variety	Seedlings inoculated (no.)	Seedlings infected (%)	Insects tested (no.)	Av life span (days)
PTB 21	437	5	200	2.8
WC1240	361	34	200	6.0
Gangala	368	85	200	3.2
TN1	388	91	200	6.4

was 76, 86, 84, 92, 86, 86, 90, and 100%, respectively, for 4, 5, 6, 7, 8, 9, 10, and 11 insects/seedling. The mean of 6 to 8 insects/seedling was used for inoculation. With the method, 928 seedlings in 32 pots or 32 entries in 2 inoculation cages can be inoculated in a day.

Resistance to ragged stunt vs resistance to BPH. Varietal resistance to ragged stunt, as tested by the mass-screening method, is not always associated with varietal resistance to its vector, the BPH. Resistance to the BPH is determined by the insect's average life span on the seedlings of each variety in test tubes. Table 19 shows that PTB 21 (acc. no. 11053) was resistant to both ragged stunt and BPH; WC1240 was more resistant to ragged stunt but more susceptible to BPH than Gangala; and TN1 was susceptible to both the disease and BPH.

Bacterial blight. *Resistance groups.* Tests of varieties from IRRI's germplasm collection indicated that rices differ in reaction to *X. oryzae*. Four distinct resistance groups of rice were identified (Table 20).

The *overall resistance group* includes rices resistant to infection caused by a specific pathotype at all plant growth stages. Infection by a pathotype of different virulence may change the disease reaction of such rices. IR20, IR1545-339, and DB85 exemplify rice in this group. Most IR rices with the dominant gene *Xa 4* are resistant to pathotype 1 in the Philippines but susceptible to pathotype 2. IR1545-339 and other lines with the recessive gene *xa 5* are resistant to this pathotype but susceptible to pathotype 3 in the Philippines. DV85 is resistant to all three pathotypes.

The *adult plant resistance group* includes rices that, based on flag-leaf infection, are resistant at the adult stage but not at the seedling stage. Examples are Malagkit Sungsong and Zenith. Numerous rice varieties had *moderate* and *partial resistance*. They showed intermediate disease reactions, but such reactions changed according to locality and season. Few varieties in the two groups seemed to have stable moderate or partial resistance.

Rices are being evaluated and tested at various Philippine locations to determine to which resistance groups they belong. Similar collaborative testing and evaluation with national scientists interested in bacterial blight will be initiated.

Influence of nitrogen levels. Increased nitrogen fertilizer is generally believed to increase bacterial blight infection. Having identified rices that differ in resistance and pathotypes with specific virulence, scientists can evaluate interactions among levels of nitrogen fertilization, rice resistance, and pathotype virulence. Initially, greenhouse experiments showed that the length of lesions on varieties susceptible to strains of a specific pathotype increased with nitrogen level (Table 21). But increased nitrogen level did not affect the severity of disease observed on varieties resistant to specific pathotype strains (e.g. IR20, resistant to PXO 61, or IR1545, resistant to PXO 86), unless pathotype strains with specific virulence overcame the resistance (e.g. infection of IR20 by strain PXO 86). The increment in lesion length in rice with intermediate reaction to bacterial blight infection (e.g. Pulo and Sailboro 302) was considerably less than that in rice with no resistance (e.g. IR8 or TN1) and that in rice with specific resistance (e.g. IR20, which is overcome by a specific pathotype, such as PXO 79).

Table 20. Rice entries[a] from the IRRI germplasm collection classified into 4 resistance groups. 1978.

Resistance group	Reaction[b] at Tillering stage	Reaction[b] at Flowering stage	Entries (no.)
Overall resistance	R	R	152
Adult plant resistance	S	R	32
Moderate resistance	MR	MR	6
Partial resistance	MS	MS	5

[a]Based on 2 years' testing of 329 entries in the field at IRRI. [b]R = resistant, S = susceptible, MR = moderately resistant, MS = moderately susceptible.

Table 21. Effect of nitrogen levels[a] on bacterial blight infection caused by *Xanthomonas oryzae*. IRRI greenhouse, 1978.

Variety	Lesion length (cm)[b] at			
	N_1	N_2	N_3	N_4
		PXO 61		
TN1	28.4 ab	22.4 ab	26.0 a	28.2 ab
IR8	21.7 ab	22.9 ab	25.3 a	27.2 ab
IR944	18.7 ab	22.0 ab	22.4 a	26.2 ab
IR1695	14.7 abc	18.1 ab	18.8 ab	23.0 ab
Cas 209	34.8 a	25.2 a	28.9 a	34.7 a
Pare Karurung	10.6 bc	16.1 ab	20.1 ab	20.7 bc
Saitboro 302	9.5 c	11.7 bc	14.8 ab	16.0 bc
Pulo	5.0 d	6.5 c	8.9 b	11.1 c
IR20	2.0 e	2.5 d	2.5 c	2.3 d
IR1545-339	2.4 e	2.6 d	2.8 c	2.9 d
		PXO 86		
TN1	18.7 a	22.2 a	25.7 a	28.1 a
IR8	17.0 ab	18.8 ab	20.4 a	24.4 ab
IR944	18.7 ab	16.4 abc	23.5 a	26.2 ab
IR1695	14.8 abc	15.6 abc	17.2 a	20.4 ab
Cas 209	1.7 d	1.9 d	1.9 b	2.1 c
Pare Karurung	11.5 abc	14.3 abc	18.1 a	22.4 ab
Saitboro 302	8.6 bc	10.3 bc	12.6 a	15.0 ab
Pulo	7.5 c	8.2 c	12.3 a	12.5 b
IR20	12.0 abc	13.5 abc	15.4 a	17.1 ab
IR1545-339	2.6 d	2.6 d	2.6 d	2.8 c

[a]N_1 = 0 kg N/ha, N_2 = 60 kg N/ha, N_3 = 120 kg N/ha, N_4 = 240 kg N/ha; P and K levels = 60 kg/ha. [b]In each column for each isolate, means followed by a common letter are not significantly different at 5% level.

The lesion length in rices with adult plant resistance, such as IR1698 and IR944, did not differ from that of rices with no resistance when infected at the tillering stage (45 DS), such as IR8.

Plant age. At 40, 60, and 80 DS, rices with overall resistance and with adult plant resistance were evaluated for reaction to infection by three pathotype strains. Lesions were measured 14 days after inoculation. The disease reactions of rices with overall resistance (IR1545 and DV85) did not differ drastically, but each rice reacted at all ages to pathotypes with specific virulence. The lesions on IR1545, which is resistant to PXO 61 and PXO 79, did not lengthen, but because the line is susceptible to strain PXO 71, lesions were somewhat reduced in the older plants. When infected at an older age, varieties with adult plant resistance, e.g. IR1695 and IR944, had significantly shorter lesions (Table 22). When infected at 40 DS, they were distinctly susceptible and developed longer lesions, but when infected at 80 DS, they were more resistant and had shorter lesions.

Inoculum dosage. Strain PXO 61 of pathotype 1 of *X. oryzae* was used at two inoculum dosages in evaluating seven rice varieties with different resistance types. At the

Table 22. Relation of plant age of rices with overall resistance (1) and adult plant resistance (4) to bacterial blight infection. IRRI greenhouse, 1978 dry season.

Variety	Resistance group	Lesion length[a] (cm)								
		PXO 61			PXO 79			PXO 71		
		40 DS	60 DS	80 DS	40 DS	60 DS	80 DS	40 DS	60 DS	80 DS
IR1545	1	2.7	1.9	4.1	3.8	3.4	4.8	27.0	16.0	18.2
DV85	1	2.9	3.0	2.1	4.0	2.2	2.2	2.9	1.9	2.0
IR1695	4	19.9	16.9	9.8	16.3	13.3	3.6	23.3	21.0	6.6
IR944	4	25.8	13.4	6.4	24.0	20.9	9.6	23.4	18.0	11.0

[a]DS = days after sowing.

Table 23. Reaction of rice with different levels of resistance to bacterial blight at 2 inoculum [illegible] dosages. IRRI, 1978.

Variety	Resistance group[a]	10^{-5} Infected leaves[b] (no.) P	10^{-5} Infected leaves[b] (no.) N	10^{-5} Lesion length[c] (cm)	10^{-4} Infected leaves[b] (no.) P	10^{-4} Infected leaves[b] (no.) N	10^{-4} Lesion length[c] (cm)
IR8	5	20	0	23.8 a	6	14	12.8 a
IR944	4	20	0	21.5 a	2	18	12.5 a
IR1695	4	20	0	20.8 a	3	17	12.8 a
Pulo	3	20	0	6.7 c	2	18	3.1 b
Sailboro 302	3	20	0	10.6 b	2	18	3.9 b
IR20	1	20	0	4.2 d	0	20	0 c
IR1545-339	1	20	0	2.5 e	0	20	0 c

[a]1 = overall resistance, 3 = partial resistance, 4 = adult plant resistance, 5 = susceptible check. [b]The absorbance reading was 0.9 (λ = 660 nm) at about 10^8 cells/ml for 10^0 dilution. [c]P = positive infection, N = negative infection; based on 20 leaves, and mean of 3 replications. Lesions on positive infection. [d]In each column, means followed by a common letter are not significantly different at 5% level.

higher dosage (10^0 dilution at about 10^8 cells/ml), the inoculated leaves of all varieties showed positive infection (Table 23). The reaction (lesion length), measured at 14 days after inoculation corresponded well to the strain's virulence and the variety's susceptibility. Varieties with partial resistance, such as Pulo and Sailboro 302, had shorter lesion than the susceptible check IR8. They differed from such varieties as IR20 and IR1545, which are resistant to the strain. At the low inoculum dosage, rices with adult plant resistance and partial resistance differed in positive infection but they had lower percentages of positive infection than IR8. No infection was noted on varieties with overall resistance when 20 leaves of each variety were introduced in 3 replications. No measurable lesion was visible at 14 days after inoculation. But as expected, the lesions on Pulo and Sailboro 302 were considerably shorter than those on IR8. Varieties with adult plant resistance at tillering, such as IR1695 and IR944, reacted essentially like IR8 at both inoculum dosages.

Specific resistance. Rice lines developed from specific resistance donors showed specific resistance to pathotype strains of *X. oryzae* with specific virulence. Three rices with *Xa 4*, the gene for bacterial blight resistance to pathotype 1, inherited from TKM6, were equally resistant to five strains of pathotype 1 and susceptible to five strains of pathotype 2 with different virulence (Table 24, 25). Likewise, the two lines that inherited resistance from DZ192 through the *xa 5* were resistant to strains of both pathotypes. But IR1545-179, although a sister line of

Table 24. Interaction between rice cultivars conveying the bacterial blight resistance genes *Xa 4* and *xa 5* and virulence of pathotype 1 isolates of *Xanthomonas oryzae*. IRRI, 1978.

Cultivar	Lesion length[a] (cm) PXO 61	BB 90	BB 100	PXO 52	IRN 152
Susceptible check					
IR8	25.7 a	27.5 a	25.8 a	23.1 a	12.4 b
IR1545-179[b]	26.9 a	30.3 a	26.5 a	26.5 a	26.4 a
With *Xa 4*					
TKM6[c]	3.3 b	4.1 b	3.5 c	3.8 b	3.2 cd
IR20	4.4 b	4.1 b	4.1 bc	4.6 b	3.1 cde
IR36	3.7 b	3.7 b	5.5 b	4.0 b	3.5 cd
IR40	3.8 b	4.3 b	4.2 bc	4.5 b	3.6 c
With *xa 5*					
DZ192[d]	2.3 c	2.4 c	2.0 d	2.4 c	2.4 e
IR1545-339	3.3 b	2.7 c	2.2 d	3.7 b	2.7 de
IR4563-62	4.0 b	3.6 b	2.7 d	3.8 b	2.7 cde

[a]In each column, means followed by a common letter are not significantly different at 5% level. [b]The resistance gene is lost through selection. [c]Donor for the resistance gene *Xa 4*. [d]Donor for the resistance gene *xa 5*.

Table 25. Interaction between rice cultivars conveying the bacterial blight resistance genes *Xa 4* and *xa 5* and virulence of pathotype 2 isolates of *Xanthomonas oryzae*. IRRI, 1978.

Cultivar	Lesion length[a] (cm)				
	PXO 68	PXO 79	PXO 82	IBA-16	IBA 146
Susceptible check					
IR8	25.1 ab	26.2 ab	24.0 ab	27.4 a	28.8 a
IR1545-179[b]	28.2 a	28.1 a	26.1 a	26.5 a	28.6 a
Xa 4					
TKM6[c]	15.4 c	17.7 c	19.2 b	13.5 c	16.2 b
IR20	19.9 c	20.2 bc	19.8 b	20.8 ab	19.2 b
IR26	20.0 bc	21.0 c	19.2 b	22.0 ab	20.1 b
IR40	20.1 bc	20.0 bc	19.3 b	19.0 b	19.9 b
xa 5					
DZ192[d]	2.5 d	2.6 e	2.7 d	2.6 e	2.1 d
IR1545-339	3.5 d	4.1 d	3.1 d	3.4 d	3.7 c
IR4563-52	4.0 d	3.9 d	3.9 c	3.8 d	4.0 c

[a]In each column, means followed by a common letter are not significantly different at 5% level. [b]The resistance gene is lost through selection. [c]Donor for the resistance gene *Xa 4*. [d]Donor for the resistance gene *xa 5*.

IR1545-339, was as susceptible as IR8 to every pathotype strain, because its resistance was lost during selection.

Methods of inoculation. At least two inoculation methods, the leaf clip and the pin-prick, are widely used in Asia for evaluating, testing, or screening rice varieties for bacterial blight resistance. The two methods and the spraying method were evaluated on three rice differentials for efficiency with strains of three pathotypes. All rices responded to infection caused by the three strains through the leaf-clip method. Their latent periods were 3 days for compatible combinations and as long as 5 days for incompatible combinations (Table 26). The latent period was longer with the spray method. Differential interactions were demonstrated by the three inoculation methods, but results from the spray method were more variable. Infection through the pin-prick method, however, seemed more severe (longer lesions) than that through the leaf-clip method. Probably because *X. oryzae* infects primarily the vascular tissues, lesions resulting from the pin-prick method extended in both directions from the infection court, while lesions from leaf-clipping developed only downward.

Virulence of X. oryzae *pathotype 0.* Early studies indicated that the Philippines isolates of *X. oryzae* could be distinguished into three pathotypes on the basis of specificity of infection on rice differentials (1976, 1977 annual reports). Each pathotype or virulence group caused significantly longer lesions on varieties

Table 26. Effect of method of inoculation on infection of rice differentials by 3 strains of *Xanthomonas oryzae*. IRRI, 1978.

Variety	Latent period (days)			Lesion length (cm)		
	PXO 61	PXO 71	PXO 79	PXO 61	PXO 71	PXO 79
			Leaf-clipping method			
IR8	3–4	3–4	3–4	21.8	27.2	16.1
IR20	3–5	3–5	3–5	3.0	4.1	13.1
IR1545	4–5	3–4	4–5	3.0	12.7	2.3
			Pin-prick method			
IR8	4–6	4–6	4–6	29.8	33.8	26.3
IR20	4–6	4–6	4–6	1.2	2.2	23.9
IR1545	4–6	4–6	4–6	3.1	17.9	2.2
			Spraying method[a]			
IR8	6–8	6–8	6–8	S	S	S
IR20	8+	6–8	6–8	R	MR	S
IR1545	8+	6–8	8+	R	S	R

[a]Initial infection per leaf was greater but lesion length varied. R = resistant, MR = moderately resistant, S = susceptible.

carrying different major genes for resistance. Thus, pathotype 1 caused susceptible-type lesions on IR8, which carries no functional gene for resistance to bacterial blight. Pathotype 2 caused susceptible-type lesions on varieties (e.g. IR20 and IR36) carrying dominant resistance gene *Xa 4*. Pathotype 3 caused susceptible-type lesions on varieties that carry the recessive gene *xa 5* for resistance (e.g. IR1545-339) but produced on IR20 or IR36 shorter lesions than did pathotype 2. Some strains that seemed to have lost their virulence and that caused fewer lesions even on IR8 were included in pathotype 0 or virulence group 0.

When three pathotype 0 strains (B 19, PXO 40, PXO 46) were tested against the Japanese differentials, susceptible-type lesions appeared on TN1 of the Kinmaze rice varieties. Unlike strain PXO 10 of pathotype 1, the three did not cause longer lesions (Table 27). Tetep of the Rantajemas rice group was susceptible to B19 and PXO 40 but resistant to PXO 46; Chinsurah Boro II was resistant to all three. PXO 10 of pathotype 1 caused twice as many lesions on TN1 as any of the three strains of pathotype 0. The results indicate the lower virulence of the latter. The data also revealed Japanese rice differentials that show differential interactions with the four strains.

Single colonies from the same strains and lesions. Daughter colonies of single strains of *X. oryzae* previously varied from less to more virulent (1969 Annual Report). This variation was expected to correlate with the wide pathogenic variability of the bacterium and with the development of new strains. In this study, the more aggressive PXO 61 and the less aggressive PXO 80 strains of pathotype 1 of the Philippine *X. oryzae* were used to establish their ranges of variation on IR8, a variety susceptible to the pathotype. Ten plants of IR8 were individually inoculated with 50 colonies of each strain. Figures 1a and 1b show the frequency distribution of lesion length of the colonies. The variation in lesion length suggested a wide range of differences among the daughter colonies of each strain, but the reaction of IR8 was susceptible.

Fifty colonies each of *X. oryzae* isolated from single lesions of naturally infected IR22 and IET4832 leaves were tested in the same manner. The mean length of lesions that each single colony culture caused on the two varieties differed ($\bar{X}$ = 15.6 cm in IR22; $\bar{X}$ = 22.2 cm in IET4832) (Fig. 1c, 1d).

The data suggest that IR8's disease reaction to the two strains and to the isolates was fairly stable but lesion length continuously varied.

Testing of individual subcultures from single

Table 27. Reactions of the Japanese differentials to strains in the virulence group 0 of *Xanthomonas oryzae* in the Philippines. IRRI, 1978.

Japanese differential	Lesion length[a] (cm) caused by				Japanese pathotype		
	PXO 10[b]	Pathotype 0					
		B 19	PXO 40	PXO 46	1	2	3
Kinmaze group TN1	28.2(A) a	11.8(S) a	12.9(S) a	7.6(S) a	S	S	S
Kogyoku group Hoyoku	10.9(S) a	5.2(M) abc	7.6(S) bc	3.9(M) ab	R	S	S
Shiniriki	9.1(S) a	4.8(M) ab	6.4(M) abc	3.8(M) ab			
Rantaj-emas group Tetep	17.6(S) a	8.9(S) ab	9.5(S) ab	4.7(M) ab	R	R	S
Chinsurah Boro II	1.2(R) b	2.5(R) bc	2.8(R) abc	1.9(R) b			
Wase Aikoku group Wase Aikoku	1.5(R) b	1.8(R) c	2.0(R) c	1.8(R) b	R	R	R
IRRI susceptible check	19.7(S) a	6.1(M) a	8.6(M) ab	4.1(M) ab			

[a]In each column, means followed by a common letter are not significantly different at 5% level. R = resistant, M = moderate, S = susceptible. [b]A strain of pathotype 1.

Table 28. Variation in length of lesions caused by strains of pathotype 1 and 2 on 3 rice differentials.[a] IRRI greenhouse, 1978.

Range	Lesion length (cm)		
	IR8	IR20	IR1545
	Pathotype 1, 22 isolates		
Low	9.4	2.3	1.4
High	29.4	6.1	4.3
Mean	22.0 ± 5.7	4.2 ± 1.0	2.5 ± 0.8
	Pathotype 2, 12 isolates		
Low	11.0	9.3	1.2
High	21.7	15.3	2.3
Mean	17.8 ± 3.5	13.2 ± 2.1	1.8 ± 0.3

[a]Interaction effect (variety x isolate), F = 1.1[ns] for pathotype 1 and F = 2.0[ns] for pathotype 2.

strains and lesions from naturally infected plants of the rice differentials will continue.

Pathotype strains. Classification of *X. oryzae* virulence in the Philippines into three groups of pathotypes was on the basis of specificity in infection of rice differentials. The length of lesions caused by strains of the same pathotype or virulence group varied. Tests determined if the variation among individual strains of a pathotype was comparable to that among daughter colonies of single strains.

Initially, 24 pathotype 1 strains and 12 pathotype 2 strains were each tested in the greenhouse for virulence on 3 rice differentials. Fifty-day-old plants of IR8, IR20, and IR1545, were inoculated by the leaf-clipping method.

Strains of pathotype 1 caused wide variation in lesion length on susceptible IR8 (Table 28). The lesion length ranging from 9.4 cm (caused by strain PXO 80) to 29.4 cm (caused by PXO 39) differed significantly. On IR20 and IR1545, the lesions were from 2.3 to 6.1 cm long; the difference was not significant, and the disease reactions were resistant.

Pathotype 2 strains also caused wide variation in lesion length in IR8 and IR20. The differences in length of lesions were significant, but the disease reaction was susceptible. On IR8, the lesions were from 11.0 cm (caused by strain ISA-15) to 21.7 cm long (caused by PXO 63). On IR20 they were from 9.3 cm (strain ISA-5) to 15.3 cm long (PXO 63) (Table 28). The strains caused insignificant lesions on IR1545 whose disease reaction was resistant. Analysis of variance of the data for pathotypes 1 and 2 indicated no significant interactions between the strains and the varieties. The varieties and the strains differed significantly, however. On the basis of specificity in infection (pathotype 1 on IR8 and pathotype 2 on IR8 and IR20), the strains of each pathotype could be ranked high or low according to the initial length of the lesion on the susceptible varieties. The difference in lesion length on such varieties may be associated with the virulence of the strains on each pathotype. The differences among strains

Table 29. Infectivity on 3 rice differentials of 5 isolates of *Xanthomonas oryzae* pathotype 1 at different dosages. IRRI, 1978.

Variety	Leaves (%) with lesion length > 50% of leaf length[a]														
	PXO 61			PXO 52			PXO 80			BB 90			BB 100		
	10^9	10^8	10^7	10^9	10^8	10^7	10^9	10^8	10^7	10^9	10^8	10^7	10^9	10^8	10^7
	14 days after inoculation														
IR8	45 (24)	46 (26)	5 (23)	45 (24)	86 (31)	6 (21)	1 (16)	5 (15)	— —	46 (25)	96 (29)	3 (20)	48 (23)	51 (22)	3 (21)
IR20	0 (3)	0 (4)	0 (3)	0 (3)	0 (5)	0 (3)	0 (4)	0 (3)	0 (2)	0 (3)	0 (5)	0 (3)	0 (3)	0 (3)	0 (2)
IR1545	0 (4)	0 (3)	0 (2)	0 (3)	0 (3)	0 (2)	0 (3)	0 (3)	0 (2)	0 (2)	0 (3)	0 —	0 (2)	0 (1)	0 (1)
	21 days after inoculation														
IR8	100 (35)	100 (36)	100 (33)	100 (33)	100 (45)	100 (39)	86 (26)	53 (27)	46 (23)	100 (40)	100 (46)	100 (36)	100 (40)	100 (39)	100 (39)
IR20	0 (5)	0 (9)	0 (7)	1 (5)	2 (9)	1 (5)	0 (5)	0 (7)	0 (8)	1 (5)	5 (11)	1 (4)	5 (8)	0 (6)	0 (6)
IR1545	0 (5)	0 (4)	0 (4)	0 (5)	0 (3)	0 (3)	0 (4)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (4)	0 (4)	0 (4)

[a]Figures in parentheses denote mean lesion length.

Table 30. Infectivity on 3 rice differentials of 5 isolates of *Xanthomonas oryzae* pathotype 2 at different dosages. IRRI, 1978.

Variety	Leaves (%) with lesion length > 50% of leaf length[a]														
	PXO 63			PXO 79			PXO 82			ISA-15			ISA-146		
	10^6	10^8	10^7	10^6	10^8	10^7	10^6	10^8	10^7	10^6	10^8	10^7	10^6	10^8	10^6
14 days after inoculation															
IR8	43 (22)	26 (21)	1 (17)	48 (24)	45 (22)	1 (19)	61 (25)	58 (25)	7 (21)	76 (26)	63 (24)	5 (22)	85 (27)	73 (25)	5 (19)
IR20	5 (16)	4 (18)	1 (16)	6 (20)	7 (19)	1 (16)	7 (22)	6 (19)	4 (16)	12 (21)	8 (20)	1 (15)	12 (22)	17 (24)	6 (19)
IR1545	0 (2)	0 (3)	0 (2)	0 (3)	0 (2)	0 (2)	0 (4)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)	0 (3)	0 (3)	0 (2)
21 days after inoculation															
IR8	100 (38)	100 (37)	100 (36)	100 (39)	100 (40)	100 (38)	100 (42)	100 (43)	100 (42)	100 (42)	100 (43)	100 (40)	100 (41)	100 (43)	100 (40)
IR20	100 (30)	100 (29)	100 (25)	100 (31)	100 (32)	100 (27)	100 (30)	100 (28)	100 (24)	100 (31)	100 (30)	100 (27)	100 (32)	100 (34)	100 (31)
IR1545	0 (5)	0 (5)	0 (5)	0 (6)	0 (4)	0 (4)	0 (6)	0 (5)	0 (5)	0 (5)	0 (4)	0 (4)	0 (6)	0 (4)	0 (4)

[a]Figures in parentheses denote mean lesion length.

of pathotype 1 appeared distinct and stable. At three inoculum dosages, four of five selected strains of pathotype 1 showed good ability to cause lesions more than half the length of the leaf. At the highest dosage the strain PXO 80, which appeared less aggressive, caused only 1% of the leaves to be covered with lesions whose length exceeded 50% of the leaf length. The four other strains infected more than 46% of the leaves, producing lesions exceeding 50% of the leaf length. The difference among strains of pathotype 2 was not distinct (Table 29, 30). That could indicate that pathotype 2 strains varied more than the strains of other pathotypes.

Infectivity of strains of pathotypes 1 and 2. Strains of a pathotype varied in the relative capacity to cause lesions on a leaf area in a given time, usually measured at 14 days after inoculation for bacterial blight. The factors that affect the variation in virulence among strains of a single pathotype were compared.

Five strains each of pathotypes 1 and 2 were studied for virulence to three rice differentials: IR8, susceptible to both pathotypes 1 and 2; IR20, susceptible to pathotype 2 but resistant to pathotype 1; and IR1545, resistant to both pathotypes. The variation in lesion initiation among strains was apparently similar to that among subcultures of single strains on compatible varieties (Table 31, 32). The lower limit of the lesions caused by the pathotype 2 strains on IR20 and IR8 was of the susceptible type and was comparable with that of pathotype 1 strains on IR8. The difference was graduated and

Table 31. Initial infection caused by strains of pathotype 1 of *Xanthomonas oryzae* on 3 rice differentials. IRRI, 1978.

DI[a]	Inoculum (cells/ml)	Positive infection (%)														
		PXO 61			PXO 52			PXO 80			BB 90			BB 100		
		IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545
3	10^6	63	0	0	36	0	0	0	0	0	61	0	0	78	0	0
	10^7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	10^6	100	3	0	100	13	0	35	0	0	100	16	0	100	0	0
	10^7	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0
5	10^6	100	23	0	100	16	0	63	6	0	100	47	0	100	100	0
	10^7	0	2	0	0	3	0	0	0	0	3	0	0	72	12	0
7	10^6	100	110	100	100	100	100	100	100	100	100	100	77	100	100	100
	10^7	100	13	7	100	42	3	100	10	0	100	72	3	100	100	100

[a]Days after inoculation.

Table 32. Initial infection caused by strains of pathotype 2 of *Xanthomonas oryzae* on 3 rice differentials. IRRI, 1976.

DI[a]	Inoculum (cells/ml)	Positive infection (%)														
		PXO 63			PXO 79			PXO 82			ISA-15			ISA-146		
		IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545	IR8	IR20	IR1545
3	10^8	53	36	0	78	46	0	63	36	0	70	18	0	60	58	0
	10^7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	10^8	100	100	0	100	100	0	100	100	0	100	100	0	100	100	0
	10^7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	10^8	100	100	38	100	100	15	100	100	33	100	100	5	100	100	20
	10^7	72	83	0	30	48	0	57	83	0	23	38	0	38	100	0
7	10^8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	10^7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a]Days after inoculation.

Table 33. Rate of lesion development initiated by selected strains of pathotype 1 of *Xanthomonas oryzae* on 3 rice differentials. IRRI, 1976.

DI[a]	Variety[b]	Lesion length (cm)				
		PXO 61	PXO 52	PXO 80	BB 90	BB 100
4	IR8	1.5	1.7	0	1.5	0
	IR20	0	0	0	0	0
	IR1545	0	0	0	0	0
6	IR8	7.3	7.1	2.9	8.3	2.0
	IR20	0.7	0.3	0.4	1.3	0.5
	IR1545	0.8	0.6	0.5	1.6	0.6
9	IR8	16.5	14.8	6.0	17.6	4.8
	IR20	1.4	1.1	1.5	1.6	1.3
	IR1545	1.7	1.2	1.5	3.2	1.4
12	IR8	25.0	22.0	12.9	25.3	11.8
	IR20	3.2	2.0	3.1	1.9	1.6
	IR1545	4.4	2.6	2.2	5.0	1.8

[a]Days after inoculation. [b]Latent period of strains is 4 days on IR8, 6 days on IR20, and 6 days on IR1545.

Table 34. Rate of lesion development initiated by selected strains of pathotype 2 of *Xanthomonas oryzae* on 3 rice differentials. IRRI, 1976.

DI[a]	Variety[b]	Lesion length (cm)				
		PXO 63	PXO 79	PXO 82	ISA-146	ISA-15
4	IR8	1.1	1.0	0.6	1.2	0.4
	IR20	1.5	0.9	0.9	1.5	0.9
	IR1545	0.4	0	0	0	0
6	IR8	5.7	4.8	4.1	5.6	3.6
	IR20	7.7	6.7	3.9	7.0	3.7
	IR1545	1.4	1.8	1.3	1.6	1.1
9	IR8	13.5	11.0	8.0	11.7	8.2
	IR20	12.7	11.7	8.8	12.0	5.6
	IR1545	2.1	2.1	1.7	2.2	1.4
12	IR8	19.3	16.3	13.5	17.2	11.6
	IR20	15.3	14.1	12.1	15.1	7.1
	IR1545	2.6	2.1	1.7	2.2	1.4
15	IR8	23.5	20.7	16.6	21.1	13.6
	IR20	17.0	16.1	13.1	18.2	9.1
	IR1545	3.0	2.7	2.4	3.0	1.8

[a]Days after inoculation. [b]Latent period of strains is 4 days on IR8, 4 days on IR20, and 6 days on IR1545.

Table 38. Comparative characterization of strains of pathotypes 1 and 2 of *Xanthomonas oryzae* with low and high infectivity on IR8 and IR20. IRRI, 1978.

Reaction	Differential	Pathotype 1		Pathotype 2	
		PXO 61	PXO 99	PXO 63	IBA-16
Disease reaction	IR8	S	S	S	R
	IR20	R	R	S	S
Initial infection (lesion in cm)	IR8	1.5	0	1.1	0.6
	IR20	0	0	1.5	0.9
Final infection (lesion in cm)	IR8	25.0	12.9	23.5	13.6
	IR20	3.2	3.1	17.0	9.1
Positive infection (%) at low dosage 5 days after inoculation	IR8	0	0	72	23
	IR20	2	0	83	38
Infected leaves (%) with lesion length >80% of leaf length at low dosage	IR8	100	46	100	100
	IR20	0	0	100	100
Latent period (days)	IR8	3–4	3–4	3–4	3–4
	IR20	3–4	3–4	3–4	3–4

revealed a continuous variation among the strains on compatible varieties.

The latent period (the time needed to initiate a visible symptom after the inoculation of the strains) on a given variety did not differ, either within a pathotype or between two pathotypes. Lesion increment over compatible varieties, such as pathotype 1 and IR8 or

Table 39. Indonesian rice cultivars analyzed for inheritance of resistance to bacterial blight. IRRI, 1978.

Variety	IRRI acc. no.	Variety	IRRI acc. no.
Andel	17153	Rengsel	18628
Bajang	17183	Rodjolele	9909
Balecung	19232	Sampang Kuning	18678
Balik Semah	17201	Sampang Lempuyang	18679
Bandja III	17216	Sampangan Perak	18677
Beek Genggas	17253	Sekarek	18740
Benong	13530	Sereh	16566
Boder	17315	Sidjongguk	18626
Bulu Beselijen	17341	Sidjaro Gundil	18629
Bulu Djembu	17343	Sintawati	18663
Bulu Menggali	17348	Item	14662
Bulu Putih	17350	Jawa Renges II	17763
Bulu Sampang	17352	Ketan Bajong	17830
Buntak Tuwungbatu	17356	Ketan Bas	17834
Camor	17366	Ketan Bendu	17838
Djalewara	17471	Ketan Gabel	17851
Djrabeng	17543	Ketan Gadjih	13512
Djelita	13714	Ketan Gondel	17857
Gaja Beru	17568	Ketan Gondopuro	17859
Genjah Urang	17630	Ketan Gundel	17865
Gewal Bangoran	17651	Ketan Gundil	24568
Gropek Gede	17667	Ketan Kunang	17887
Hegar Maneh	17733	Ketan Laler	17897
Indel	17746	Ketan Lumbu	16461
Palotan Mclati	18426	Ketan Mari Kangen	17910
Pare Buwun	18456	Ketan Pandan	17932
Pare Djerah	18468	Ketan Seponjono	17959
Pautauj	18484	Ketan Temon	17967
Plampeyan	18494	Ketan Tjendani	17970
Pulu Banrakaja	20073	Kentjana	9224
Pulut Banda Kaya	27391	Lenggang Genuk Bulu	18119
Pulut Bongo	27397	Mudjaer	18296
Pulut Kemandi	24621	Oleh Bandung	18357
Bandjani	18596	Padi Tomat	18408
Rangun Serta	18600	Slendoran	18602
Ranta	18608	Sogol	18605
Ranta	18609	Sri Kuning	14622
Ramadja	679	Sukonandi	18637
Ramadja Bulu	18620	Walen	16666

pathotype 2 and IR8 and IR20, appeared to differ among the strains. Strain PXO 80 of pathotype 1 caused fewer lesions on IR8 than other strains during the period the lesions were measured. The trend was similar on strain ISA-15 of pathotype 2 on IR8 and IR20. The low infective capacity of strain PXO 80 was distinguished earlier than 7 days after inoculation at two inoculum dosages. But strain ISA-15 was distinct from the other strains at a low inoculum dosage (about 10^7 cells/ml) (Table 33, 34). Table 35 summarizes the characteristics of strains with low and high infectivity.

Inheritance of resistance. In 1978, 76 resistant Indonesian varieties were studied (Table 36). Only Mudjaer was resistant at all growth stages. The others were resistant at booting and flowering, but susceptible at the seedling and maximum tillering stages. All the varieties were crossed with susceptible TN1; the F_1 and F_2 populations were inoculated at the flowering stage with isolate PXO 61. The F_1 populations of all crosses except TN1/Mudjaer were resistant. The F_2 population of TN1/Mudjaer segregated in a 1–3 ratio of resistant to susceptible seedlings. Mudjaer clearly has one recessive gene for resistance. The F_2 populations from the other crosses segregated in a 3-1 ratio of resistant to susceptible seedlings, showing that a single dominant gene conditions resistance in those varieties. The X^2-value for the 3-1 ratio was nonsignificant in most of the crosses, but significant in four: TN1/Gaja Baru, TN1/Remadja, TN1/Rengeei, and TN1/Sintawati. F_3 families from the four crosses were studied for bacterial blight resistance. The X^2-values for the expected monogenic 1:2:1 were nonsignificant. Therefore, all the varieties except Mudjaer obviously have one dominant gene for resistance.

All the varieties except Mudjaer were crossed with IR22, which is homozygous for *Xa 4*. Mudjaer was crossed with IR1545-339, which carries *xa5* for resistance. The F_1 and F_2 populations of all the crosses were resistant, showing that all the varieties except Mudjaer have *Xa 4* and that Mudjaer has *xa 5* for resistance. Because all the varieties except Mudjaer are susceptible at the seedling and maximum-tillering stages, they obviously have $Xa\ 4^b$ alleles.

Bacterial leaf streak. Eighty-two elite lines were artificially inoculated to determine resistance to bacterial leaf streak in the greenhouse. Nine lines were uniformly resistant to infection by *X. translucens* f. sp. *oryzae* (from both young and old leaves) and eight lines were susceptible. The resistant lines were IR[illegible]80-13-10, IR4427-51-6-3, IR4570-117-2-1-2, IR5178-1-1-3, IR5853-198-1-2, IR8606-298-3-1, IR9732-119-3, IR9761-75-3, and IR9814-63. The disease reaction of the 63 other lines, including all named IR varieties, varied. Methods of evaluating lines for resistance to bacterial leaf streak will be studied in 1979.

Insect resistance

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SOURCES OF RESISTANCE

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In 1978 screening of varieties for insect resistance covered four hopper species, two stem borers, and the whorl maggot (Table 1).

Yellow stem borer. The search for sources of resistance to the yellow stem borer was intensified. Varieties from the germplasm collection were evaluated in the IRRI screenhouse and at a yellow borer *hot spot* at the Maligaya Rice Research and Training Center, Philippines. Of 237 varieties selected for further testing (Table 1), 3 Indian varieties — CO7, a pure line selection from Sadai Sanba; CO15, known as Jadu Malakolukulu in Tamil Nadu State; and IARI5829 — were found equal to the IRRI resistant check IR1820-52-2-4-1.

Experience from screening thousands of rices for yellow stem borer resistance has indicated that the level of resistance is low and continuous; however, some improved high yielding rices show a consistently moderate level of resistance. To cumulate resistance from several donors into improved varieties, a systematic program of multiple crosses of several rices with low or moderate levels of resistance was followed.

In the first cycle of the hybridization program, which started in the 1975 wet season, IR1514A-E666, IR1539-823, IR1628-632, IR1704-3-2, IR1721-11, IR1820-52-2-4-1, IR1917-3-19, IR2061-628, Ratna, WC1253, and IR36 were used. Progeny of crosses with IR36 survived severe field infestations of ragged stunt in 1976. In the 1977 dry season, plants were selected in the F_2 field and 459 F_3 lines from 10 crosses were screened under stem borer infestation through 1977 (Table 2). In the 1978 wet season, 54 F_4 lines identified as stem borer resistant were also tested in an observational yield trial for resistance to blast, bacterial blight, 2 brown planthopper (BPH) biotypes, and the green leafhopper (Table 3). These F_4 lines are now ready for dissemination to Burma, Indonesia, Thailand, and the national programs of other interested countries. The flow of breeding materials is indicated in Figure 1.

In the second cycle of the breeding program several new stem borer-resistant sources from the elite breeding lines and from the International Rice Observational Nursery were used. IR2307-217-2-3, IR3941-97-1, and IR4427-51-6-3, which were as resistant as IR 1820-52-2-4-1, and a GEU elite line, IR4427-51-6-3, were crossed with noted sources such as IR1514A-E666, IR1820-52-2-4-1, and IR1917-3-19-2. In most crosses IR36 was topcrossed or included as a component of the parentage because it has resistance to the BPH and green leafhopper, and moderate resistance to stem borer.

In the 1978 wet season and the 1978–79 dry season, 1,750 F_3 lines from 10 F_2 populations were grown at the Maligaya Rice Research and Training Center under severe stem borer pressure (Table 4). Many entries, including IR19392 lines, had outstandingly low deadheart readings compared with IR1820-52-2-4-1 (Table 5) and will be included in the observational yield trial to select for other important traits.

Table 1. Screening of germplasm collection varieties and breeding lines for resistance to insects. IRRI, 1978.

Insect	Germplasm collection (no.)		IR breeding lines (no.)	
	Tested	Selected	Tested	Selected
Brown planthopper			[illegible]	[illegible]
Biotype 1	2,200	178	[illegible]	[illegible]
Biotype 2	100	8	[illegible]	[illegible]
Biotype 3	100	6	[illegible]	[illegible]
Whitebacked planthopper	3,940	348[a]	[illegible]	[illegible]
Green leafhopper	2,470[b]	269	0	0
Zigzag leafhopper	361	91	[illegible]	16
Striped stem borer	0	0	1,130	222
Yellow stem borer	5,000	237	2,219	[illegible]
Whorl maggot	2,087	87		

[a]Includes 247 *Oryza glaberrima* varieties. [b]Includes 481 *O. glaberrima* varieties.

Table 2. Resistance of selected F_1 lines of the first breeding cycle to the yellow stem borer. IRRI, 1977.

Cross	Lines tested (no.)	Lines selected (no.)	Deadhearts (%)		
			Mean of parents	Mean of selected progeny	Mean of all lines
IR13954	50	6	41	34	43
IR13959	50	18	41	36	41
IR13962	50	14	38	34	40
IR13965	120	5	40	36	46
IR13965	40	11	41	24	37
IR13969	40	6	38	24	40
IR13941	36	23	38	23	27
IR13943	10	0	38	—	40
IR13968	25	9	29	24	33
IR13980	22	1	29	31	42
Total	469	93			

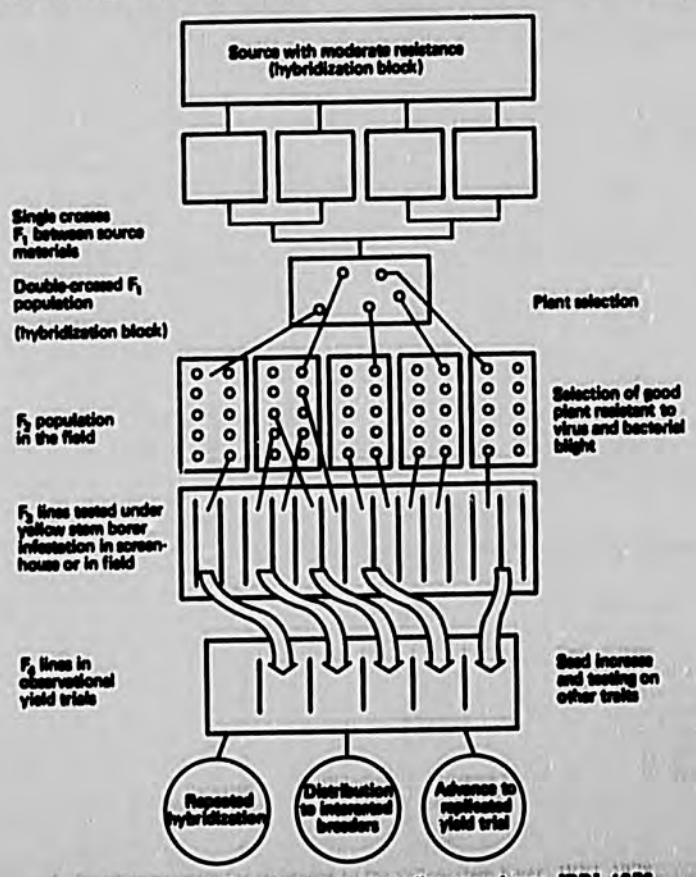
Table 3. Resistance of 93 selected F_1 stem-borer resistant lines to insects and diseases. IRRI, 1978.

Line	Stem borer-resistant lines (no.)	Resistance rating[a]				
		Blast	Bacterial blight	BPH[b] biotype 1	BPH[b] biotype 2	GLH[c]
IR13959-37	26	1	1	1	1	3
IR13959-42	34	1	1	1	3	3
IR13941-4	14	1	1	1	5	3
IR1529-82-2-4-1 (check)	39	2	7	1	9	3
Remoro (check)	74					

[a]1 = resistant, 9 = susceptible. [b]Brown planthopper. [c]Green leafhopper.

In the third breeding cycle, begun in the 1978 wet season, sources selected from the First International Rice Stem Borer Nursery — IET 2815, IET 2830, IET 2845, and IET 5540 — were used. These selections were hybridized with breeding lines selected in the first cycle of the breeding program. Single F_1's will be crossed with breeding lines that have new genes for resistance to the BPH.

Brown planthopper. Of the 2,200 evaluated varieties from the germplasm collection 178 (8%) were resistant to BPH biotype 1, 8 to



1. Breeding program for resistance to the yellow stem borer. IRRI, 1978.

Table 4. Number of multiple crosses evaluated for yellow stem borer resistance (second cycle). IRRI, 1978.

IR no.	Cross	Lines tested (no.)	Lines selected (no.)
IR[illegible]	IR2041-6-3/IR1514A-[illegible]//IR2071-625-1-252	200	43
IR[illegible]	IR2061-6-3/IR1917-3-19-2//IR2071-625-1-252	200	
IR[illegible]	IR4427-59-3-3/IR1514A-[illegible]//IR2071-625-1-252	200	47
IR[illegible]	IR4427-59-3-3/IR1917-3-19-2//IR2071-625-1-252	200	
IR[illegible]*	IR4427-61-6-3/IR1514A-[illegible]//IR2071-625-1-252	200	19[b]
IR[illegible]	IR4427-61-6-3/IR1[illegible]-63-3-4//IR2071-625-1-252	244	
IR[illegible]*	IR4427-61-6-3/IR1917-3-6-2//IR2071-625-1-252	361	
Total		1760	

[a]Currently being tested at the Maligaya Rice Research and Training Center, Nueva Ecija province, Philippines. [b]Selected from the first 100 lines tested. Another 100 lines are yet to be tested.

biotypes 1 and 2, and 6 to biotypes 1 and 3 (Table 1). Only one entry, 77–3990, a selection from Sri Lanka, had resistance to the three biotypes. Seventeen elite breeding lines had resistance to the three biotypes.

In the 1975 Annual Report two genes for BPH resistance — *Bph 3* from Rathu Heenati and *bph 4* from Babawee — and two unidentified genes in PTB 33 were reported. Those sources were incorporated into the breeding program and several breeding lines now have resistance to the three biotypes (Table 6).

Table 5. Resistance of selected lines from multiple crosses to yellow stem borer. IRRI, 1978.

Line	Deadhearts (%)	
	IRRI screenhouse	Field test MRRTC[a]
IR19382-1	19.6	19.1
IR19382-6	18.7	13.2
IR19382-95	19.8	20.9
Rexoro (susceptible check)[b]	65.2	84.9
IR1820-52-2-4-1 (resistant check)[b]	23.2	22.9

[a]Maligaya Rice Research and Training Center, Nueva Ecija province, Philippines. [b]Av of 10 rows.

Whorl maggot. Field screening of 2,087 germplasm collection varieties indicated that 87 have levels of whorl maggot resistance near that of IR40, the resistant check (Table 1). The 87 were further evaluated with a new greenhouse screening technique. Two varieties from Indonesia, Barleyan and Ketan Kasturi, had damage ratings below that of IR40 (Table 7).

In the new greenhouse screening technique seeds of each variety were sown in seedboxes with 5- × 5-cm squares. IR40 was the resistant and TN1 the susceptible check in each box. Seedlings were thinned to 1/square. Ten days after sowing, field-collected adult whorl maggot flies were placed in the seedboxes, which were covered with a nylon mesh cage.

To facilitate field screening, the whorl maggot rating system published in 1976 was simplified as follows:

Damage grade	Extent of damage
1	0–1 leaf damaged
3	>1 but less than ½

Table 6. Reactions of breeding lines with new genes for resistance. IRRI, 1978.

Breeding line	Source of resistance	Resistance gene	Reaction to BPH[a]		
			Biotype 1	Biotype 2	Biotype 3
IR[illegible]-84-3	Rathu Heenati	*Bph 3*	R	R	R
IR[illegible]-69-3	Rathu Heenati	*Bph 3*	R	R	R
IR[illegible]-61-1	Babawee	*bph 4*	R	R	R
IR[illegible]-69-1	Babawee	*bph 4*	R	R	R
IR[illegible]-163-1	PTB 33	?[b]	R	R	R
IR[illegible]-164-2	PTB 33	?	R	R	R
Mudgo (check)		*Bph 1*	R	S	R
ASD7 (check)		*bph 2*	R	R	S
TN1 (check)		None	S	S	S

[a]R = resistant, S = susceptible, BPH = brown planthopper. [b]PTB 33 has two unidentified genes.

Table 7. Reaction of selected germplasm collection entries [illegible] against the wheat maggot in the greenhouse.[a] [illegible], [illegible].

Acc. no.	Variety	Country of origin	Rating[b]
[illegible]	H.P. 128	India	6.3 abc
[illegible]	Makalioka 72	Malagasy Republic	6.6 bcd
[illegible]	ARC 6661	India	6.0 abcd
[illegible]	ARC 10647	India	6.6 ab
[illegible]	Muscangan	Sri Lanka	5.6 bcde
[illegible]	Hsen Rath	Sri Lanka	3.6 de
[illegible]	Handaravela	Sri Lanka	4.6 bcde
15770	CR99-95	India	6.0 abcd
[illegible]	Tandask	Senegal	6.0 abcd
[illegible]	Yaye Cas 156	Senegal	5.0 bcd
[illegible]	Sene Kamoasor	Senegal	4.6 bcde
[illegible]	Berenting Cas 177	Senegal	6.0 abcd
17340	Berlayan	Indonesia	2.6 e
17661	Ketan Kasturi	Indonesia	2.6 e
21694	ARC 16661	India	4.5 bcde
21699	ARC 16666	India	4.6 bcde
24669	Campo Rowet	Indonesia	6.0 abcd
	IR40	IRRI	3.6 de
	TN1	Taiwan	8.9 a

[a]Total of 87 selected varieties from field screening and further selected from greenhouse screening with 3 replications. [b]Av of 6 replications; based on a 0–9 grading system; 0 = no damage, 9 = severely damaged. In a column any two ratings followed by a common letter are not significantly different at the 5% level.

	of leaves damaged
5	½ to ½ of leaves damaged
7	>½ of leaves damaged with no leaf breaking
9	>½ of leaves damaged with leaf breaking

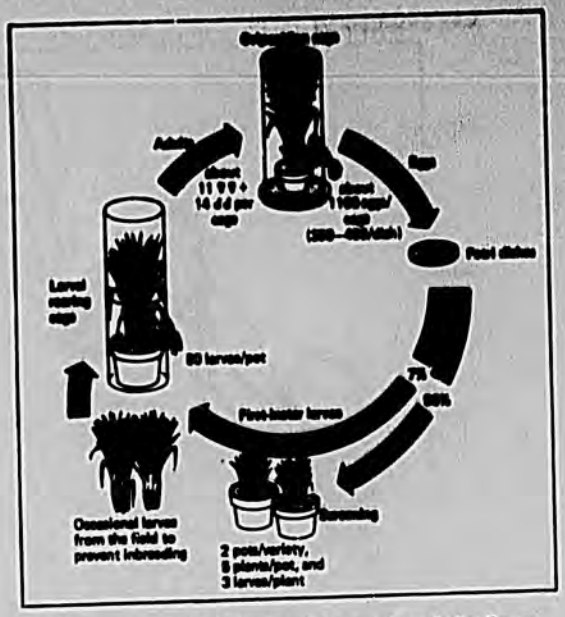
Leaf folder. Because of the increasing importance of the leaf folder a search for sources of resistance began with field screening in 1977 (1977 Annual Report). Because field infestation at IRRI was unreliable, in 1978 a leaf folder rearing method was developed for greenhouse screening.

To screen 300 varieties/week, the method (Fig. 2) uses 84 hours of labor in hand-infesting newly hatched larvae on potted plants.

NATURE AND CAUSES OF RESISTANCE

Entomology Department

Levels of brown planthopper resistance. The seedbox technique used in mass screening rice varieties for BPH resistance is rapid, but it gives poor detection of intermediate levels of resistance. There is a need for a precise, rapid method for identifying 1) moderately resistant

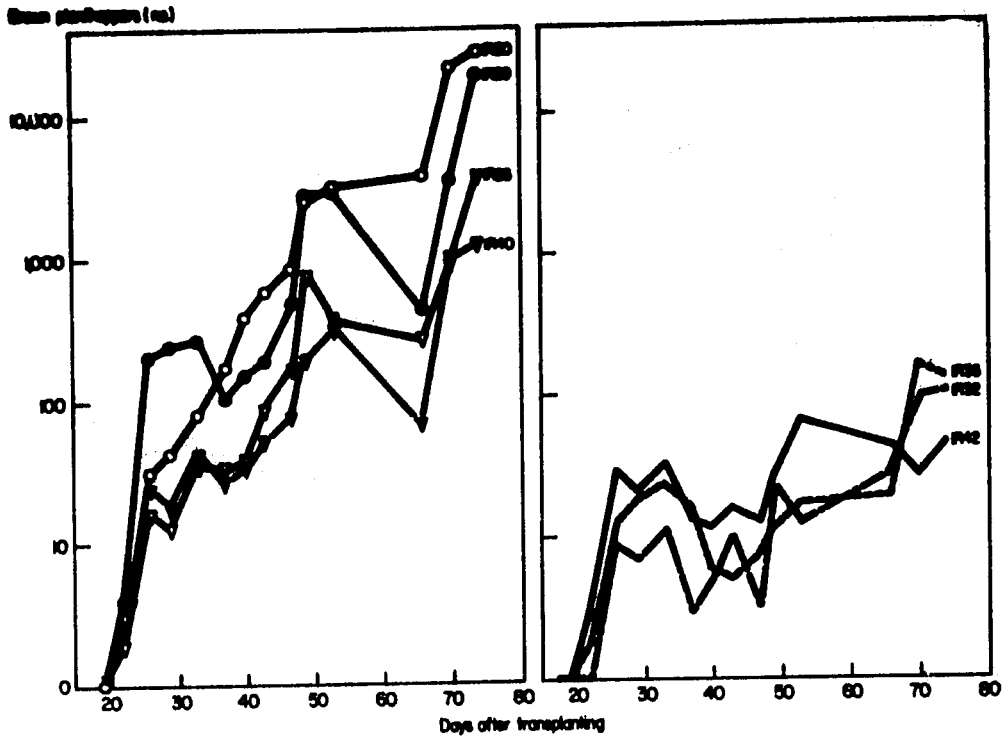


2. Mass-rearing method developed to screen varieties for resistance to the leaf folder. IRRI, 1978.

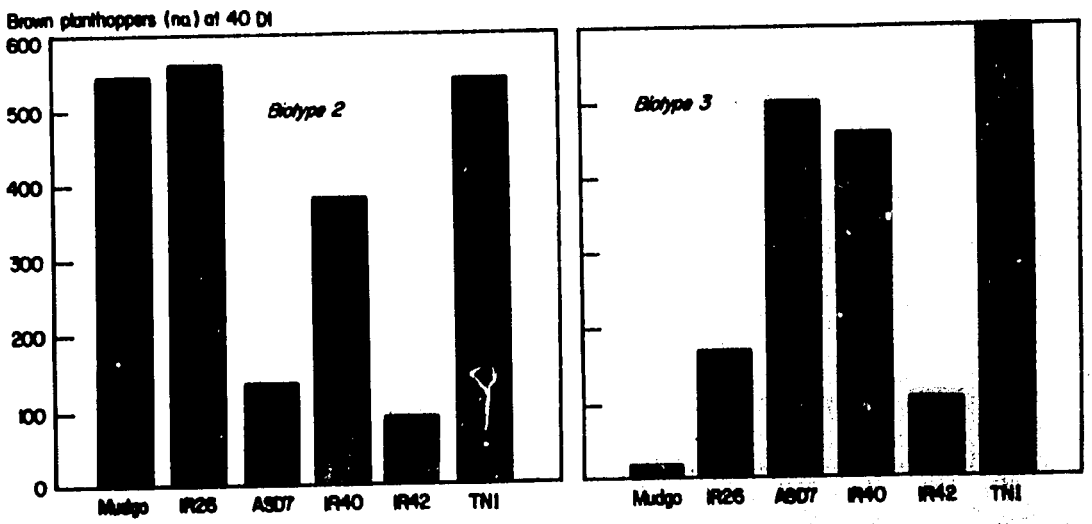
varieties, which may exert less pressure on the population for selection of a new biotype; 2) field-resistant varieties which often have lower levels of resistance than varieties having major resistance genes but perhaps have a horizontal resistance to all biotypes; and 3) the biotype composition of field populations. In 1978, the practicability of assessing the level of varietal resistance with methods that indicate the population increase and feeding activity of the planthopper on various varieties and breeding lines was determined.

Field screening of varieties for BPH resistance has shown that varieties respond differently to planthopper attack although they may have the same major genes for resistance. Studies at IRRI indicated that IR32, IR36, and IR42, which have the *bph 2* gene for resistance, had low BPH populations whereas IR40, which has the same major gene, had high populations (Fig. 3) and was hopperburned. The techniques used detected the higher susceptibility of IR40, which was not distinct with the seedbox technique.

Population increase technique. The level of resistance of selected varieties to biotypes 2 and 3, based on the population increase technique, is indicated in Figure 4. As in the field studies,



3. Brown planthopper (BPH) field population on IRRI varieties. The population was induced by spraying 20 g a.i. cypermethrin/ha 6 times at 10-day intervals. IRRI, 1978 dry season.



4. Population resulting from females of brown planthopper biotypes 2 and 3 feeding on selected varieties at 40 days after infestation (DI). IRRI greenhouse, 1978.

the increase in the population of both biotypes 2 and 3 on IR40 was significant compared with that on IR42. That indicates that the population increase technique makes it possible to detect the higher levels of resistance of IR42, which may be due to the action of minor genes or some other factor that makes it more resistant than ASD7 to biotype 3.

IR32 and IR36, and the elite breeding lines IR2863-38-1-2 and IR4432-52-6-4, which have the *bph 2* gene for resistance, were compared with ASD7, which has the same major gene (Table 8). Although biotype 3 destroyed all *bph 2* gene varieties when 7-day-old seedlings were screened by the seedbox technique, there was a distinct difference from population development in the population increase technique. This indicates that the progenies of CR94-13 shown in Table 8 may possess not only the major *bph 2* gene, as in ASD7, but possibly also some additional factors, possibly minor genes, providing resistance to biotype 3.

Feeding studies. The feeding activity of BPH biotypes was studied to determine its value in measuring levels of resistance. Three techniques were used: 1) area of ninhydrin stained honeydew on filter paper, 2) volume of honeydew excreted, and 3) densitometer measurements of honeydew color intensity.

Honeydew excreted on filter paper by five planthoppers feeding within a chamber was stained with ninhydrin and the stained area measured. Varieties with no BPH resistance gene and those with the *bph 2* gene all had larger stained areas than the *Bph 1* varieties with resistance to biotype 3. The *bph 2* gene varieties IR32, IR36, IR38, and IR42 fed less than those with no gene for resistance, but IR40 was again the most susceptible of the *bph 2* gene varieties, as indicated by the extent of the stained area. The results are similar to those in the field study on population development (Fig. 3). The filter paper technique for measuring honeydew excretion can identify biotypes, as indicated in Table 9.

A parafilm sachet or a feeding chamber can be used to collect honeydew for volume measurements. Assuming that honeydew excretion is closely related to feeding activity, the feeding

Table 8. Reaction of brown planthopper biotype 3 on rice lines or lines containing the *bph 2* gene [illegible] 20 and 40 days after infestation [illegible], IRRI greenhouse, 1978.

Cultivar	Major resistance gene	BPH (no.) 20 DI	BPH (no.) 40 DI
IR32	*bph 2*	98 abc	217 bc
IR36	*bph 2*	46 bcd	348 bc
IR2863-38-1-2	*bph 2*	30 abc	89 abc
IR4432-52-6-4	*bph 2*	94 abc	134 abc
Mudgo (resistant check)	*Bph 1*	40 bcd	168 bcd
ASD7 (susceptible check)	*bph 2*	68 a	1612 a
TN1 (susceptible check)	None	82 a	1667 a

activity of the planthopper can be indirectly assessed on various varieties by a volumetric method. Results obtained with the feeding chamber indicate distinct differences in honeydew excretion by both biotypes 2 and 3 feeding on susceptible and resistant varieties (Fig. 5). Biotype 3 hoppers feeding on IR40 excreted significantly more honeydew than those feeding on IR42.

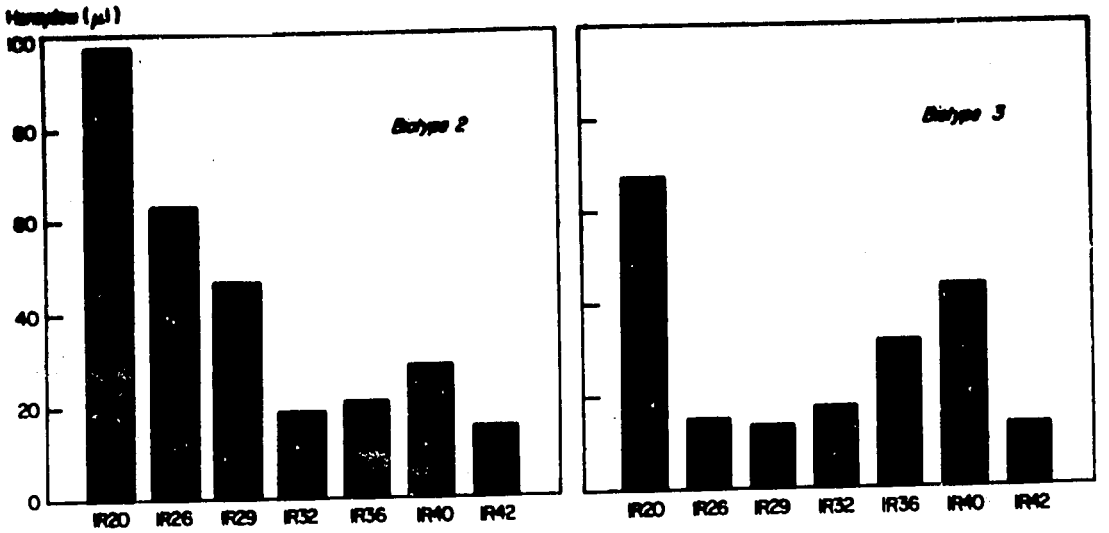
The techniques for determining honeydew volume and honeydew area on filter paper require readily available materials and are practical means of determining feeding activity. They can be used by scientists in any place where BPH varietal resistance is studied.

Tests with color intensity of honeydew, which was streaked on filter paper and treated with ninhydrin (for amino acids) or aniline hydrochloride (for sugars), were used to indirectly indicate the level of feeding activity. Color intensity readings, based on measurements of ninhydrin-treated paper with a densitometer, indicated that the peak was much higher on

Table 9. Area of ninhydrin-positive honeydew excreted by BPH biotypes 1, 2, and 3 on rice varieties with different genes for resistance.[a] IRRI, 1978.

Variety	Resistance gene	Area (mm²) Biotype 1	Biotype 2	Biotype 3
TN1	None	688 a	836 a	929 a
Mudgo	*Bph 1*	83 b	904 a	74 b
ASD7	*bph 2*	68 b	219 b	625 a

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

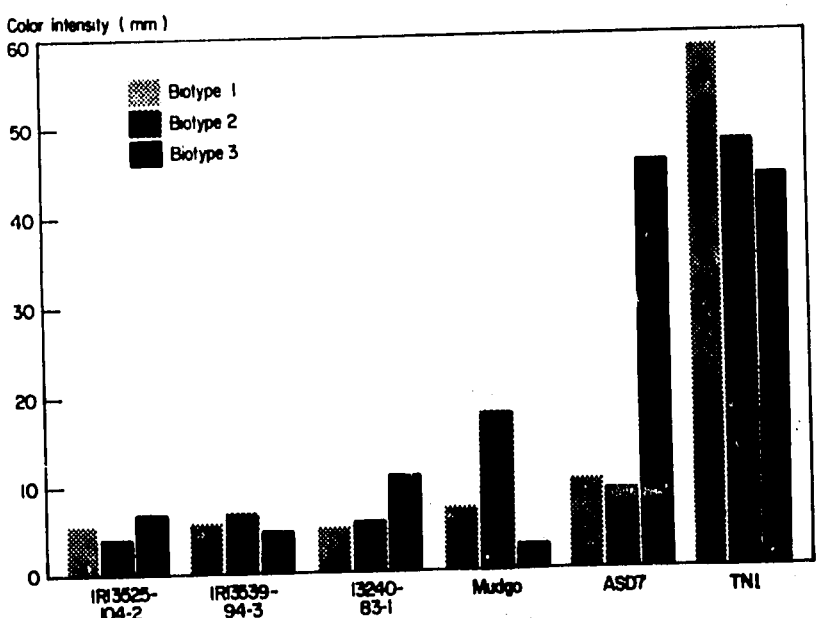


5. Volume of honeydew excreted by 5 brown planthopper females feeding on IR varieties. IRRI, 1978.

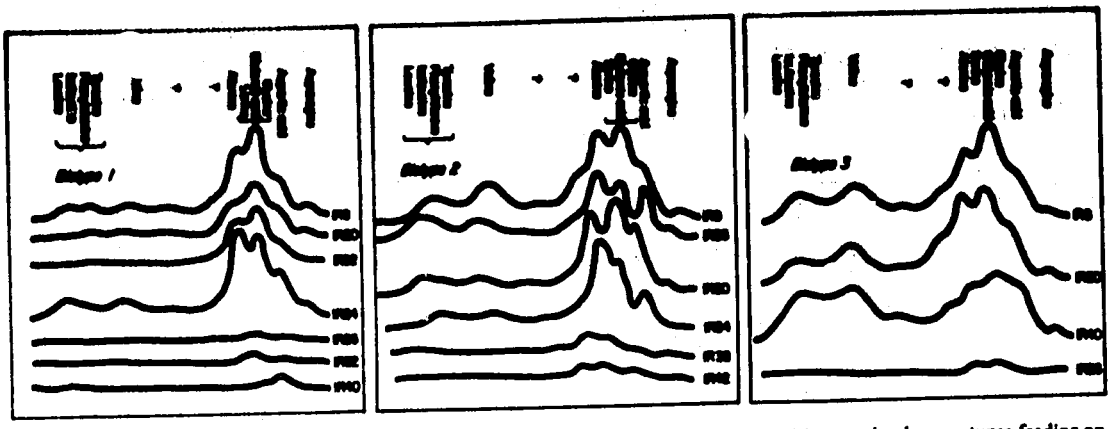
IR40 than on IR42. This confirmed that there was more feeding on IR40 than on IR42.

IRRI breeding lines with resistance to the three BPH biotypes in screening by the seedbox technique were evaluated with the densitometer technique (Fig. 6): IR13525-104-2 (PTB33 [2 unidentified genes]/IR30 [*Bph1*]//IR36 [*bph 2*]); IR13539-94-3 (Rathu Heenati [*bph 3*]/IR30/ /IR36); and IR13240-83-1 (IR30/Babawee [*bph 4*]/ /IR36). Feeding activity on the lines by the three biotypes, as indicated by the densitometer readings, was low, suggesting resistance to the three biotypes.

The densitometer was also used to determine



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



7. a, b, c. Densitometer reading of separated amino acid bands from honeydew excreted by 3 brown planthopper types feeding on different rice varieties. IRRI, 1978.

the color intensity of amino acid bands separated through paper chromatography (Fig. 7). With the use of standard differential varieties the method appears to hold promise for use in biotype identification. As indicated in Figure 7a, honeydew produced by biotype 1 feeding on varieties with no gene for resistance (IR8, IR20, IR22, and IR24) separated into eight amino acid bands of high color intensity. Measurements were obtained on bands corresponding to the aspartic acid, the glycine glutamic acid-serine, and the alanine band (Fig. 7a). On the resistant varieties IR28, IR32, and IR40, a maximum of only three bands separated, the color intensity of which was low. Honeydew of biotype 2 feeding on the resistant varieties IR38 and IR42 (Fig. 7b), and that of biotype 3 feeding on the resistant variety IR26 (Fig. 7c), produced low densitometer measurement, but the honeydew from biotypes feeding on the susceptible varieties gave high densitometer readings.

Levels of green leafhopper resistance. Studies of honeydew production and the survival and feeding of the green leafhopper (GLH) on IR varieties indicated distinct differences in resistance levels (Table 10). Survival was zero on IR28 and IR29 and low on IR34. These varieties were also most resistant with the seedbox

Table 10. Survival of and amount of honeydew excreted by the green leafhopper *Nephotettix virescens* 5–20 days after caging (DC) on different IR varieties. IRRI, 1978.

Variety	Seedbox rating	Survival[a] (%)				Densitometer reading[b] (mm)
		5 DC	10 DC	15 DC	20 DC	
IR8	5	44	33	30	27	14.69
IR20	9	91	89	88	88	51.81
IR22	9	89	82	82	82	33.75
IR24	9	70	67	66	64	60.94
IR26	3	61	52	46	35	26.75
IR28	3	3	3	1	0	10.82
IR29	1	7	1	0	0	21.87
IR30	5	42	39	36	36	14.75
IR32	5	76	71	71	71	46.00
IR34	3	16	14	14	9	18.94
IR38	5	70	63	63	53	46.81
IR39	5	84	81	81	77	40.81
IR40	3	34	33	31	27	7.25
IR42	5	84	79	79	76	41.81
TN1 (susceptible check)	9	98	91	91	90	72.81

[a]Mean of 20 replications, each consisting of 5 first-instar nymphs. [b]Av of 4 replications, each consisting of 5 adults.

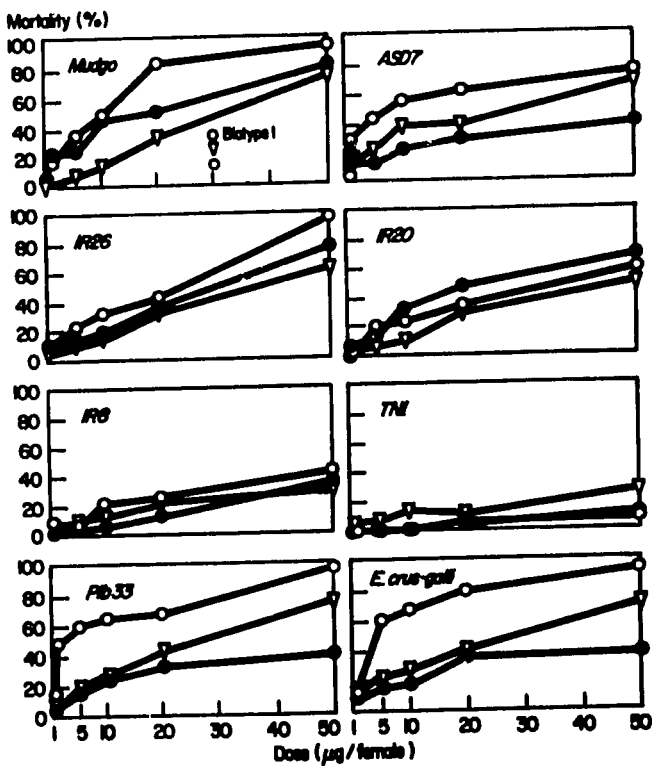
method of screening seedlings. Feeding, as indicated by densitometer readings of honeydew, was least on IR40 and IR28.

Biochemical bases of resistance. *Steam distillate extracts.* Previous studies have indicated that rice varieties and *Echinochloa* sp. possessed characteristic odors that influenced the BPH's orientation to those plants. The effect of the plant's volatile components was tested by topical application to BPH.

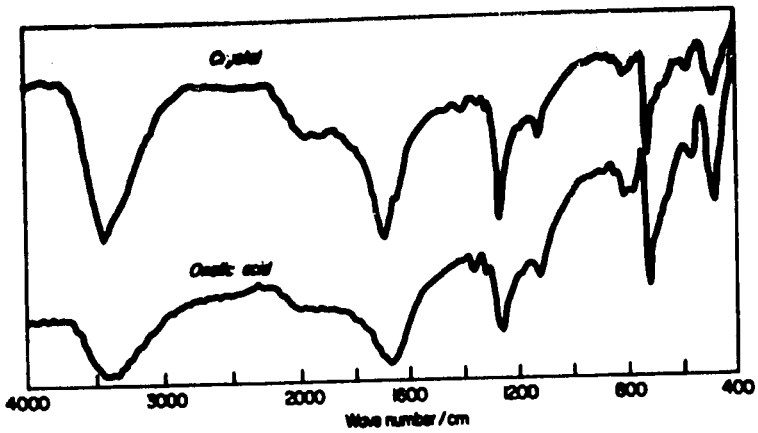
Steam distillate extracts of resistant rice varieties and *Echinochloa* not only affected the BPH's orientation but also reduced its survival on prolonged contact. In general, the yield of volatile components from resistant plants was higher than that from susceptible plants.

The volatile oils were extracted with diethyl ether from the steam distillates of 200 g of fresh leaf sheaths of Mudgo, ASD7, and IR26 (resistant to BPH biotype 1), IR20, IR8, and TN1 (susceptible to biotype 1), PTB 33 (resistant to all three biotypes), and nonhost *Echinochloa* sp. The oily extract from each plant was dissolved separately in acetone to make 6 serial dilutions, 0.1 μl of which gave dosages of 0.1, 1, 5, 10, 20, and 50 μg of the extract. Six-hour-old brachypterous females of all three biotypes were lightly anaesthetized with carbon dioxide and individually treated with application of 0.1 μl of each test dilution on the dorsum by microapplicator. Each dosage was replicated 3 times with 10 females/replication. The control females were similarly treated with acetone only. The insects were then caged on 10- to 15-day-old TN1 seedlings, and insect mortality was recorded at 1, 4, and 24 hours after treatment. Mortality values were corrected for mortality in the control treatment by use of Abbott's formula.

Differential mortalities of BPH biotypes were recorded (Fig. 8). Biotype 1 was highly susceptible to the extracts of all the resistant varieties and *Echinochloa;* nearly 100% died at the dose of 50 μg/female. IR26 extract caused high mor-



8. Mortality of brachypterous females of *Nilaparvata lugens* biotypes 24 hours after topical application of steam distillates of different rice varieties and barnyard grass. IRRI, 1978–79.



9. Infrared absorption spectrums of the crystal of sucking inhibitory substance extracted from Mudgo plant and authentic oxalic acid. IRRI, 1978.

tality only at the 50-μg level. Few insects died at high doses of extracts of susceptible IR8 and TN1, but IR20 extract was fairly toxic at the 50-μg level.

Biotype 2 suffered high mortality with extracts of *Echinochloa*, PTB 33, and ASD7. Insect mortality was quite low at lower doses of Mudgo extract; but at the 50 μg level, mortality was as high as that with equal doses from resistant varieties. The mortality of biotype 2 with IR8 and TN1 extracts was much lower than that caused by IR20 and IR26 extracts.

Biotype 3 insects suffered relatively higher mortality in treatments with extracts of Mudgo, IR26, and IR20 than in those with ASD7, IR8, and TN1 extracts. The toxic effects of PTB 33 and *Echinochloa* sp. extracts, however, were not as pronounced as those on other biotypes.

Nutritional factors. A comparison of the profiles of seven common rice amino acids — alanine, asparagine, aspartic acid, glutamic acid, leucine, serine, and valine — showed that their contents differ in Mudgo, ASD7, and TN1. The amino acids were assayed at five concentrations (0.5, 1, 2, 3, and 4%), and their role was tested in stimulation of feeding of BPH biotypes that show distinct feeding preferences for the three varieties. The pH of all amino acid solutions was adjusted to 6.5 and water was used as the control. The amino acid solutions in a given concentration and water in weighed parafilm sachets were offered simultaneously to 10 BPH females in replicated trials. After 24 hours, the sachets were reweighed and the difference between their initial and final weights indicated the amount of solution or water ingested. The ratio of intake of amino acid solution to water indicated the degree of feeding stimulation by the particular amino acid.

For biotype 1, asparagine and valine were highly stimulatory at a 4% concentration, while alanine and serine were only moderately stimulatory. For biotype 2, a 4% alanine solution was most stimulatory while valine, serine, and asparagine were moderately stimulatory. For biotype 3, valine and serine were most stimulatory followed by asparagine and alanine at 4% concentration. Leucine was almost inert for the three biotypes.

The amounts of asparagine and valine, which were most stimulatory to biotype 1, were relatively higher in TN1 than in Mudgo. Alanine, most stimulatory to biotype 2, was higher in Mudgo than in ASD7 or TN1. Valine and serine, most stimulatory to biotype 3, were relatively higher in ASD7 than in other varieties. The findings indicate a chemosensory specificity of BPH biotypes for different amino acids in rice varieties. The nutritive balance in combination with other chemical factors may be quite important in eliciting optimal interactions between the BPH and the rice plant.

Oxalic acid, a potential antifeedant chemical for BPH, was isolated from Mudgo through a combination of column chromatography for fractionation of plant extracts (Fig. 9). At a concentration of 0.1%, the extracted oxalic acid, which occurs mainly as potassium oxalate

Table 11. Comparison of the inhibitory effects of authentic oxalic acid and 2 compounds crystallized from Mudge extracts on the sucking activities of the brown planthopper. IRRI, 1978.

Substance	Chemicals used to neutralize	Sucking response of insects[a] 0.2%	0.1%	0.05%
Oxalic acid	Sodium hydroxide	–	±	+
	Potassium hydroxide	–	±	+
	Ammonium hydroxide	–	–	±
Crystal A[b]	Sodium hydroxide	–	±	+
	Potassium hydroxide	–	+	+
	Ammonium hydroxide	–	±	+
Crystal B		++	++	++

[a]Based on visual estimation of honeydew excretion: ++ = excreted as much as or more than the control; + = excreted considerably but less than the control; ± = excreted traces; – = did not excrete. [b]Identified as oxalic acid.

and partially as sodium oxalate in rice, inhibited planthopper feeding (Table 11). It was also discovered that soluble silicic acid, commonly present in crude rice extracts, exhibits a strong antifeeding property against the BPH at a concentration of 0.01 mg Si/ml, although it was not a variety-specific resistant factor.

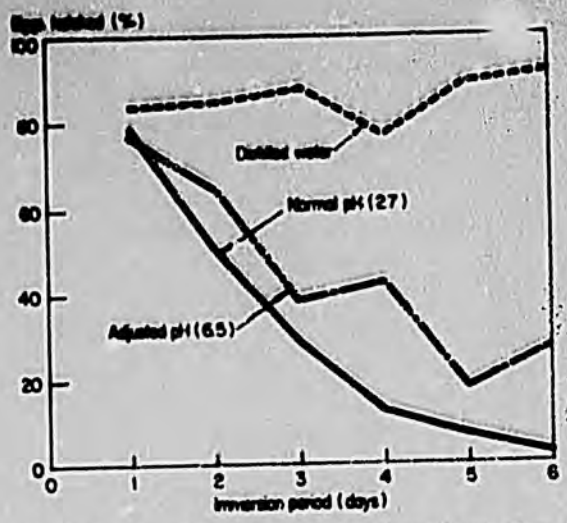
BPH egg-hatching inhibitor. Previous studies have indicated that a high percentage of BPH eggs remained unhatched on *Echinochloa* sp. and certain hopper-resistant rice varieties. Transaconitic acid (t-AA), a major *Echinochloa* sp. chemical, was tested for its effect on BPH hatching. Freshly laid eggs were removed from rice plants and placed on filter paper immersed in t-AA solutions of varying concentrations and pHs. In the control, eggs were immersed in water. Each test was replicated 8 to 10 times. The eggs were incubated at 27 ± 1°C for a 12-hour photoperiod at 70-80% relative humidity for 10 days. Hatchability of eggs of all the three BPH biotypes was low when t-AA concentration was high and the solution acidic (Table 12). Hatching increased as the concentration decreased but even in 0.001% solution, hatching was only 70-83%, compared with 88 to 92% in the control. Even when t-AA was neutralized with calcium hydroxide, its adverse effects on hatching persisted, particularly at 0.1, 0.5, and 1% concentrations. In *Echinochloa* sp., the concentration of t-AA is about 0.5% of the fresh plant weight.

To determine the stage of BPH's embryonic development that is most susceptible to t-AA, 0- to 12-hour-old biotype 1 eggs were immersed for 1 to 6 days in 0.5% t-AA solutions with normal and 6.5 neutral pHs. After immersion the eggs were washed in water and kept on moist filter paper. Immersion of eggs for 3 days or longer reduced hatchability much more than immersion for 1 or 2 days, indicating that the embryos developing in eggs were highly susceptible to the plant's internal chemistry at about 3 days after oviposition (Fig. 10). This developmental stage coincides with the disappearance of the vitelline membrane (which is particularly resistant to chemical reagents) and exposes the embryo to the surrounding chemical environment. Development of embryo and hatching proceed normally if the host plant's internal chemistry is devoid of injurious chemicals, but are disrupted if these chemicals are present in the plant sap. On the other hand, a few insect species may be tolerant of such chemicals. For example, hatchability of the GLH

Table 12. Effect of trans-aconitic acid on hatching of brown planthopper eggs.[a] IRRI, 1978.

Concn (%)	Eggs hatched[b] (%) Biotype 1 Normal pH	Biotype 1 Adjusted pH	Biotype 2 Normal pH	Biotype 2 Adjusted pH	Biotype 3 Normal pH	Biotype 3 Adjusted pH
1	4 e	22 d	13 e	26 d	5 e	16 c
0.5	21 d	27 d	21 e	36 c	27 d	28 d
0.1	40 c	34 d	42 c	42 c	43 c	46 c
0.01	59 b	60 c	66 c	62 b	70 b	54 c
0.001	70 b	70 b	83 b	84 a	77 b	73 b
0.000 (water)	88 a	83 a	90 a	86 a	92 a	90 a

[a]Normal pHs of 1–0.001% acid solutions were 2.5, 2.7, 3.0, 3.8, and 5.0; adjusted pH of solutions was 6.5, as that of water. [b]Av of 8 replicates; means followed by a common letter are not significantly different at 5% level.



10. Hatchability of brown planthopper biotype 1 eggs after immersion in trans-aconitic acid solution for varying periods. IRRI, 1978.

eggs in neutralized 0.5% t-AA solution was as high as in water, indicating that GLH eggs can tolerate t-AA levels that are lethal to BPH eggs. In nature, GLH thrives on *Echinochloa* sp., which is completely unsuitable for BPH establishment.

COLLABORATIVE GALL MIDGE BIOTYPE STUDIES

Entomology and Plant Breeding Departments

For the second year collaborative work with scientists in India, Indonesia, Sri Lanka, and Thailand aimed at identifying the gall midge biotypes in the various regions where the insect is distributed. Five groups of varieties based on parentage were sent to collaborators. The reaction of the differential groups to the gall midge at various sites indicated there are at least four biotypes (Table 13). Even within India, the reactions in Orissa and Andhra Pradesh varied.

INHERITANCE OF RESISTANCE TO THE WHITEBACKED PLANTHOPPER

Plant Breeding Department

Results of the genetic analysis of N22 for resistance to the whitebacked planthopper (WBPH) were reported in the 1976 Annual Report. The variety was found to possess a single dominant gene for resistance, which was designated *Wbph*. Twelve (Table 14) more WBPH-resistant varieties were analyzed in 1978 and were crossed with TN1. The inheritance of the F_1, F_2, and F_3 progenies from the crosses was studied. All the F_1 progenies were resistant, showing that all the varieties have at least one dominant gene (Table 15). The F_2 data indicated that P580, Sathra 267, Sonpattar 45, Sufaida 172, ARC10239, N32, Jhinuwa, and Latighawar have one dominant gene. The F_2 populations of crosses of these varieties with TN1 segregated in a ratio of 3 dominant to 1 recessive. The F_2 population of the cross TN1/IR2035-117-3 segregated in a ratio of 15 resistant to 1 susceptible seedlings, indicating that 2 dominant genes govern resistance in this line. The crosses TN1/368, TN1/Colombo, and TN1/WC1240 segregated in a ratio of 13 resistant to 3 susceptible, showing that resistance in

Table 13. Gall midge reaction patterns of varietal groups. IRRI, 1978.

Group	Gall midge reaction patterns*				
	Thailand	Indonesia	Orissa, India	Andhra Pradesh, India	Sri Lanka
Suwandhara group	R	S	S	R	S
PTB group	S	S	R	R	S
Siam 29 group	S	R	R	R	R
Leuang 152 group	S	R	R	R	R
CO27 group	S	R	R	R	R

*R = resistant, S = susceptible.

Table 14. Whitebacked planthopper-resistant rice cultivars used at IRRI, 1978.

Variety	IRRI acc. no.	Country of origin
IR2035-117-3		Philippines
P580	28088	Pakistan
Sathra 267	28237	Pakistan
Sonpattar 45	28308	Pakistan
Sufaida 172	28209	Pakistan
368	28451	Pakistan
ARC10239	20803	India
Colombo	6862	India
N32	3717	India
WC1240	13742	India
Jhinuwa	28810	Nepal
Latighawar	23684	Nepal

Table 16. Reaction to whitebacked planthopper of F_1 and F_2 populations from the crosses of rice cultivars with TN1, IRRI, 1978.

Cross	F_1 reaction	F_2 seedlings				X^2			*P* value		
		Total (no.)	Resistant (no.)	Susceptible		3:1	15:1	13:3	3:1	15:1	13:3
				No.	%						
TN1/IR2035-117-3	Resistant	[illegible]	742	[illegible]	7.20	134.40	0.40		<0.01	0.50–0.60	
TN1/P560	Resistant	[illegible]	[illegible]	100	12.74	0.70			0.40–0.50		
TN1/Sathra 267	Resistant	700	[illegible]	104	25.00	0.30			0.50–0.60		
TN1/Sonpatter 46	Resistant	[illegible]	416	100	25.00	0.08			0.40–0.50		
TN1/Sufaida 172	Resistant	910	670	240	26.14	0.64			0.40–0.50		
TN1/[illegible]	Resistant	1000	847	222	20.77	10.21		2.84	<0.01		0.10–0.20
TN1/ARC10239	Resistant	701	521	180	25.67	0.17			0.60–0.70		
TN1/Colombo	Resistant	1042	[illegible]	187	17.94	27.66		0.44	<0.01		0.50–0.60
TN1/R32	Resistant	700	[illegible]	100	28.10	3.64			0.5–0.10		
TN1/WC1240	Resistant	1400	1104	296	18.21	26.80		0.27	<0.01		0.60–0.70
TN1/Jhinuwa	Resistant	1120	847	273	24.37	0.23			0.60–0.70		
TN1/Latighawar	Resistant	1122	828	294	26.20	0.86			0.40–0.50		

these varieties is conveyed by 1 dominant and 1 recessive gene.

The conclusions drawn from the F_2 data were confirmed by the reaction of F_3 families of the crosses of the varieties with TN1. As the data in Table 16 show, F_3 families from the crosses of 8 varieties that showed monogenic segregation in the F_2 segregated in the expected ratio of 1 resistant to 2 segregating to 1 susceptible. The F_3 families from the remaining 4 crosses, as expected, segregated in a ratio of 7 resistant to 8 segregating to 1 susceptible.

All 12 varieties were crossed with N22 to determine the allelic relationships of their genes with *Wbph*. The data on the reactions of F_1 and F_2 populations are given in Table 17. As expected, all the F_1 progenies were resistant.

The crosses N22/ARC10239 and N22/Colombo showed genetic segregation in the F_2. As noted earlier, ARC10239 has a dominant gene

Table 16. Reaction to whitebacked planthopper of F_3 lines from the crosses of rice cultivars with TN1, IRRI, 1978.

Cross	Lines (no.)				X^2		*P* value	
	Total	Resistant	Segregating	Susceptible	1:2:1	7:8:1	1:2:1	7:8:1
TN1/IR2035-117-3	154	69	73	12	42.61	0.83	<0.01	0.60–0.70
	154	67	74	13	38.10	1.30	<0.01	0.50–0.60
TN1/P560	150	38	83	29	2.83		0.20–0.30	
	152	40	77	33	0.78		0.60–0.70	
TN1/Sathra 267	148	40	80	28	2.91		0.25–0.30	
	150	39	76	35	0.24		0.80–0.90	
TN1/Sonpatter 46	148	37	77	34	0.36		0.80–0.90	
	150	36	77	38	0.22		0.80–0.90	
TN1/Sufaida 172	150	39	77	34	0.44		0.90–0.95	
	135	36	68	29	1.20		0.50–0.60	
TN1/[illegible]	154	63	79	12	33.88	0.92	<0.01	0.60–0.70
	154	67	74	13	38.10	1.30	<0.01	0.50–0.60
TN1/ARC10239	154	38	80	35	0.44		0.80–0.90	
	154	39	85	30	2.71		0.25–0.30	
TN1/Colombo	153	69	73	11	44.29	0.44	<0.01	0.80–0.90
	154	68	77	9	46.20	0.04	<0.01	0.95–1.00
TN1/R32	154	40	76	38	0.23		0.80–0.90	
	153	37	80	36	0.33		0.80–0.90	
TN1/WC1240	176	82	80	14	54.00	1.87	<0.01	0.40–0.50
	154	77	67	10	60.89	2.68	<0.01	0.25–0.30
TN1/Jhinuwa	153	38	76	38	0.02		0.95–1.00	
	154	38	79	37	0.11		0.95–1.00	
TN1/Latighawar	153	36	76	41	0.33		0.80–0.90	
	150	36	77	37	0.12		0.90–0.95	

Table 17. Reaction to whitebacked planthopper of F_1 and F_2 populations from the crosses of rice cultivars with N22, IRRI, 1978.

Cross	F_1 reaction	F_2 seedlings				X^2		*P* value	
		Total (no.)	Resistant (no.)	Susceptible (no.)	Susceptible (%)	15:1	63:3	15:1	63:3
N22/IR2035-117-3	Resistant	923	923	0	0.0	—	—	—	—
N22/P580	Resistant	946	946	0	0.0	—	—	—	—
N22/Sathra 267	Resistant	1049	1039	9	0.86	—	—	—	—
N22/Sonpattar 45	Resistant	986	984	2	0.20	—	—	—	—
N22/Sufaida 172	Resistant	791	788	3	0.37	—	—	—	—
N22/368	Resistant	1143	1136	7	0.61	—	—	—	—
N22/ARC10239	Resistant	1254	1187	67	5.34	1.76	—	0.10–0.30	—
N22/Colombo	Resistant	1494	1419	75	5.02	3.86	0.36	<0.05	0.50–0.80
N22/N32	Resistant	816	816	0	0.0	—	—	—	—
N22/WC1240	Resistant	883	883	0	0.0	—	—	—	—
N22/Jhinuwa	Resistant	1014	1013	1	0.0	—	—	—	—
N22/Latighawar	Resistant	831	831	0	0.0	—	—	—	—

Table 18. Reaction to whitebacked planthopper of F_3 families from the crosses of rice cultivars with N22, IRRI, 1978.

Cross	Lines (no.)				X^2		*P* value
	Total	Resistant	Segregating	Susceptible	15:1[a]	63:1	15:1/63:1
N22/IR2035-117-3	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/P580	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/Sathra 267	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/Sonpattar 45	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/Sufaida 172	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/368	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/ARC10239	154	80	68	6	1.456	—	0.25–0.30
	154	75	70	9	0.044	—	0.80–0.90
N22/Colombo	200	121	74	5	—	1.143	0.25–0.30
	154	98	54	2	—	0.068	0.75–0.80
N22/N32	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/WC1240	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/Jhinuwa	154	154	0	0	—	—	—
	154	154	0	0	—	—	—
N22/Latighawar	154	154	0	0	—	—	—
	154	154	0	0	—	—	—

[a]Ratio refers to resistant and segregating lines combined versus susceptible lines.

for resistance that must be different from *Wbph*. Similarly Colombo has two genes for resistance, both of which must also be nonallelic to *Wbph*. No susceptible seedlings were observed in the F_2 populations of 5 of the 10 remaining crosses. In the 5 other crosses a few susceptible seedlings were recorded, but a similar proportion of susceptible seedlings were also observed in the resistant parents. It appears that the F_2 populations of these 5 crosses did not show any segregation for susceptibility. The data indicate that the single dominant gene for resistance in varieties P580, Sathra 267, Sonpathar 45, Sufaida 172, N22, Jhinuwa, and Latighawar is allelic to *Wbph*. It also appears that one of the two dominant genes of IR2035-117-3 and the dominant genes of 368 and WC1240 are also allelic to *Wbph*.

The conclusions regarding the allelic relationships of the resistance genes were confirmed by the reactions of the F_3 populations of crosses of N22 with the varieties. As shown in Table 18,

Table 20. Reaction to whitebacked planthopper of F_1 and F_2 populations from the crosses of rice cultivars with IR2035-117-3.

Cross	F_1 reaction	F_2 seedlings: Total (no.)	Resistant (no.)	Susceptible: No.	Susceptible: %	χ^2 63:1	P value 63:1
IR2035-117-3/P850	Resistant	1025	1025	0	0	—	—
IR2035-117-3/Sathra 267	Resistant	950	950	0	0	—	—
IR2035-117-3/Sonpatter 46	Resistant	940	940	0	0	—	—
IR2035-117-3/Sufaida 172	Resistant	792	791	1	0.12	—	—
IR2035-117-3/368	Resistant	833	833	0	0	—	—
IR2035-117-3/ARC10239	Resistant	1071	1056	15	1.40	—	—
IR2035-117-3/Colombo	Resistant	827	826	1	0.12	—	—
IR2035-117-3/N32	Resistant	1050	1040	10	0.80	—	—
IR2035-117-3/WC1240	Resistant	829	829	0	0	—	—
IR2035-117-3/Jhinuwa	Resistant	1033	1031	2	0.18	—	—
IR2035-117-3/Latighewer	Resistant	795	795	0	0	—	—

Table 20. Reaction to whitebacked planthopper of F_2 lines from the crosses of rice cultivars with IR2035-117-3. IRRI, 1978.

Cross	Lines (no.): Resistant	Segregating	Susceptible	Total	χ^2 63:1	P-value 63:1
IR2035-117-3/P850	154	0	0	154	—	—
IR2035-117-3/Sathra 267	154	0	0	154	—	—
IR2035-117-3/Sonpatter 46	154	0	0	154	—	—
IR2035-117-3/Sufaida 172	154	0	0	154	—	—
IR2035-117-3/368	154	0	0	154	—	—
IR2035-117-3/ARC10239	154	0	0	154	—	—
IR2035-117-3/Colombo	154	0	0	154	—	—
IR2035-117-3/N32	154	0	0	154	—	—
IR2035-117-3/WC1240	154	0	0	154	—	—
IR2035-117-3/Jhinuwa	154	0	0	154	—	—
IR2035-117-3/Latighewer	153	0	0	153	—	—

Table 21. Summary of information on the mode of inheritance of resistance to the whitebacked planthopper and allelic relationships of the genes for resistance in 12 rice varieties. IRRI, 1978.

Variety	Nature of resistance	Gene(s) for resistance
IR2035-117-3	Digenic (two dominant)	*Wbph 1* *Wbph 2*
P850	Monogenic (one dominant)	*Wbph 1*
Sathra 267	Monogenic (one dominant)	*Wbph 1*
Sufaida 172	Monogenic (one dominant)	*Wbph 1*
Sonpatter 46	Monogenic (one dominant)	*Wbph 1*
ARC10239	Monogenic (one dominant)	*Wbph 2*
Colombo	Digenic (one dominant and one recessive)	*Wbph 2* + 1 recessive
368	Digenic (one dominant and one recessive)	*Wbph 1* + 1 recessive
WC1240	Digenic (one dominant and one recessive)	*Wbph 1* + 1 recessive
Jhinuwa	Monogenic (one dominant)	*Wbph 1*
N32	Monogenic (one dominant)	*Wbph 1*
Latighewer	Monogenic (one dominant)	*Wbph 1*

no segregating or susceptible families were observed in the F_2 populations of 10 crosses. In the cross N22/ARC10239, however, genetic segregation for susceptibility occurred, as expected, closely approximating 15:1. The data show that the dominant resistance gene of ARC10239 segregates independently of *Wbph*. According to rules of nomenclature for gene symbolization in rice, the dominant resistance in ARC10239 is designated *Wbph 2* and that of N22 is now redesignated as *Wbph 1*. Susceptible and segregating families were also observed

among the F_3 families of N22/Colombo, confirming that none of the two genes for resistance in Colombo is allelic to *Wbph 1*.

Eleven varieties were crossed with IR2035-117-3, which has two dominant genes for resistance. The data on the reaction of the F_1, F_2, and F_3 populations of the crosses are presented in Tables 19 and 20. As the data show the progenies of all the crosses were resistant and no segregation for susceptibility was observed in any cross. Because ARC10239 has *Wbph 2* and the progenies of its cross with IR2035-117-3 were resistant, it is obvious that one of the two dominant genes for resistance in IR2035-117-3 is *Wbph 2*. Similarly, one of the two genes of Colombo, probably the dominant gene, must be allelic to *Wbph 2*. The summary of information on the mode of inheritance and allelic relationships of the genes for resistance in the 12 varieties is given in Table 21.

Protein content

Chemistry, Plant Breeding, and Statistics Departments

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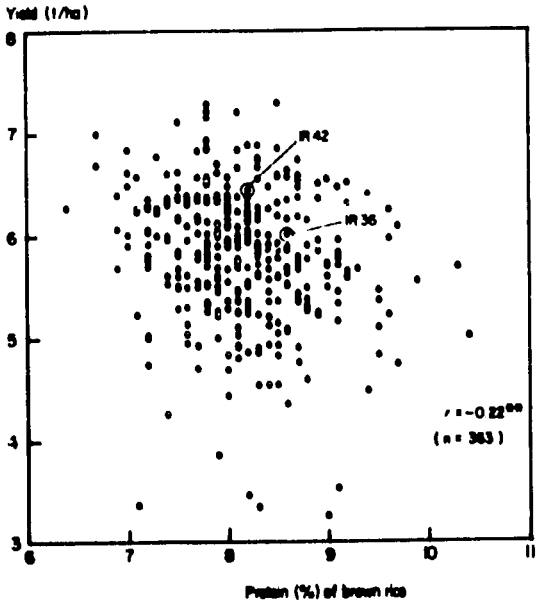
EVALUATION TRIALS

Plant Breeding, Statistics, and Chemistry Departments

Yield trials (*Plant Breeding, Statistics, and Chemistry*). Plant breeders evaluated 368 improved breeding lines and varieties in the 1978 dry season and 552 in the wet season. Because the wet-season trial was damaged by a typhoon, only the dry-season data are reported.

The dry-season yield ranged from 3.38 to 7.35 t/ha (mean of 5.84 t/ha) and protein content from 6.4 to 10.4% (mean of 8.2%). The correlation coefficient between percentage of protein content and yield was negative and highly significant ($r = -0.22^{**}$). But several entries had both high grain yield and high protein content (Fig. 1). IR36 and IR42, the check varieties, were superior to many other varieties in grain yield and protein content. IR36 is now widely grown in many countries. IR42 is versatile and has performed well in diverse conditions. Some entries with grain yield higher than 6 t/ha had close to 9% protein.

High-protein parents (*Statistics and Plant Breeding*). In the 1977 wet season, the brown-rice protein values of 121 normal-grained, high-protein (>12% in both seasons or >14% in one season and not less than 11% in another) indica accessions from the germplasm bank showed no significant correlation with earlier protein values (Fig. 2). The results for 31 entries in the 1978 dry-season crop were similar. In the larger 1978 plots, the protein contents of the two crops were positively correlated ($r = 0.42^{*}$, $n = 29$).



1. Grain yield and brown-rice protein of 361 entries and 2 check varieties in the replicated yield trials (4 replications). IRRI, 1978 dry season.

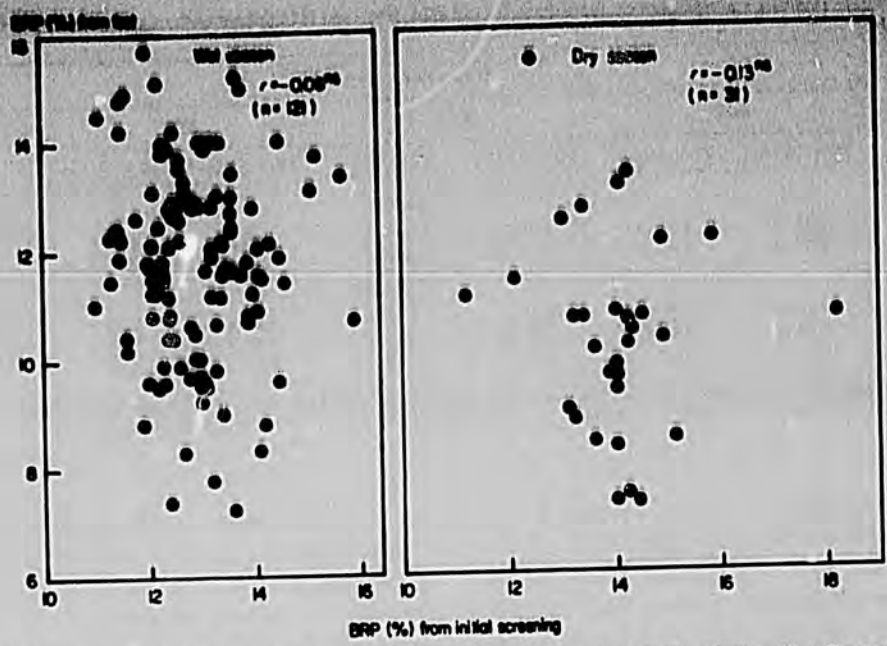
The results confirm previous findings that environment greatly influences the protein content of rice, particularly in small plots such as those used for germplasm multiplication. Insect and disease incidence further aggravates the difficulty of comparing varieties. Consequently, the protein level of the germplasm-bank samples has limited predictive value in identifying accessions as sources of high protein content.

About 1,500 high-protein (>11%) indica accessions in the germplasm bank with good seed fertility and heavy grain weight were grown in the 1978 wet season but the trial was damaged by typhoons. Protein content of 106 entries that were saved ranged from 8.8 to 17.5% (mean of 12.8%).

Factors affecting protein content (*Statistics*). Studies with single and split applications of nitrogen fertilizer at two rates, two management levels, and two varieties (IR34 and IR36) in the 1977 wet season suggested that protein content in a variety with short growth duration and relatively high yield response to nitrogen responded more to split applications than to a single high-rate application (Table 1).

In a 1977 dry-season study of the effects of seedling management on the grain protein content of IR32, the variety with relatively long growth duration and high tillering did not differ significantly (Table 2). In IR28 and IR30, the protein content tended to be higher when the seedlings were raised by the wetbed method (seedlings grown in soil) than when they were raised by the *dapog* method (seedlings grown on banana leaves or concrete; no soil), especially at the 20– × 10-cm spacing. In IR28, protein content was higher when older wetbed seedlings were used.

The protein content of IR38, determined from 864 harvest units from a 1,728-m²



2. Associations between brown-rice protein (BRP) contents of accessions in the IRRI world collection, obtained from actual field tests and from initial screening. IRRI, 1977 wet and 1978 dry seasons.

uniformly managed area at IRRI, ranged from 3.8 to 11.5% (mean of 7.4% and C.V. of 12%). The field variation could be explained by the inherent soil heterogeneity, as reflected by a high correlation between grain yield and protein content (0.65**).

NUTRIENT DISTRIBUTION IN MILLING FRACTIONS

Chemistry Department

Continued study of nutrient distribution in milling fractions of a high-protein (IR480-5-9) and an average-protein rice (IR32) revealed that only starch was replaced by an increase in protein. The reported low ash content of the low-protein sample (0.8%) was not shown by other brown-rice samples of the same variety with a protein content of 7% (1.3–1.5% ash). About 70% of brown-rice phosphorus, 40% of milled-rice phosphorus, and 85% of rice-bran phosphorus was phytin phosphorus. Milled rice had a phytin phosphorus content of less than 0.1%. Only 20% of phytate phosphorus of brown rice was in the milled-rice fraction. Brown rice had 0.7% crude fiber, 2% dietary fiber (neutral detergent method), and 3% crude fat. Milled rice had 0.1% crude fiber, 0.6% dietary fiber, and 0.4% crude fat. Eighty per-

Table 1. Effect of method of nitrogen application on brown-rice protein content of IR34 and IR36 grown under different management and fertility levels. IRRI, 1977 wet season.

Method of nitrogen application	Brown-rice protein[a] (%)				
	IR34		IR36		Av
	30 kg N/ha	90 kg N/ha	30 kg N/ha	90 kg N/ha	
	Low management level[b]				
Single	8.5 a	8.6 b	8.9 a	8.2 b	8.6
Two splits	8.4 a	9.4 a	8.7 a	10.3 a	9.2
Three splits	8.0 a	9.2 ab	9.0 a	9.7 a	9.0
	High management level[b]				
Single	8.2 a	8.8 b	8.6 a	8.6 b	8.6
Two splits	8.3 a	9.0 ab	8.6 a	10.9 a	9.2
Three splits	8.3 a	9.6 a	8.8 a	10.7 a	9.4

[a]Data are averages over 4 times of application for "single" (basal, 10 days after transplanting [DT], tillering, and 7–7 days before panicle initiation [PI]); 3 times of application for "2 splits" (basal + PI, 10 DT + PI, and tillering + PI) and 2 times of application for "3 splits" (basal + tillering + PI and 10 DT + tillering + PI). In a column under the same management level, means followed by a common letter are not significantly different at the 5% level. [b]Involving land preparation, water management, weed control, and insect control.

Table 2. Effects of seedling management on protein content of IR20, IR26, and IR32 grown under varying test conditions, IRRI, 1977 dry season.

Seedling age (DAS[b])	Brown-rice protein[a] (%)						
	IR20		IR26		IR32		
	20 × 10 cm	20 × 20 cm	20 × 10 cm	20 × 20 cm	20 × 10 cm	20 × 20 cm	Av
				Dapog			
8	7.23 b	7.34 b	8.05 ab	7.80 a	8.00 a	8.02 a	7.35
21	7.34 b	7.42 ab	7.77 b	8.08 a	8.76 a	8.02 a	7.41
				Wetbed			
14	7.30 b	7.42 ab	8.23 a	7.93 a	8.00 a	8.02 a	7.40
30	7.35 a	7.60 a	7.94 ab	8.02 a	7.86 a	7.19 a	7.60
Av	7.32	7.43	8.00	7.96	8.02	8.00	

[a]Data are averages of 2 fertilizer rates and 2 levels of land preparation, each with 2 replications and 2 samples/replication. In each column, means followed by a common letter are not significantly different at 5% level. [b]Days after seeding.

cent of the protein, 95% of the starch and amylose, 10% of the crude fiber, 15% of the crude fat, and 30% of the crude ash of brown rice were in milled rice. Among the minerals, zinc had the highest fraction in milled rice (60%), magnesium had the lowest (15%).

Amino acid analysis of the milling fractions of IR32 and IR480-5-9 showed decreasing levels of the first limiting essential amino acid (lysine) in the protein from the outermost layer (bran) to the subaleurone layer of the endosperm (Table 3). In the low-protein rice, the lysine content of the protein in the central endosperm was similar to that in the subaleurone layer, but in the high-protein rice, it was higher in the central endosperm.

PROPERTIES OF RICE PROTEIN

Chemistry Department

Nitrogen balance studies with high-protein rice. Nitrogen balance studies in which 8 preschool Filipino children at the Food and Nutrition Research Institute, Manila, had a daily rice protein intake of 250 mg N/kg body wt, confirmed that the apparent digestibility and apparent nitrogen retention of high-protein (11.0%) rice (IR480-5-9, 3.4 g lysine/16 g N) were only slightly inferior to those of low-protein (7.2%) rice (IR32, 3.8 g lysine/16 g N) (Table 4). Similar results were obtained with eight Peruvian infants at the Instituto de Investigacion Nutricional, Lima, fed the same two rices. The studies verify previous studies in which protein intakes differed. In both sets of subjects fat absorption was high for both rice and casein diets. The similarity of results suggest that nitrogen balance studies of similar procedures at different nutritional evaluation laboratories may be compared despite differences in the staple food of the subjects.

At the National Taiwan University, Taipei, the high-protein IR480-5-9 was compared with Chianon-Shien 8, a local rice variety, in a nitrogen-balance experiment on 5 adults fed a 90% rice protein diet. By a linear regression

Table 3. Lysine content of protein in milling fractions of a low-protein (IR32) and a high-protein rice (IR480-5-9). IRRI, 1978.

Milling fraction	Protein content (%)		Lysine (g/16.8 g N)	
	Low-protein rice	High-protein rice	Low-protein rice	High-protein rice
Bran (0-6)[a]	14.0	13.8	5.3	5.1
Pulish (6-12)	13.0	16.0	4.1	3.8
Endosperm				
Subaleurone (12-20)	12.2	21.2	3.6	3.3
Core (20-100)	5.5	7.4	3.6	4.2

[a]Weight percentage fraction of brown rice starting from the outer layer.

Table 5. Comparative nitrogen balance data on 8 Filipino and 8 Peruvian male preschool children fed diets containing high-protein rice (IR480-5-9, 11.0% protein [N × 5.95]) and low-protein rice (IR8, 7.5% protein), Food and Nutrition Research Institute, Manila, and Instituto de Investigación Nutricional, Lima, Peru, 1977–78.

Subjects, property	Diet and major protein source[a]		
		Rice diet	
	First casein diet	Low protein	High protein
Filipino children			
Daily N intake (mg/kg body wt)	248 a	256 b	257 b
Apparent N digestibility (% of intake)	76.8 c	88.2 b	80.0 a
Apparent N retention (% of intake)	30.8 b[b]	26.9 a	23.4 a
Peruvian children			
Daily N intake (mg/kg body wt)	240 a	240 a	240 a
Apparent N digestibility (% of intake)	86.1 b	68.6 a	64.9 a
Apparent N retention (% of intake)	36.2 b	28.6 a	23.0 a

[a]In a line, means followed by a common letter are not significantly different at the 5% level. [b]Based only on the first 4 children.

equation, the mean daily maintenance protein (N × 5.95) requirement for young men on 43–46 kcal rice diet/kg body weight was 0.63 g/kg with IR480-5-9, and 0.70 g/kg with Chianon-Shien 8 (8.2% protein, 3.5 g lysine/16 g N).

A cooperative 1-year growth study with the Christian Medical College and Hospital, Vellore, Tamil Nadu, India, compared the effects of diets containing high-protein rice (IR2153-338-3: 9.8% protein, 3.8 g lysine/16 g N) and low-protein rice (Ponni: 6.8% protein, 4.2 g lysine/16 g N) on 29 pairs of preschool children in an orphanage. No difference in height, weight, and hematological data were noted between the control and experimental groups after 5 months on a south Indian diet in which rice contributed 80% of the calories and at least 75% of the protein. Other protein sources in the diet were black gram (*Phaseolus mungo*) and pigeon pea (*Cajanus cajan*). The diet consisted (per 1,000 kcal) of 235 g rice, 10 g black gram, 5 g pigeon pea, 50 g vegetables, and 15 g vegetable oil. After 3 months, 17 pairs of children indicated comparable absorption and retention of the protein from both diets despite a 30% difference in protein intake (Table 5).

Table 6. Mean nitrogen balance on 17 pairs of preschool children fed, for 3 months, a rice-based south Indian diet[a] in which the protein content of rice was either low or high, Christian Medical College and Hospital, Vellore, Tamil Nadu, India, and [illegible], 1978.

Property	Experimental (high-protein rice)	Control (low-protein rice)
N intake (g/day)	5.31 ± 0.79	4.69 ± 0.38
Apparent absorption (% of intake)	68.8 ± 0.81	68.2 ± 0.41
Apparent retention (% of intake)	27.6 ± 0.77	26.1 ± 0.81

[a]Rice contributed 80% of the calories and at least 75% of the protein in the diet.

The foregoing studies confirmed that the utilizable protein of milled rice increased with increase in protein content — the drop in protein quality was not statistically significant when protein content was increased by 3 to 4 percentage points.

Undigested protein of cooked rice. The study to ascertain the mechanism by which cooking reduces the digestibility of milled-rice protein bodies (1977 Annual Report) was continued. Because electron microscopy showed that previous destarched milled-rice preparations were contaminated by cell walls and membrane fragments, pepsin treatment was repeated, but with sieving. The fungal α-amylase-treated cooked rice was passed through a 53-μm sieve, pepsin treated, and passed through a 37-μm sieve.

The undigested core protein body had a higher oil content than the whole protein body, confirming 1977 results (Table 6). It again had lower lysine content and higher cysteine and methionine contents. However, the ratio of lipid fractions during pepsin treatment did not change. The lipid fractions of both preparations also had similar fatty acid composition.

Lipids of the protein bodies were the major source of free lipids of the rice endosperm. Extraction for 8 hours with chloroform:methanol (2:1 vol/vol) removed 85% of the lipids of destarched milled rice, and a 5-minute extraction of the residue with water-saturated butanol increased the cumulative extraction to 95%. Free lipids of the inner endosperm had a neutral lipids-glycolipids-phospholipids ratio of 66:18:16, whereas lipids

Table 6. Properties of stored whole and pepsin-treated cooked IR400-5-9 milled-rice protein bodies. IRRI, 1978.

Property	Whole protein bodies	Pepsin-treated protein-bodies
Recovery (%)	100.0	34.5
Crude protein (%)	79.1	62.4 (27.2*)
Total lipids (%)	9.51	22.0 (69.1*)
Lysine (g/16.0 g N)	4.0	1.3
Cysteine (g/16.0 g N)	2.6	4.6
Methionine (g/16.0 g N)	3.1	4.0
Ratio of neutral lipids:	92	92
glycolipids:	5	5
phospholipids	3	3
Fatty acid composition of neutral lipids		
Palmitic (% of total)	32	34
Oleic (% of total)	24	24
Linoleic (% of total)	42	40
Others	2	2

*Percentage recovery based on whole protein bodies.

of protein bodies destarched with food grade fungal α-amylase had 92:5:3. Earlier preparations without sieving and using crystalline bacterial α-amylase had 76:12:12. Membrane lipids tended to have more glycolipids and phospholipids than protein-body lipids. The ratios of lipid fractions in protein bodies prepared from cooked rice by destarching with bacterial α-amylase and fungal α-amylase differed.

Extractability of the protein and lipids of destarched rice changed with cooking (Table 7). Thus, cooking caused a more intimate association among proteins in the core portion of the protein bodies, as indicated by the reduced extractability of protein and the increased extractability of lipids. The higher cysteine content of the core protein (Table 6) contributed to easy disulfide cross-linking of this protein. Interestingly, raw-rice protein bodies, prepared by destarching with crystalline pancreatic α-amylase, had a lower lipid content (7%) than cooked-rice protein bodies destarched with fungal or bacterial α-amylase (9% lipids).

Table 7. Comparative extractability of protein and lipids of destarched raw and cooked IR400-5-9 milled rice. IRRI, 1978.

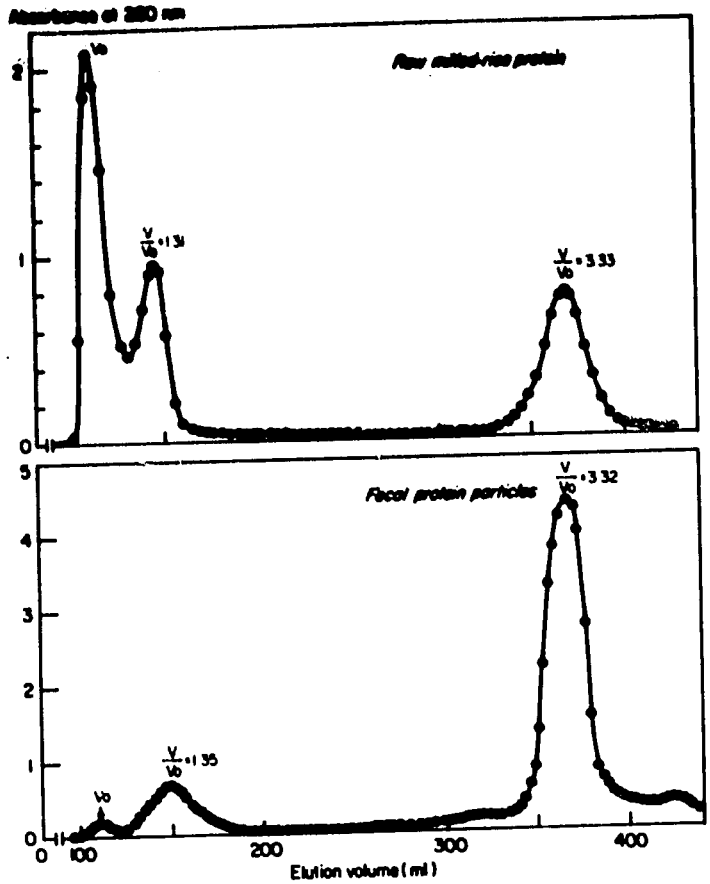
Fraction	Solvent	Extraction rate (% of total)	
		Raw-rice protein bodies	Cooked-rice protein bodies
Protein	0.5% SDS-0.5% β-ME	98	73
Lipid	Petroleum ether	33*	72*

*Percentage of lipids extracted by petroleum ether followed by water-saturated butanol.

Sodium dodecyl sulfate (SDS)-Sephadex G-75 (cross-linked dextran) gel filtration of fecal protein particles verified the presence of the molecular weight (MW) 16000 subunit (V/V_e = 1.3) characteristic of glutelin (Fig. 3). But the major polypeptide component had a much lower molecular size (V/V_e = 3.3). This polypeptide subunit corresponded to MW 5000. It stained poorly with Coomassie blue dye, which explained why it escaped detection during disc gel electrophoresis. The subunit passed through the dialysis membrane. It was also the major component of pepsin-treated destarched milled rice. Bio-Gel P-10 fractionation of pepsin-treated protein bodies in 70% formic acid also revealed the presence of this low-MW protein subunit.

Because the low-MW polypeptide was characteristic of the core of protein bodies, its occurrence was investigated in untreated milled rice. SDS-Sephadex gel filtration confirmed its presence in native protein bodies at about 10% of total UV absorption (Fig. 3). This fraction had been observed in previous SDS-Sephadex and SDS-Ultrogel (polyacrylamide) fractionation of rice glutelin, but had been ignored because it has low capacity to adsorb protein stains. Raw milled rice is preferred for the isolation of this low-MW polypeptide subunit because it is relatively free of contaminant degradation products of proteolysis that probably are present in fecal protein particles and pepsin-treated protein bodies.

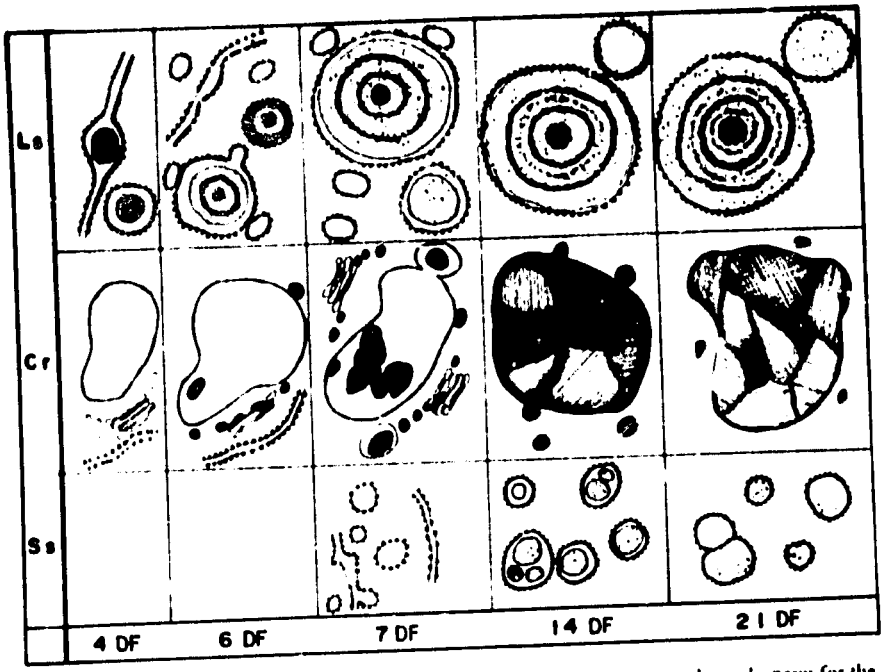
Terminal amino acid and molecular weight of protein subunits. Attempts at the University of Durham (England) to determine the N-terminal amino acid of milled-rice prolamin and α-globulin were unsuccessful, reflecting a block to the amino group of the amino acid either in vivo or during preparation. Similar problems were previously noted for glutelin subunits. Confirmatory molecular weight estimation in SDS-17% polyacrylamide gels for prolamin, glutelin and α-globulin, and fecal protein particles showed results similar to those obtained at IRRI.



3. Sodium-dodecyl sulfate (SDS)-Sephadex G-75 gel filtration of total raw IR480-5-9 milled-rice protein extracted by 0.5% SDS-0.6% β-mercapto-ethanol, and of fecal protein particles from a man on an IR480-5-9 rice diet. IRRI, 1978.

Other cooperative studies. In the cooperative study with chemists at the U.S. Grain Marketing Research Laboratory on morphological changes during grain development, three types of endosperm protein bodies were found in both a high-protein (IR480-5-9) and a low-protein rice (IR26). Each type is deposited differently. First secreted was the large spherical protein body. It was deposited within tubular rough endoplasmic reticulum, had a dense center and a concentric ring appearance, and was bound by a single membrane (Fig. 4). The second protein body to form was the crystalline type, which was found in vacuoles and was secreted via the Golgi apparatus. The third type, the small spherical protein body, was secreted late in development and deposited in a vesicular rough endoplasmic reticulum. It had one to three bodies per vesicle, and lacked dense centers and concentric rings.

In a 2-year cooperative study with protein chemists at the Australian National University at Canberra, methods for the clean separation of aleurone cells and pericarp, besides the embryo, were developed. Analysis indicated that although the embryo, aleurone cells, and pericarp amounted to only about 9% of an average-protein brown rice (IR32, 7% protein), they contained 17% of the protein, 23% of the lysine, and 21% of the threonine of brown rice. Aleurone cells plus pericarp, pre-



4. A diagrammatic scheme of protein body formation in rice subaleurone starchy endosperm for the 3 types of protein bodies observed at various days after flowering (DF). Ls = large spherical, Cr = crystalline, and Ss = small spherical. US Grain Marketing Research Center, Manhattan, Kansas, and IRRI, 1978.

pared by scraping endosperm from cut rice immersed in water for 3 days, produced intact aleurone cells while a 5-minute treatment with formic acid containing 0.8 M sucrose caused disruption of aleurone cell walls, disorganization of the cytoplasm, and leaching of nonprotein contents.

A cooperative study on the biochemical and physiological bases for the negative relationship between protein content and overall yield of rice was formalized with biochemists at the University of Durham (England). IRRI varieties and lines differing in grain protein content were sent to Durham. Bioenergetic considerations indicate that protein accumulation requires more energy or glucose equivalent than starch accumulation in the cereal endosperm.

reported the presence of rats in their storage facilities. Most farmers considered rat damage to be an inevitable feature of grain storage on the farm. Grain loss from containers was estimated to be 0.4 kg/bag of paddy. In granaries, loss was about 0.3 kg/bag. Natural enemies like cats and dogs were the most popular means for controlling rats. Some farmers used rodenticides or traps with natural enemies.

Farmers estimated losses from insects to be small — 0.1 kg/bag. No visible fungus damage was reported.

Technical evaluation trials. To determine the quality of paddy stored in household facilities, grain samples were subjected to laboratory analysis. The results are summarized in Table 1. The technical criteria considered were moisture content, crack ratio, damaged grain, purity, and length of time from harvest to storage. Moisture content averaged 13.9% and ranged from 11 to 17%. About half of the samples had moisture content above 14%, the maximum level considered safe for prolonged storage. Farmers indicated moisture content as the most important factor affecting storability. Most had dried their paddy to 14% or below before placing it in storage. Many farmers did not, however, seem well informed about the hygroscopic property of paddy, which increases or decreases moisture content in response to changes in temperature and relative humidity.

The average crack ratio was about 20%, with a coefficient of variation of nearly 100%. The crack ratio varied widely because all farmers sun-dried their paddy and thus had little control over rate of drying and tempering.

The average damaged grain count was 1.6/100, with a CV of 69%. Damaged grain included broken and husked grains. Damage was caused mainly by improper threshing or improper drying or both. The correlation coefficient between moisture and percentage of damaged grain was not strong at −0.3. It indicates, however, that drier grain is more susceptible to damage. Eleven samples were threshed mechanically with either power or pedal threshers, and 15 were threshed by hand. The correlation coefficient between threshing methods and percentage of damaged grain was −0.07. There was essentially no relationship between threshing methods and damaged grain in the field.

Average purity was 96.5%, with a CV of only 2.0%. Seventy-two percent of the paddy samples were cleaned by hand, the remainder with a manual cleaner or thresher. Because the CV was small and only 1 sample showed a purity above 99%, purity can be considered relatively poor. Improved cleaning methods are needed if purity without appreciable loss is to be attained.

The duration of the prestorage processes — threshing, cleaning, and drying — ranged from 4 to 27 days. Many farmers stacked the rice and waited for good threshing and drying weather. Four samples were mechanically threshed. Farmers using machines were often required to wait up to 1 month.

More than 66% of the samples had a varietal purity above 99%. Only 18 samples out of 28 were identified by farmers. The remainder were given local names.

About 90% of the samples were mature grains, indicating that the harvest was carried out at the proper time or beyond the maturity date. Less than 1% of the grains were discolored, indicating that no serious deterioration

Table 1. Statistical analysis of the factors used in describing the condition and quality of paddy in farm storage in Luzon, Philippines, 1977–78.

Factor	Mean	SD	CV (%)
Technical			
Moisture content* (%)	13.9	1.5	11
Crack ratio (%)	19.5	19.2	98.5
Damaged grain (%)	1.6	1.1	69
Purity (%)	96.5	1.9	2.0
Duration (days) of harvest-storage	12.2	7.4	61
Physical, agronomic			
Varietal purity (%)	98.1	3.8	3.9
Mature grain (%)	89.6	5.8	6.5
Spoiled grain (%)	2.7	1.5	56
Green kernel (%)	5.8	3.1	53
Chalky kernel (%)	3.6	2.3	64
Discolored grain (%)	0.07	0.19	271
Biological			
Fungus infection			
Field fungi (%)	38.1	23.5	61.7
Storage fungi (%)	2.2	4.8	218
Insect infestation			
Frass (%)	0.05	0.06	120
Infected grains (no./100 g)	1.6	3.7	231
Insect population (no./100 g)	1.4	4.7	336

*Wet basis.

took place during the storage period, which ranged from 1.3 to 25.4 weeks at the time of the survey.

Average field infection by fungi was 38.1% (CV of 61.7%). In contrast, infection by storage fungi averaged only 2.[illegible]% with a CV as high as 271%. Field fungi represented the dominant type detected in the paddy samples. Six species were detected: *Trichoconis* sp., *Nigrospora* sp., *Rhynchosporium* sp., *Rhizopus* sp., *Phoma* sp., and *Curvularia* sp. Storage fungi detected were *Penicillium* spp. and *Aspergillus* spp.

Sixty percent of the samples showed evidence of insects, with either frass, insect-damaged grain, or insects.

The influence of agronomic factors on the quality of stored paddy was determined by measuring chalky grain, green kernels, and varietal purity. The coefficient of variation for varietal purity was only 3.9% for chalky grain, indicating a weak correlation between this factor and spoiled grain. Of three biological factors studied, storage fungus infection and insect infestation were zero or nearly zero, indicating little effect on spoiled grain yield.

Green kernels, chalky grain, field fungus infection, moisture content, crack ratio, damaged grain, and the duration from harvesting to storage were introduced in a regression model to assess their relative contribution to quality deterioration.

The following regression model was used:

$$SG = a_0 + a_1(FF) + a_2(CG) + a_3(MC)$$

where SG = percentage of spoiled grain, FF = percentage of field fungus infection, CG = chalky grain, and MC = percentage of moisture content.

Results:

$$SG = 1.4503 + 0.0358(FF) + 0.2738(CG) - 0.0781^{ns}(MC)$$

t values = 4.1175 3.0011 −0.5838

$R^2 = 0.545$

The correlation coefficient for moisture content was the highest at 0.16. The partial regression coefficient for MC did not pass the t-test. To obtain significant values for this coefficient, more samples are required.

The coefficients for field fungus infection and for chalky grain were significant at the 0.1% level.

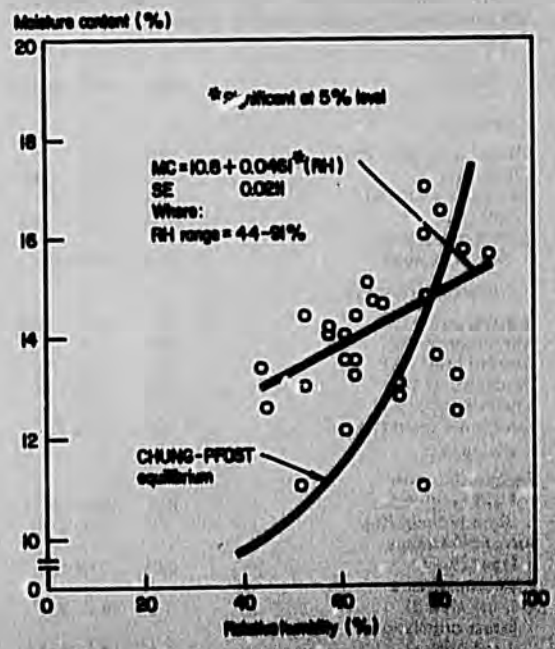
[illegible] grain losses for [illegible] spoilage. As [illegible] zero moisture [illegible] in conditioning grain for safe storage. [illegible] and equation indicate that even if the moisture content is in the range of 11 to 17%, up to 5% spoiled grains can be expected. Such spoilage would be due mainly to agronomic and biological factors, both of which showed a directly proportional relationship with spoiled grain.

Figure 3 shows the relationship between moisture content and relative humidity. Assuming that MC of stored paddy is in direct proportion to the relative humidity, the following equation is obtained:

$$MC = 10.8 + 0.0461\ (RH)$$

where RH = relative humidity, with a range of 44 to 99%.

To sustain a safe storage moisture content of about 14% under normal storage conditions, the relative humidity should be about 65%. During the wet season in the tropics, grain storage facilities should be moisture-proofed for protection from high outside humidity.



3. Relationship between relative humidity (RH) and moisture content (MC) in farm paddy storage, IRRI, 1978.

RICE MILLING SYSTEMS

Agricultural Engineering Department

The evaluation of village-level rice milling systems in the Bicol River Basin was continued in 1978. The work was divided into four phases: assessing village-level operating systems, evaluating factors influencing milling performance, examining potential improvements in small-scale mills, and evaluating the economics of alternative milling systems.

Assessing village systems. The first step in studying village milling systems was evaluating their potential performance. Replicated technical assessment trials using clean, well-dried paddy (IR36) were run with each of eight systems during the 1976 wet and the 1977 dry seasons. The results are summarized in Table 2. The rubber roll-steel huller combination mill gave the best overall recovery rate. Head rice was significantly higher than with any other system. Milling performance was slightly better during the dry season for all mill types because there were fewer immature grains in the sample.

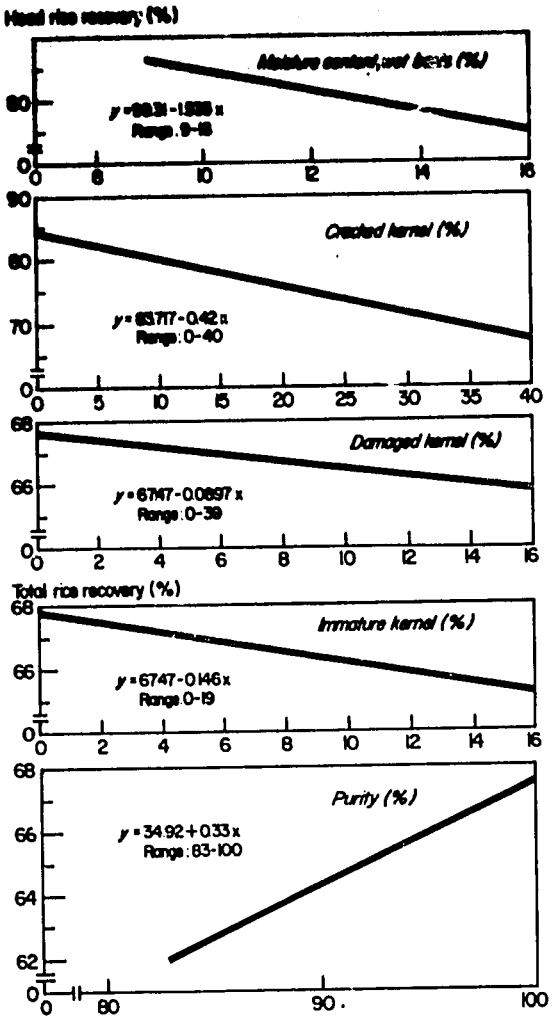
Factors influencing milling recovery. A weekly monitoring schedule to collect paddy and milled-rice samples from 8 village mills in Camarines Sur and Albay was followed for 1 year. Laboratory analysis of the samples allowed the assessment of the condition and characteristics of the paddy being milled in each system and the resulting quality of the milled rice. Several factors affect total milling recovery and the amount of head rice produced. Moisture content (MC) influences the hardness and tensile strength of the grain and, consequently, head-rice recovery rates. The top panel in Figure 4 shows that head-rice recovery decreased by 1.5% for each percent increase in MC in the range of 9 to 16%. The recommended MC range for milling is 12–14%. Breakage increases below 12% MC because of the brittleness of the grains. The grouping in the scatter diagram indicates that most paddy was within or slightly below the recommended range. Cracked kernels result from environmental conditions during the period from maturity through drying of the paddy. Delays in harvesting, or improper or delayed drying resulting in fluctuation in the internal moisture content of the grain, produce fissuring. This internal damage is generally not evident until the grain is dehusked and whitened, at which time it is subjected to thermal and mechanical stresses, particularly in the steel-huller one-pass mill. The proportion of broken grains after milling increases significantly when cracked kernels are present.

Damaged and immature kernels also affect milling performance. Damaged kernels result from the methods of handling , threshing, and drying used. All samples from the monitoring survey were sun-dried. The threshing method was not recorded. The results shown in the third panel of Figure 4 indicate a moderate incidence

Table 2. Performance of village milling systems in technical evaluation trials using dry, clean paddy. Bicol River Basin, Philippines, 1976–77 wet and dry seasons.

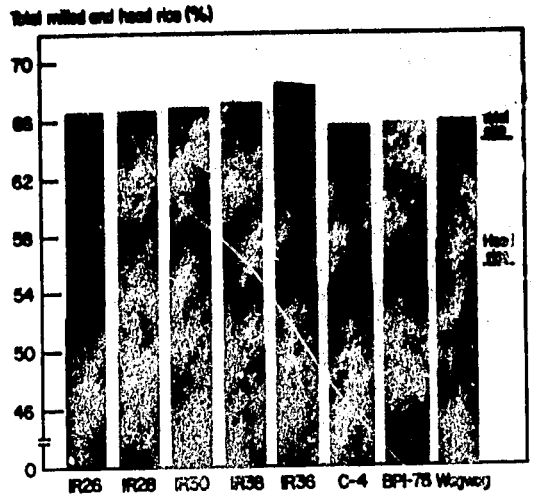
Milling system	Quantity (t) of paddy milled			Total milled rice (%)			Head rice (%)		
	Wet	Dry	Av	Wet	Dry	Av[a]	Wet	Dry	Av[a]
Steel huller									
Dycoco RM	1.0	1.0	1.0	63.5	67.2	65.5 cd	21.6	61.0	42.1 d
Rutta RM	0.6	0.8	0.7	63.3	63.2	63.1 de	29.9	34.1	32.0 e
Olanó RM	0.8	1.0	0.9	64.4	70.5	67.6 ab	38.7	57.7	48.0 bcd
Torres RM	1.0	1.0	1.0	66.8	71.3	68.7 a	26.4	64.9	44.6 cd
Multiple steel huller	0.4	1.0	0.7	65.8	68.2	68.2 a	44.2	58.2	51.4 bcd
IRRI experimental single-pass steel huller	0.4	0.4	0.4	64.5	65.2	64.8 d	54.6	54.7	54.4 bc
Storis disc-steel huller combination	1.0	1.0	1.0	65.9	67.9	67.0 bc	53.4	55.1	55.4 b
Rubber roll-steel huller combination	1.0	1.0	1.0	68.5	69.2	69.2 a	63.7	77.7	71.2 a

[a]Adjusted to purity based on laboratory analysis. Any two means followed by a common letter are not significantly different at the 5% level.



4. Effects of paddy purity, damage, and immaturity on total rice recovery; and of moisture content and cracking on head rice recovery. 150 paddy samples, Bicol River Basin, Philippines, 1977–78.

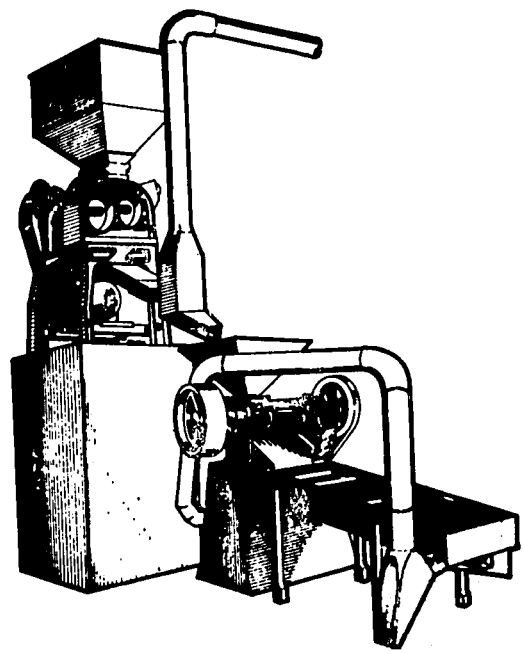
of damaged kernels and a relatively minor influence on total milling recovery. The regression in the second panel demonstrates that immature kernels decrease milling recovery by 15% for a 1% increase in weight of immature kernels. Immature kernels are a result of uneven maturity, which in turn is primarily under genetic control. Modern photoperiod-insensitive varieties appear to have a higher proportion of immature kernels than traditional varieties. Although most immature grains can be removed through proper cleaning before milling, village millers in the Philippines do not use



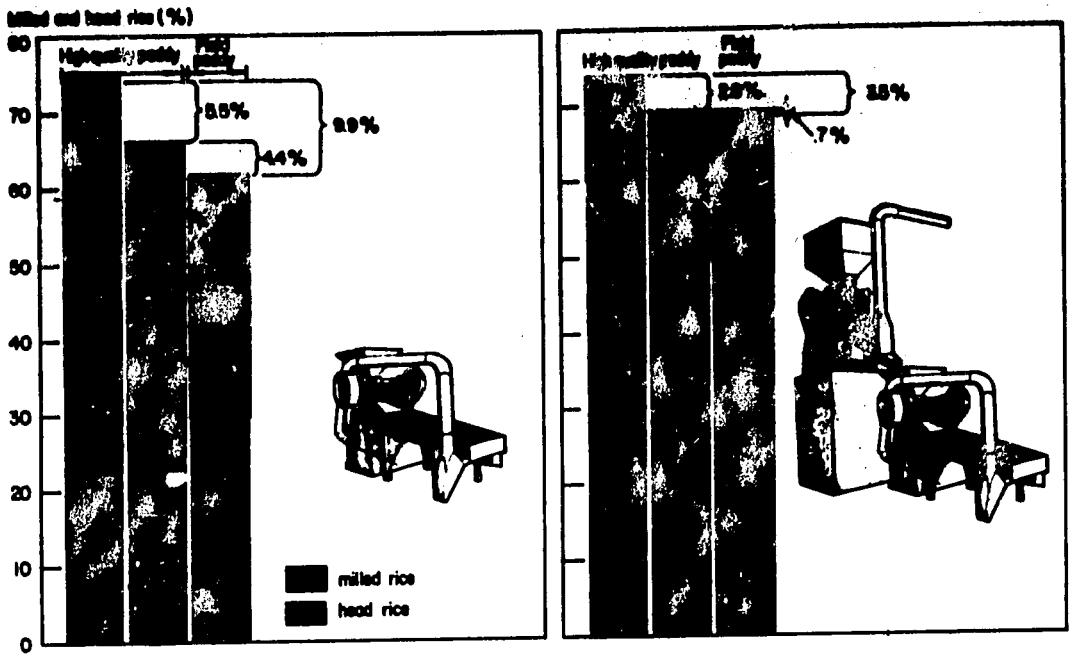
5. Field milling characteri 'cs of selected varieties, Bicol region, Philippines, 1977–78.

cleaning equipment. Farmers are also opposed to sale of paddy with immature grains removed because removal of such grains reduces the weight of the paddy but gives no compensating price increase for better quality.

Impurities like stones, sand, chaff, and sticks also affect total milling recovery to a greater

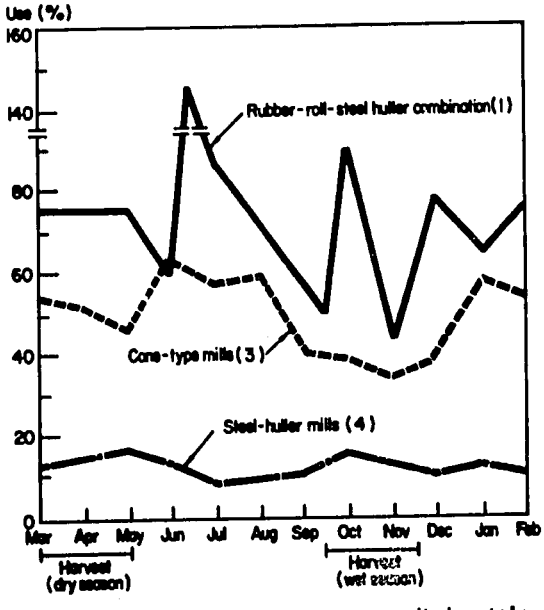


6. The rubber roll huller-Engelberg-type steel roll whitener rice mill combination, Bicol region, Philippines, 1978.



7. The recovery gap for two village processing systems, Bicol region, Philippines, 1978.

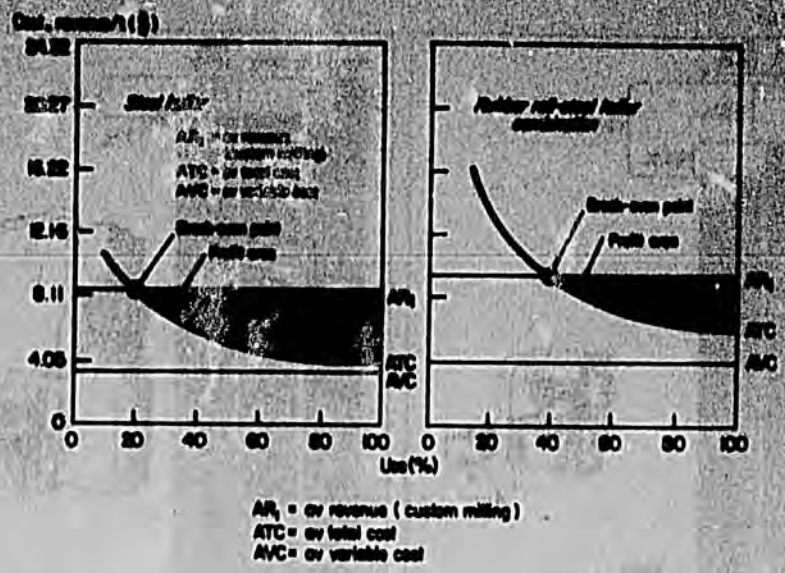
degree than do immature kernels. Every 1% increase in the purity of paddy entering the village mill increases recovery rate by 33%. Most impurities can also be removed, but no village mill observed used cleaning equipment. Impurities also increase the repair and maintenance problems of the milling operation.



8. Observed use of rice mills included in monitoring study, Bicol River Basin, Philippines, 1977–78. The figures in parentheses denote the number of units observed.

The influence of variety on milling performance is shown in Figure 5. In general, the IR varieties gave a high degree of recovery, particularly IR36, which had both high head- and total milled-rice recovery rates.

Improving village systems. In the course of the Bicol project, a modernized village milling unit consisting of a single rubber-roll husker connected in series with a traditional steel-roll huller used for whitening was evaluated (Fig. 6). Milling recovery rates of this milling system are compared with those of traditional milling systems in Figure 7. Two types of paddy were used in this comparative assessment. With clean, dry, high-quality paddy, the traditional milling system achieved a total milling recovery of 66.2% and 27% head rice. Using the same good-quality paddy, the modernized mill achieved a milling recovery of 69.2% with a head-rice recovery of 50%. Improving the quality of paddy entering each system improved recovery rates by 4.4% for the traditional system and 0.7% for the modernized mill, com-



9. Average total cost and revenue for two village milling systems, Bicol River Basin, Philippines, 1977–78.

pared with results obtained using field-grade paddy. When good-quality paddy was milled by the traditional system, head-rice recovery decreased.

Milling samples of good-quality paddy in the laboratory revealed the potential upper limit for milling recoveries. The modernized system gave only 2.1% less total milled rice than controlled laboratory milling. The milling gap between realized and potential yields for the traditional mill was 9.9% with field-grade paddy and 5.5% with a controlled paddy sample. These observations indicated that improved handling of paddy during the threshing, drying, and storage phase before milling can improve overall milling recovery in existing village milling systems by approximately 4.4%. A modernized village milling system would further improve performance by 3.0%. Introduction of improved technology without a commensurate increase in the quality of input paddy could improve recovery by about 5%. Combining improved technology and better quality paddy results in the most significant increase — 7.4%.

Economics of village milling systems. Most village-level systems operate from 2 to 3 hours a day, with a maximum milling rate during the period May to October (Fig. 8). Overall use was 12% of rated capacity. The modernized milling unit operated at approximately 77% of rated capacity on an annual basis. In addition, it charged $3/t of paddy more than traditional systems did for custom milling. Users preferred the higher quality and recovery rates achieved by this system. Figure 9 shows the comparative economics of the traditional system and of the modernized unit. While the annual use rate necessary to operate the modernized unit profitably is higher than that for traditional mills, there is a parallel increase in the profitability per ton. The additional investment required for converting a traditional steel huller of 0.5t/hour capacity to the modernized system is approximately $900. Variable costs are approximately $0.80/t higher. At normal operating levels an average village mill would be able to justify the investment after milling 350 t paddy. For normal mills, that would require about 3 years of operation.

Constraints on rice yields

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ECONOMIC CONSTRAINTS

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Research on constraints to high rice yields in farmers' fields has been under way since 1974 in 10 locations in 6 countries of Asia. The projects have followed the general approach outlined in previous annual reports. The empirical findings to date are summarized here.

Project objective. The objective of the constraints research was to evaluate the performance of the *currently available* high-yielding rice technology in farmers' fields in those situations where some components of the technology had been adopted. The project sought to identify the potential farm yield and compare it with the farmer's actual yield, and to seek reasons for the difference between the two. The two components sought were:

1. the biological or physical factors (inputs) that, added to the farmer's practices, resulted in higher yields;
2. reasons why the farmers were not using the inputs at the level and in the way that would achieve the potential yield.

For convenience the two components are referred to as *biophysical constraints* and *socioeconomic constraints*.

A large number of researchers in six countries were involved in the project. IRRI coordinated the efforts, and scientists at the individual locations conducted the actual research. (A publication containing a paper on each area is available at IRRI.) Research planned in 1974 was under way in many areas in 1975. It continues in a number of the original sites and has been extended to others.

The yield gap. The yields of 410 wet-season trials averaged 3.6 t/ha with farmers' inputs and 4.5 t/ha with high inputs. The average yield gap was 0.9 t/ha (Table 1).

The yield gap in 5 sites was small (av 0.4–0.6 t/ha). Two sites with a small yield gap—Subang (Indonesia) and the dry zone of Sri Lanka—had very low farmers' yields. A third area, Camarines Sur (Philippines), had intermediate farmers' yields. In these three areas the researchers' treatments did not raise yields substantially above the farmers' low level. In Yogyakarta (Indonesia) and Taiwan, farmers' wet-season yields were high (about 5 t/ha); the researchers' high levels of inputs failed to raise yields further because farmers were already using high inputs.

In the remaining 5 sites, the wet-season yield gap was 0.9 t/ha or more, indicating considerable potential for increased yields. Among the 5, Joydebpur (Bangladesh) had the lowest farmers' yield, 2.9 t/ha. The other sites had 3.4–4.0 t/ha. In Laguna, Philippines, the yield gap of 1.8 t/ha was 0.6 t/ha more than that of the next poorest site.

Dry-season constraints experiments were conducted in 372 farmers' fields at the 10 sites between 1975 and 1977. Farmers' yields averaged 4.3 t/ha, and yields with the high inputs were 5.6 t/ha; the average yield gap was 1.3 t/ha

Table 1. Wet-season trials by year and average yields in constraints experiments in farmers' fields in 6 countries of Asia, 1974–77.

Site	Wet-season trials (no.)				Yield (t/ha)		
	1975	1976	1977	Total	Farmers'	High input	Gap
Subang, Indonesia	—	4[a]	24	28	1.4	2.0	0.6
Dry zone, Sri Lanka		12	20	32	2.9	3.4	0.5
Yogyakarta, Indonesia	3	3	35	41	4.7	5.1	0.4
Taiwan	3	16	18	37	5.0	5.6	0.6
Joydebpur, Bangladesh	3	20[b]	29[c]	52	2.9	3.8	0.9
Camarines Sur, Philippines	6	6	27	39	3.9	4.5	0.6
Nueva Ecija, Philippines	11	9	37	67[d]	3.4	4.5	1.1
Laguna, Philippines	20	13	6	49[e]	3.6	5.4	1.8
Iloilo, Philippines		7	23	30	3.8	5.0	1.2
Central Plain, Thailand	6	6	20	36[f]	4.0	4.9	0.9
All sites	52	96	219	410[g]	3.6	4.5	0.9

[a]In addition, 20 simple trials were conducted but they involved the high level of only 1 factor. [b]Includes 9 aus season trials and 11 aman season trials. [c]Includes 11 aus season trials and 18 aman season trials. [d]Includes 10 trials in 1974. [e]Includes 16 trials in 1974. [f]Includes 3 trials in 1974. [g]Includes 23 trials in 1974.

Table 2. Dry-season trials by year and average yields recorded in constraints experiments in farmers' fields in 6 Asian countries, 1975–78.

Site	Dry-season trials (no.)				Yield t/ha		
	1975	1976	1977	Total	Farmers'	High input	Gap
Dry zone, Sri Lanka		11	20	31	2.5	2.9	0.4
Subang, Indonesia		24	40	64	3.8	4.4	0.6
Taiwan		3	34	37	6.6	7.3	0.7
Joydebpur, Bangladesh		6	23	29	3.6	4.6	1.0
Yogyakarta, Indonesia	2	2	36	38	4.8	6.1	1.3
Iloilo, Philippines		2	17	19	3.9	5.3	1.4
Camarines Sur, Philippines	3	5	20	28	4.0	5.8	1.8
Central Plain, Thailand	7	6	26	39	4.2	6.1	1.9
Laguna, Philippines	9	12	19	40*	4.5	6.5	2.0
Nueva Ecija, Philippines	3	9	28	40	4.6	6.8	2.2
All sites	24	80	262	372*	4.3	5.6	1.3

*Includes 6 1974 trials.

(Table 2). There was a low positive correlation between farmers' yields and yield gap (r = 0.17). Except in the dry zone of Sri Lanka, the yield with high inputs was higher in the dry season than in the wet, the differences between the seasons averaging 1.1 t/ha. The dry-season yield gap was also larger than the wet-season gap everywhere except in the dry zone of Sri Lanka.

In 3 sites the yield gap in the dry season was small (about 0.5 t/ha). In the dry zone of Sri Lanka and in Subang, both farmers' yields and the yield gap were small, indicating that the technology applied could not overcome the constraints. In Taiwan the gap was small because the farmers' yields were already close to the potential yield.

The dry-season yield gap in 3 other sites — Joydebpur, Iloilo, and Yogyakarta — was about 1 t/ha. Iloilo and Yogyakarta had somewhat higher farmers' yields and slightly larger yield gaps.

The yield gap in the remaining 4 sites was approximately 2 t/ha, and in all cases the farmers' yields averaged 4.0 t/ha or higher. These areas, which demonstrate the largest unrealized potential for yield increases, already have fairly high farmers' yields.

Biophysical constraints. The constraints experiments were designed to separate the yield gap into components attributable to each of the variable factors tested. An IRRI handbook presents the methodology of the integrated experiment-survey approach used in the rice constraints project. In each site, the researchers decided before the experiment which farmer practices or input levels should be changed to achieve higher yields. Each participating research group was urged to choose the two to four factors that appeared to be most limiting in its area.

Fertilizer and insect control were the most frequently used test factors. Others were weed control, variety, plant spacing, land preparation, organic manure, and separate fertilizer elements. The experimental design permitted direct allocation of the total yield gap to each test factor. The wet-season contributions to the yield gap are shown in Table 3. The total contributions do not equal the yield gap in Table 1 because

1. there is usually a residual that is not attributable to individual factors; and

2. the total gap in Table 1 was calculated from three types of trial (complete factorial, minifactorial, and supplemental) and the three together cannot be used to determine separate contributions to the gap.

The contributions of various factors were determined from 272 wet-season experiments. Fertilizer, a factor in all trials, contributed an average of 0.4 t/ha to the wet-season yield gap (Table 3). High levels of insect control, tested in 254 trials, contributed an average of 0.4 t/ha to the gap. More intensive weed control than that practiced by the farmers, tested in 229 trials, contributed 0.1 t/ha.

Fertilizer was tested in 187 dry-season trials

[illegible]

Site	Year	Trials (no.)	Contribution (t/ha) to yield gap			Others
			Fertilizer	Weed control	Insect control	
Jaydebpur, Bangladesh	[illegible]a	8	0.1	−0.1	0	
	[illegible]a	11	1.2	0.1	0.2	
	1977b	9	0		0	(interactions[c])
	1977a	6	0.6		0.3	0.5 (sulfur[c])
Yogyakarta, Indonesia	1976–5	3	0.7	−0.1	−0.1	
	1976–6	3	−0.1	0.3	−0.1	
	1976–7	8	0.2		0.1	
Subang, West Java, Indonesia	1976–6	4	0.1		0.3	−0.1 (land preparation)
	1976–7	4	0.2		1.6	
Dry zone, Sri Lanka	1976–6	12	0	0.1	0.7	0.2 (depth) 0 (spacing)
	1976–7	20	0.2	0.1	−0.2	
Taiwan	1976	3	0.7	0.2	0.1	0.3 (spacing) 0.2 (manure)
	1977	12	0.3			
Central Plain, Thailand	1974	3	0.7	0.3	0.3	
	1975	6	0.5	0.1	0.2	
	1976	6	0.2	0.1		
Laguna, Philippines	1974	10	1.1	0.2	0.7	
	1975	20	0.7	0.3	0.7	
	1976	13	0.7	0.2	1.4	
	1977	6	0.2	0.2	0.9	
Nueva Ecija, Philippines	1974	10	−0.1	0.2	0.5	0.1 (land preparation)
	1975	11	0.3	0.1	0.2	
	1976	9	0.6	0.0	0.9	
	1977	24	0.4	0.0	0.5	
Camarines Sur, Philippines	1975	6	0.4	0.1	0.6	
	1976	6	0.4	0	0.2	
	1977	15	−0.1	−0.1	−0.2	
Iloilo, Philippines	1976	7	0.7	0.4	0.5	
	1977	16	0.6	0.3	0.4	
Av (no. of trials)			0.4 (272)	0.1 (229)	0.4 (254)	
Standard deviation[d]			0.32	0.14	0.45	

[a]Aus season. [b]T. aman season. [c]Interactions were significant in this case. Where individual contributions are shown as 0, only interactions were significant. [d]Calculated as the simple (unweighted) standard deviation of the averages shown in each line. The averages shown in the preceding line were calculated as unweighted averages and as averages weighted by the number of trials in each site, but in no case did the averages by the 2 methods differ by more than 0.04 t/ha.

(Table 4); its average contribution to the gap was 0.9 t/ha. The high level of insect control contributed an average of 0.6 t/ha in 195 trials. Weed control, tested in 163 trials, contributed an average of 0.2 t/ha.

Inadequate fertilizer in the dry season was the most important of the measured yield constraints; insect control, the second. In the wet season, the two factors were equal, but their contributions were smaller than in the dry season. The contribution of insect control was more variable than that of fertilizer. High insect control had a higher coefficient of variation (73% in the dry season, 113% in the wet) than fertilizer (58% in the dry season, 80% in the wet).

The high levels of weed control tested increased yields by an average of 0.2 t/ha in 163 dry-season trials and 0.1 t/ha in 229 wet-season trials. These relatively small contributions may be attributed in part to:

1. the farmers' adequate control of weeds;
2. the failure of high weed control to do better than the farmers' inadequate control;
3. the absence of a weed problem in experimental fields;
4. the extra care farmers took to remove weeds because researchers were present.

[illegible]

Site	Year	Trials (no.)	Contribution (t/ha) to the yield gap			
			Fertilizer	Weed control	Insect control	Others
Jaydebpur, Bangladesh	1975–76	6	1.0	0.4		
	1976–77	28	0.3	0.1	0.1	
Yogyakarta, Indonesia	1976	2	1.6	0.4	−0.3	
	1976	2	2.0		0.6	
	1977	6	0.7		0.2	
Subang, West Java, Indonesia	1976	4	0.3		0	0 (land preparation)
	1977	40			0.7	
Dry zone, Sri Lanka	1976	11	0.2	−0.2	0.1	−0.2 (spacing)
	1977	5	0	0.2	0.1	
Taiwan	1976	3	0.5	0.2	0.1	
	1977	12	0.4			0.3 (spacing) 0.2 (manure)
Central Plain, Thailand	1975	7	1.5	0.4	0.3	
	1976	6	1.7	0.5		
	1977	8	1.2	0.2		0.4 (variety)
Laguna, Philippines	1974	6	0.9	0.3	1.5	
	1975	9	1.2	0.3	1.0	
	1976	12	1.0	0.2	0.6	
	1977	6	0.9	−0.2	0.9	
Nueva Ecija, Philippines	1975	3	0.2	0.5	0.2	
	1976	9	1.4	0.3	0.8	
	1977	16	0.9	0.2	1.0	
Camarines Sur, Philippines	1975	3	1.1	0.1	0.4	
	1976	5	1.3	0.2	0.2	
	1977	12	1.2	0.3	1.0	
Iloilo, Philippines	1976	2	1.6	0.4	0.2	
	1977	9	1.2	0.2	0.3	
Av (no. of trials)		(224)	0.9 (187)	0.2 (163)	0.6 (196)	
Standard deviation			0.52	0.19	0.44	

Socioeconomic constraints. Experiments have shown that in many cases it is possible to increase rice yields in farmers' fields by 1 t/ha or more. The socioeconomic constraints part of the study sought to explain why farmers were not achieving that yield potential.

Farmers do not use a higher level of weed control because the additional output is so small that it is not obvious. In only 6 out of 32 season-site cases did the increased yield with high weed control exceed 300 kg/ha. In 4 out of 32 cases, the yield with high weed control was lower than that with farmers' weed control. Farmers are unlikely to be impressed by small yield gains (5% or less of their yield levels), even without considering the relative costs of the high and existing practices of weed control.

The high levels of fertilizer and insect control, on the other hand, produced 3 or 4 times higher yields than the high weed control, and an economic analysis is required to determine whether they would be economically attractive. The economic analysis compared the profitability of the high input levels and the farmers' practices.

In the 239 wet-season experiments amenable to economic analysis, the farmers' yields averaged 3.5 t/ha and the yield gaps averaged about 1 t/ha (Table 5). The value of incremental rice output was calculated at prevailing local prices for each site and, in the case of the Philippine sites, was reduced by the prevailing share-based harvesting and threshing costs. The high inputs increased yields by 0.4 t/ha and output value by $50/ha or more in all cases.

The costs of the high input technology averaged 40% higher than those of farmers' inputs, but in some cases the difference was much greater

Table 6. Economic comparisons of wet-season yields obtained with farmers' and high levels of inputs in constraints experiments in farmers' fields in 6 Asian countries, 1974–77.[a]

Site	Trials (no.)	Yield[b] (t/ha) Farmers'	Yield[b] (t/ha) Gap	Increased output value[c] ($/ha)	Input cost ($/ha) Farmers'	Input cost ($/ha) Increase to high	Increased net benefits from high inputs ($/ha)	B:C[d] of increased inputs
Joydebpur, Bangladesh	52	2.96	0.91	143	36	39	104	3.67
Yogyakarta, Indonesia	14	5.38	0.39	56	22	88	-32	0.64
Subang, Indonesia	8	3.06	1.00	122	132	66	56	1.86
Dry zone, Sri Lanka	17	2.75	0.89	168	80	140	28	1.20
Taiwan	9	4.90	0.40	130	834[e]	161	-31	0.81
Central Plain, Thailand	18	3.66	1.02	134	26	160	-25	0.84
Laguna, Philippines	41	3.75	1.77	209	51	183	26	1.14
Nueva Ecija, Philippines	29	3.51	1.10	143	73	104	39	1.38
Camarines Sur, Philippines	27	3.39	0.51	61	52	136	-75	0.45
Iloilo, Philippines	23	3.51	1.30	156	51	151	5	1.03
All sites	239	3.48	1.03	141	86	118	23	1.19

[a]Exchange rates used: Bangladesh, TK14 = US$1; Indonesia, Rp415 = US$1; Sri Lanka Rs8 = US$1; Taiwan, NT$38 = US$1; Thailand B20 = US$1; Philippines, P7.3 = US$1. Prices as shown in Table 9. [b]Yields may differ from corresponding data in Table 1, because the number of experiments differs. [c]In Philippine sites, harvesting costs are considered but in other sites they are not. [d]B = benefit, C = cost. [e]Includes labor cost of farmers' practices.

er. In the central plain of Thailand, the high inputs cost 6 times as much as the farmers' inputs. In Laguna, Philippines, they cost 3.6 times as much.

In four sites — Yogyakarta, Taiwan, the central plain of Thailand, and Camarines Sur — the added input costs in the wet season exceeded the value of added yields. Farmers would not be attracted to the high levels of inputs because their own practices were more profitable. In the remaining 6 sites, each additional dollar invested in inputs returned $1.50. In Joydebpur, the rate of return was substantially higher.

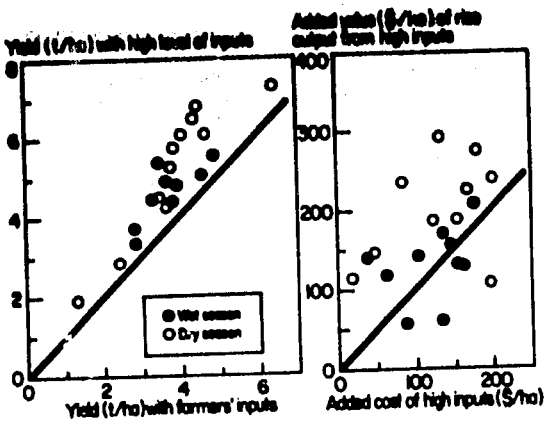
In the dry season, the high level of inputs increased net benefits in 9 out of 10 sites (Table 6). In about half, the farmers spent more on inputs in the dry season than in the wet. Incremental output averaged 0.4 t/ha more in the dry season, and, as a result, the average increase in net benefits was higher in 7 sites. In the 9 sites where net benefits increased, a $1 investment in the high inputs led to an average $1.80 return. In 4 sites — Joydebpur, Yogyakarta, Subang, and Nueva Ecija — the B-C ratio exceeded 2:1.

Figure 1 summarizes the economic results. On the left, the yield with high inputs is plotted against the yield with farmers' inputs. The vertical distance above the line shows the yield gap,

Table 6. Economic comparisons of dry-season yields obtained with farmers' and high levels of inputs in constraints experiments in farmers' fields in 6 Asian countries, 1974–77.[a]

Site	Trials (no.)	Yield[b] (t/ha) Farmers'	Yield[b] (t/ha) Gap	Increased output value[c] ($/ha)	Input cost ($/ha) Farmers'	Input cost ($/ha) Increase to high	Increased net benefits from high inputs ($/ha)	B:C[d] of increased input
Joydebpur, Bangladesh	29	3.62	0.94	145	77	47	98	3.09
Yogyakarta, Indonesia	12	4.22	1.63	236	90	84	152	2.81
Subang, Indonesia	44	3.99	0.69	115	14	19	96	6.05
Dry zone, Sri Lanka	17	2.99	0.58	108	63	201	-93	0.54
Taiwan	8	5.94	0.64	186	755[e]	124	62	1.50
Central Plain, Thailand	17	3.94	2.11	225	41	171	54	1.32
Laguna, Philippines	28	4.43	2.01	274	81	188	86	1.46
Nueva Ecija, Philippines	19	4.56	2.28	294	111	134	160	2.19
Camarines Sur, Philippines	20	3.51	2.07	242	57	207	34	1.17
Iloilo, Philippines	11	3.84	1.60	187	58	182	4	1.03
All sites	205	4.00	1.40	192	87	119	73	1.61

[a]Exchange rates used: Bangladesh, TK14 = US$1, Indonesia, Rp415 = US$1, Sri Lanka, Rs8 = US$1; Taiwan, NT$38 = US$1; Thailand, B20 = US$1; Philippines, P7.3 = US$1. Prices as shown in Table 9. [b]Yields may differ from corresponding data in Table 1, because the number of experiments differs. [c]In Philippines sites, harvesting costs are considered but in other sites they are not. [d]B = benefit, C = cost. [e]Includes labor cost of farmers' practices.



1. Yield gap and economics of the yield gap in the wet and dry seasons. Each point represents the average results from 1 of 10 sites in 6 Asian countries, 1974–77.

which is positive in every case. The economics of the gap is summarized on the right side of the figure. Points below the line are sites where the farmers' practices were more profitable than the high input practices. The figure shows a modest yield gap in the wet season. But often it is not economically attractive for farmers to reduce the gap by applying the high rates of fertilizer and insect control. In the dry season, the gap is larger and in most cases would be profitable to reduce.

The economic analysis can be extended one step further to evaluate the costs and benefits of each input and although this analysis is not possible for all trials, the available data are summarized.

The added costs for and returns from fertilizer and insect control in the wet season are shown in Table 7. The high level of insect control usually entails a much greater increased cost over the farmers' level than the high level of fertilizer, partly because farmers apply relatively more fertilizer than insecticides and partly because the cost of insect control needed to achieve maximum yields is relatively higher than the cost of needed fertilizer. As a result, the high level of insect control added more to costs than to returns in 6 of 10 sites in the wet season. The high levels of fertilizer decreased net returns in 3 sites, but on the average added $20/ha to net returns with an average B:C of 1.7:1 on the added expenditure.

The pattern of results for the dry season is similar to that for the wet but is somewhat more favorable because the added yield contributed by high input was greater in the dry season (Table 8). In one case, the high fertilizer reduced net benefits, but in nearly all other sites, it raised net returns by a substantial amount (av $71/ha). The average B:C of the high fertilizer practice compared with that of the farmers' practice was 2.6:1. High insect control, on the other hand, reduced net returns in 6 cases and barely covered its cost on the average, yielding a B:C of 1.2:1.

The breakdown by inputs shows that in the

Table 7. Added cost of and added return[a] from using high levels of fertilizer and insect control in wet-season constraints experiments in farmers' fields in 6 Asian countries, 1974–77.

Site	Trials (no.)	Fertilizer: Av increase ($/ha) Cost	Fertilizer: Av increase ($/ha) Net return	Fertilizer B:C[b]	Insect control: Av increase ($/ha) Cost	Insect control: Av increase ($/ha) Net return	Insect control B:C[b]
Joydebpur, Bangladesh	20	23	68	3.96	7	24	4.43
Yogyakarta, Indonesia	14	35	−12	0.66	43	−42	0.02
Subang, Indonesia	8	19	−10	0.47	27	93	4.44
Dry zone, Sri Lanka	32	9	15	2.67	53	−27	0.49
Taiwan	12	23	49	3.13		n.t.[c]	
Central Plain, Thailand	17	63	23	1.37	136	−103	0.24
Laguna, Philippines	41	15	59	4.93	160	−34	0.79
Nueva Ecija, Philippines	39	35	7	1.20	81	−10	0.88
Camarines Sur, Philippines	20	52	−56	−0.08	76	−43	0.43
Iloilo, Philippines	23	45	17	1.38	95	52	1.55
All sites	226	30	20	1.67	88	−16	0.81

[a]Currencies converted at the rates shown in footnote to Table 5. [b]B = benefit, C = cost. [c]Factor was not tested.

Table 8. Adjusted average [illegible] returns from using high levels of fertilizer and insect control in dry season [illegible] farmers' fields in 9 Asian countries, 1976–77.

Site	Trials (no.)	Fertilizer: Av increase (B/ha) Cost	Fertilizer: Av increase (B/ha) Net return	Fertilizer: B:C[a]	Insect control: Av increase (B/ha) Cost	Insect control: Av increase (B/ha) Net return	Insect control: B:C[a]
Jaydebpur, Bangladesh	28	31	42	2.35	5	10	3.00
Yogyakarta, Indonesia	10	66	121	2.82	22	3	1.14
Sukamandi, Indonesia	4	35	8	1.22	4	-4	0
Sukamandi, Indonesia	40[b]		n.t.[c]		7	60	8.57
Dry zone, Sri Lanka	-10	50	-34	0.32	96	-77	0.19
Taiwan	12[b]	34	68	2.00		n.t.[c]	
Central Plain, Thailand	8	64	67	1.20	151	-121	0.20
Central Plain, Thailand	10[b]	36	135	5.00		n.t.[c]	
Laguna, Philippines	10	16	113	7.20	170	74	0.56
Nueva Ecija, Philippines	10[b]	38	134	4.30	87	34	1.39
Camarines Sur, Philippines	20	82	60	1.80	116	-34	0.71
Iloilo, Philippines	11	68	62	1.94	108	-79	0.38
All sites	169[b]	46	71	2.00	65	12	1.18

[a] B = benefit, C = cost. [b] Fertilizer and insect control were not tested together in these cases, so the total number of trials included for fertilizer was 169 and for insect control was 173. [c] Factor not tested.

dry season the application of higher levels of fertilizer gives a sufficiently high return above added costs to generate a strong incentive for its use. High insect control is not sufficiently attractive to make farmers want to use it. The economic analysis indicates that the use of fertilizer levels higher than those currently used by farmers offers the best opportunity for increasing yields in the dry season.

Price incentives and the institutional setting. The literature gives considerable attention to the potential impact of institutions, tenure, credit limitations, and relative prices as factors influencing the farmer to adopt yield-increasing methods. This economic analysis used the prices prevailing in the area at the time of the study. It excluded the impact of institutions, cost of credit, or tenure conditions other than land ownership — factors that varied from farmer to farmer. It is clear, however, that such factors are important in the decision making of individuals.

Prices of rough rice and urea fertilizer represent the relative incentive to use modern technology (Table 9). The ratio of the prices varies greatly across the sites studied. In the Philippines it takes 1.7 kg paddy rice to purchase 1 kg urea; in Thailand, 1.5 kg; in Indonesia, 1.2 kg. In Sri Lanka it takes only 0.7 kg and in Taiwan 0.5 kg. The ratios directly affect the farmers' incentive to use urea and, therefore, affect the

Table 9. Prices and interest rates on credit, distribution of farms by tenure, and share-tenancy conditions prevailing in the areas where constraints studies were conducted, 1977.

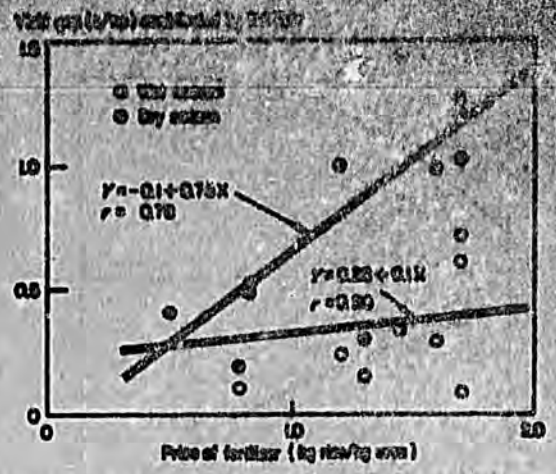
Site	Price (B/kg) Paddy	Price (B/kg) Urea	Prevailing interest rate on loans (%/yr) Private	Prevailing interest rate on loans (%/yr) Institutional[a]	Distribution of farms by tenure[b] (%) Owner	Distribution of farms by tenure[b] (%) Fixed rent	Distribution of farms by tenure[b] (%) Share rent	Prevailing share (%) of tenant Output	Prevailing share (%) of tenant Input
Jaydebpur, Bangladesh	0.16	0.11	100	9	70	1	29	50[c]	100
Yogyakarta, Indonesia	0.15	0.18	n.a.[d]	12	65	5	30	50	100
Sukamandi, Indonesia	0.14	0.18	n.a.	12	69	16	28	50	100
Dry zone, Sri Lanka	0.19	0.13	n.a.	10	69	29	29	50	50
Taiwan	0.32	0.16	13	10	100	0	0	n.a.	n.a.
Central Plain, Thailand	0.11	0.16	24	13	62	31	7	67	100
Laguna, Philippines	0.14	0.24	50	13	7	64	27	50	50
Nueva Ecija, Philippines	0.15	0.24	50	13	9	64	3	50	50
Camarines Sur, Philippines	0.14	0.24	50	13	10	68	22	75	100

[a] Rates were those for rice or agricultural credit programs. The difference between the rice and [illegible] in farms with [illegible] of some private lenders. [b] Prevailing practice in the area. In Y. [illegible] of owner [illegible] given to the landlord, in the tenant is left with 25%. [c] [illegible] [d] n.a. = information not available or credit not generally available from this source.

yield gap. Figure 2 illustrates the effect. In the [illegible] where the price of urea relative to that of rice is high, the gap contribution to fertilizer is also high, especially in the dry season. The linear regression line that describes the relationship indicates that a doubling of the real price from 1.0 to 2.0 increases the yield gap by 0.75 t/ha in the dry season. The correlation is much less in the wet season ($r = 0.2$) than in the dry ($r = 0.78$).

In addition to the high cost of fertilizer in most study areas, farmers who borrow from private credit sources must pay interest rates of 50% or more per year. Tenants who are paying for their land on a share basis in which they give 25–50% of output to the landlord and pay for all the inputs have a further disincentive to fertilizer use.

Table 10 shows the production that would be needed to pay for 1 kg urea in each site under the prevailing prices and institutional arrangement identified in Table 9. Owners using the institutional credit available in most countries at an interest rate of 9–12%/year have slightly higher effective fertilizer prices. Farmers who rent their land on a share basis in which the landlord pays none of the input cost (as in Joydebpur, Yogyakarta, Subang, Central Plain, and Camarines Sur) end up paying substantially higher effective prices for their fertilizer. If those share-tenants also borrow money from private credit sources they may, in the end, pay up to three times as much for urea as the stated price, as in Joydebpur. Such high effective prices would have a strong disincentive effect.



2. Relationship of real price of fertilizer to the yield gap contributed by fertilizer. Six Asian countries, 1978.

Fortunately only about 30% of the sample farmers report being under tenure terms that result in high effective fertilizer prices. But any combination of high-interest-rate private credit and disincentive-producing share tenure will reduce interest in the use of fertilizer. The reduced incentives mean that gross B-C ratios such as those shown in Tables 7 and 8 must be 2 or 3 rather than just over 1.

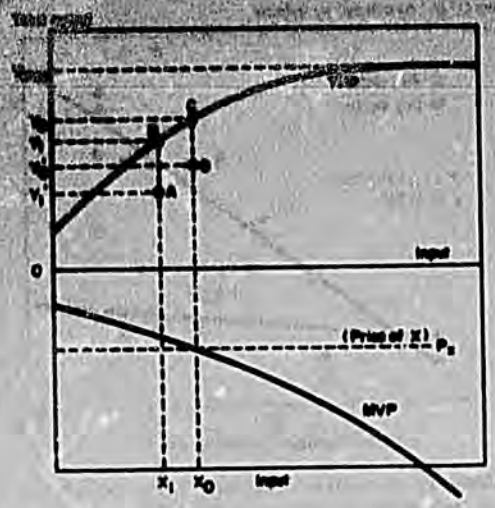
Production inefficiency as a constraint to rice yields. The failure of farmers who face the same production function to achieve the same level of efficiency arises from two sources:

1. the failure to operate on the technically efficient production function;
2. the failure to apply the level of inputs

Table 10. Effective real prices of urea for farmers under different institutional arrangements in areas with constraints analysis, Asia, 1977.[a]

Site	Rice (kg) needed to pay for 1 kg urea				
	Owner self-financed	Owner institutional credit	Owner private credit	Share-tenant institutional credit	Share-tenant private credit
Joydebpur, Bangladesh	0.73	0.77	1.60	1.59	2.19
Yogyakarta, Indonesia	1.30	1.37	n.a.	2.84	n.a.
Subang, Indonesia	1.29	1.37	n.a.	2.73	n.a.
Dry zone, Sri Lanka	0.68	0.72	n.a.	0.72	n.a.
Tehran	0.80	0.83	0.84	n.a.	n.a.
Central Plain, Thailand	1.46	1.54	1.82	2.30	2.63
Laguna, Philippines	1.71	1.82	2.14	1.82	2.14
Nueva Ecija, Philippines	1.60	1.70	2.00	1.70	2.00
Camarines Sur, Philippines	1.71	1.82	2.14	2.43	[illegible]

[a] n.a. = not available.



3. Basic model used for measuring constraints imposed by technical and allocative inefficiencies.

required for maximum profits.

The first is referred to as *technical inefficiency* and the second is *allocative inefficiency*.

Figure 3 shows the basic model used to conceptualize the constraints imposed on rice production by technical and allocative efficiency in the one variable input case. Given the response function *TPP*, economic theory implies that, in a competitive market situation, a profit-maximizing farmer will choose to utilize X_0 level of input. At this point (*C* in Fig. 3) the marginal value product (MVP) of the input equals its marginal cost and the farm is both technically and allocatively efficient. However, it is rare for farmers to produce to this point, and the difference between point *C* and the farmers' actual yield may be considered in terms of technical and allocative efficiency.

The two efficiency criteria are defined:

$$\text{Technical efficiency } (E_t) = 1 - \frac{Y_1 - Y'_1}{Y'_1}$$

$$\text{Allocative efficiency } (E_a) = 1 - \frac{Y_0 - Y_1}{Y'_1}$$

The model also allows the yield gap to be estimated as defined in the constraints project. This is, simply, $Y_{max} - Y'_1$. Given the above measures, the yield gap on the individual farmer's field can be [illegible]

1. profit-seeking behavior (i.e. use [illegible] factors to maximize profit rather than yield) ($Y_{max} - Y_0$);
2. losses from allocative inefficiency ($Y_0 - Y_1$);
3. losses from technical inefficiency ($Y_1 - Y'_1$).

To use this model, the input and output data from all of the constraints experiments conducted in Nueva Ecija were pooled to estimate a fertilizer response function. Various environmental factors were included as variables in the model to reflect the effect of variability in the physical environment from farm to farm and season to season. The inputs controlled by the farmer were fertilizer (*F*), weed control (*W*), and insect control (*I*). The environmental factors were solar radiation (*SR*), typhoon (*DT*), late water stress (*SL*), and the three soil characteristics of organic matter (*OM*), texture (*T*), and extractable phosphorus (*EP*). Two other factors that are strongly influenced by environment, insect damage (*P*), and disease incidence (*D*), were also included. Finally, a dummy variable to reflect farmer efficiency (*DFF*) was set at zero for the treatments designed by researchers and at one for the treatments simulating farmers' practices. The final model used in the analysis is shown in Table 11.

Farmers' efficiency. Three different efficiency measures based on the production function were computed for each farmer. To obtain the measures of efficiency, the values of the environmental site variables for each farm were substituted into the production function, given a response function in terms of the managed variables *F*, *W*, and *I* specific for each function. Using these functions, the prices each farmer faced, and economic contracts specific to each farmer, the three measures of efficiency were determined. Twenty-five percent of the farmers studied had measured efficiencies within 20% of the production function. Similarly, allocative efficiency was low, with only 41% of the farmers being within 20% of the economic optimum. Considering an overall measure of efficiency, only 16% of the farms were within 20% of the

Table 11. Reduced model of the production function estimated from all sites combined, Nueva Ecija, Philippines, 1974 wet season–1977 dry season.

Managed and environmental independent variables	Symbol	Regression coefficient	Standard error	Beta coefficient
Constant		1400		
Applied fertilizer (quadratic)	F^2	−0.03823***	0.00830	−0.44865
Insect control cost (linear)	I_2	0.44480***	0.05439	0.09800
Weed control cost (linear)	W^2	0.23220	0.36088	0.00665
Age of seedlings	A	−7.57336***	2.57340	−0.03550
P x F	PF	−0.11722***	0.01344	−0.11640
Disease incidence index	D	−38.76035***	5.80816	−0.15355
D x F	DF	−0.21476***	0.4716	−0.10710
Soil organic matter (linear)	OM	419.98980***	44.93288	0.16069
Soil texture (linear)	T	−7.72252***	1.40883	−0.9439
Soil extractable P	EP	2.84150***	0.25342	0.13146
SL x F	SLF	−0.16814***	0.03081	−0.06369
Solar radiation	SR	88.29694***	10.83074	0.20378
SR x F	SRF	0.96664***	0.05085	0.88883
Dummy variable for typhoons	DT	−356.04570***	42.09757	−0.10782
Farmers' av fertilizer efficiency	DFF	−4.40944***	1.56472	−0.15861
Farmers' insect control efficiency	DI	−0.65650***	0.19714	−0.03820

production function and the economic optimum.

The average yield gap, measured across all experiments, is shown in Table 12. The gap was calculated by inserting the average value of environmental, and insect and weed control variables in the estimated production function (i.e., Table 11). The maximum yield level from fertilizer with researcher's efficiency was calculated and compared with the calculated yield with the average farmer's input level and efficiency. The total yield gap is then attributed to three factors — profit-seeking behavior, allocative *inefficiency*, and technical *inefficiency*. The average yield gap was calculated directly from the experiments and indirectly from the estimated production function for the average of all wet- and dry-season experiments. The wet-season yield gap of 0.9 t/ha was principally the result of technical inefficiency, which explains 78% of the gap. Of the 1.6 t/ha yield gap in the dry season, 63% and 31% were due to technical and allocative inefficiencies. The rest was from a lack of profit-seeking behavior.

BIOLOGICAL CONSTRAINTS

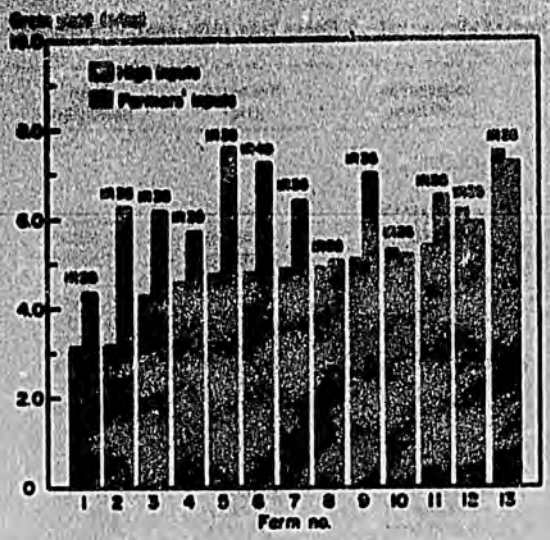
Agronomy Department

Nueva Ecija sites, dry season. Yield constraints experiments were conducted on 16 pump-irrigated farms in Nueva Ecija during the 1978 dry season. The levels of nitrogen applied by the

Table 12. Estimated yield gap and contribution of profit-seeking behavior, allocative inefficiency, and technical inefficiency. Nueva Ecija, Philippines, 1974 wet season—1977 dry season.

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

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



4. Variations in yield gap between farmers' fields in farm yield-constraints studies in Nueva Ecija, Philippines, 1978 dry season.

farmers ranged from 66 to 177 kg N/ha; the average rate of application was 112 kg N/ha. The average level of applied phosphorus was 32 kg P_2O_5/ha. Very few farmers applied potassium fertilizer. Weeds were controlled with herbicides, hand weeding, or both. The average number of applications of foliar insecticide was 3.2.

Farmers' yields ranged from 3.2 to 7.6 t/ha (Fig. 4), and averaged 5.0 t/ha (Table 13). With high inputs, yields ranged from 4.4 to 7.7 t/ha, averaging 6.3 t/ha. The average yield gap was 1.3 t/ha. Low yields from high inputs in some farms (1, 8, 10) were due mainly to stem rot infection at the ripening stage. Plots with high levels of applied nitrogen were more susceptible to stem rot disease than those with lower levels.

For the minifactorial trials, the average yield increase from high inputs was 1.5 t/ha (Table 14). To this yield gap, fertilizer contributed 1.0

Table 13. Average yields with farmers', high, and economically recoverable gap (ERG) input levels in yield constraints experiments in farmers' fields. Philippines, 1978.

Province	Sites (no.)		Yield (t/ha)			
	Irrigated	Rainfed	Farmers' inputs	High inputs	ERG inputs	Gap
			Dry season			
Nueva Ecija	13	0	5.0	6.3	—	1.3
Iloilo	9	0	4.1	5.9	—	1.8
			Wet season			
Laguna	8	0	3.2	3.7	3.1	0.5
Nueva Ecija	7	4	4.4	5.1	5.0	0.7
Camarines Sur	12	0	3.5	4.2	4.0	0.7
Iloilo	6	1	3.7	5.1	4.4	1.4

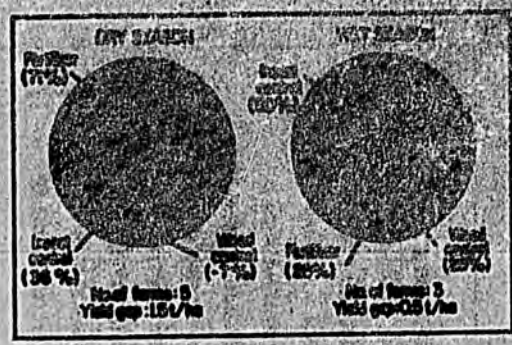
Table 14. Relative contribution of fertilizer, weed control, and insect control to increased rice yields in farmers' fields. Philippines, 1978.

Province	Sites (no.)		Yield (t/ha)			Contribution[a] (t/ha) of			
	Irrigated	Rainfed	Farmers' inputs	High inputs	Difference	F	WC	IC	R
			Dry season						
Nueva Ecija	5	0	5.2	6.7	1.5	1.0	−0.1	0.5	0.1
Iloilo	4	0	5.0	6.7	1.7	0.5	−0.1	0.6	0.7
			Wet season						
Laguna	2	0	2.4	3.3	0.9	0.6	0.4	0.5	−0.6
Nueva Ecija	2	1	4.8	5.3	0.5	0.2	0.2	0.4	−0.3
Camarines Sur	2	0	3.7	4.1	0.4	0.1	−0.4	0.2	0.5
Iloilo	2	1	4.3	6.6	2.3	1.1	0.7	1.6	−1.1

[a]Measured as yield decrease from high input due to a reduction from high to farmers' level of each input. F = fertilizer, WC = weed control, IC = insect control, and R = residual.

t/ha (71%), and insect control 0.5 t/ha (36%). Improved weed control contributed nothing to the gap (Fig. 5).

Recent findings in Nueva Ecija indicate that nearly half of the farmers applied nitrogen fertilizer inefficiently. Experiments were conducted on 4 pump-irrigated farms during the 1978 dry season to determine if the method and time of fertilizer application followed by the farmers may be related to such inefficiency. The timing of application of farmers' and high levels of nitrogen usually followed by the farmers was evaluated by applying the same amounts of nitrogen in 3 equal split doses—basal, broadcast, and incorporated—20 days after transplanting and 5-7 days before panicle initiation stage. Phosphorus and potassium fertilizers were at farmers' levels and management practices. A high level of inputs at recommended cultural practices and zero fertilizer treatment were also tested. All treatments had insect and weed protection simulating farmers' practices. The high levels and farmers' average levels of inputs are shown in Table 15.



5. Relative contribution of insect control, fertilizer, and weed control to improved rice yields in farmers' fields. Nueva Ecija, Philippines, 1978.

The high level of inputs managed under recommended cultural practices outyielded all other treatments (Table 16). Plots without fertilizer produced the lowest yield, 2.1 t/ha. With farmers' and high levels of nitrogen, the re-

Table 15. Farmers' and high levels of inputs used in fertilizer efficiency trials in farmers' fields. Philippines, 1978 dry season.

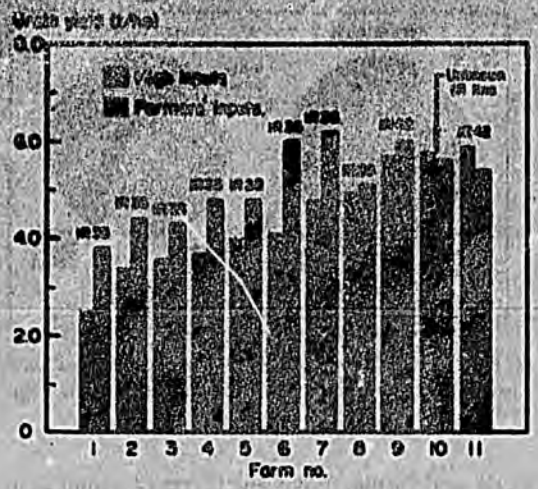
Sites (no.)	Input level	Fertilizer[a] (kg/ha) N	P_2O_5	K_2O	Weed control[b] M	C	Insect control[c] F	F
					Nueva Ecija			
2	Farmers'	90	34	0	1.0	0.5	3.5	0.5
2	High	100	30	20	1.0	1.0	1.0	4.0
					Iloilo			
4	Farmers'	70	11	0	1	0.8	3.8	0
4	High	100	30	20	1	1	3.0	4.0

[a]For Nueva Ecija: Farmers' timing of N application: first application, 13 & 15 days after transplanting (DT); last application, 29 & 60 DT. For Iloilo: farmers' timing of N application: first application, 23–33 days after seeding (DS); last application, 33–55 DS. Researchers' timing of N application: basal, 20–30 DT or DS, and 5–7 days before panicle initiation. [b]Values indicate average number of mechanical weeding operations (M)—either by hand or by rotary weeder—or chemical weedicide (C) applications. [c]Values indicate average number of foliar (F) sprays (MIPC, monocrotophos, Bromden, methyl parathion), or granular (G) applications (lindane, carbofuran, diazinon) to paddy water. The main field crops and, in some cases, seedbeds were also treated.

Table 16. Effect of timing of fertilizer application under different levels of nitrogen and cultural practices on grain yields in farmers' fields, Philippines, 1978 dry season.

Province	Sites (no.)	Yield[a] (t/ha) Level and timing of N application: No nitrogen	Farmers' F	Farmers' R	High F	High R	High + CP
Nueva Ecija	2	3.4	4.4	4.6	4.4	4.5	5.2
Iloilo	4	2.1	2.6	3.2	2.8	3.4	4.9

[a]F = farmers' timing of N application, R = researchers' timing. CP = recommended cultural practices: IR8 seed source, 21-day-old seedlings, 20- x 20-cm spacing.



6. Variations in yield gap between farmers' fields in farm yield-constraints studies in Nueva Ecija, Philippines, 1978 wet season.

searchers' timing of nitrogen application had a 0.2 or 0.1-t/ha yield advantage over the farmers' practice.

Nueva Ecija sites, wet season. In wet-season experiments on 7 irrigated and 4 rainfed farms in Nueva Ecija, the amounts of fertilizer applied by the farmers averaged 53 kg N/ha, 30 kg P_2O_5/ha, and 11 kg K_2O/ha. Five farmers controlled weeds by hand weeding once; the rest did no weeding. Nearly all farmers protected crops from insect damage with one to three foliar sprays, but only four applied granular insecticide.

Farmers' yields varied from 2.3 to 5.9 t/ha (Fig. 6), and averaged 4.4 t/ha (Table 13). Yields from high inputs ranged from 3.6 to 6.2 t/ha, and averaged 5.1 t/ha. The average yield gap was 0.7 t/ha. A series of typhoons caused severe yield losses on nearly all farms. Low yields from farmers' input in some farms were also partly due to low input levels. The contribution of test inputs to the yield gap was determined from only three trials (farms 3, 7, and 11 in Fig. 6), with an average yield increase of 0.5 t/ha from high inputs (Table 14). Plots with high inputs on two farms lodged severely; the average yield gap was low. Half of the yield gap (0.4 t/ha) was from improved insect control (Fig. 5). Improved fertilizer use and high level of weed control each contributed 25% (0.2 t/ha) to the yield gap.

A modified fertilizer efficiency experiment was further tested on 5 pump-irrigated farms in the wet season. The farmers' and researchers' timing of nitrogen application were compared at farmers' levels, two intermediate levels, and high level of nitrogen, and two levels of insect and weed management practices. Phosphorus and potassium fertilizers were held constant at

Table 17. Effect on grain yields of farmers' and researchers' timing of nitrogen application of farmers', intermediate, and high levels of fertilizer nitrogen and at farmers' and high levels of insect and weed control. Philippines, 1978 wet season.

Sites (no.)		Weed and insect control level	Nitrogen applied (farmers' level)		Yield[a] (t/ha)							
					Farmers' level		I-1		I-2		H	
Irrigated	Rainfed		Rate (kg/ha)	Timing[a] (DT)	F	R	F	R	F	R	F	R
				Laguna								
3	0	Farmers'	85		4.1	3.8	4.5	3.6	3.7	4.0	3.5	3.1
3	0	High	85		3.8	3.6	4.4	4.1	4.0	4.1	3.6	4.2
				Nueva Ecija								
3	1	Farmers'	76	10, 36	4.4	4.5	4.3	4.3	4.4	4.4	4.3	4.4
3	1	High	76		4.4	4.8	4.7	4.4	4.6	4.5	4.5	4.3
				Camarines Sur								
3	0	Farmers'	71	0, 45	3.8	4.0	4.0	3.9	4.0	4.0	4.1	3.9
3	0	High	71		4.4	4.2	4.5	4.4	4.5	4.4	4.0	4.3
				Iloilo								
3	0	Farmers'	78	15 DS &	5.5	5.4	5.5	5.0	5.6	5.6	5.4	5.2
3	0	High	78	10 DAPI	5.8	6.1	5.8	6.2	5.8	6.4	6.2	6.9

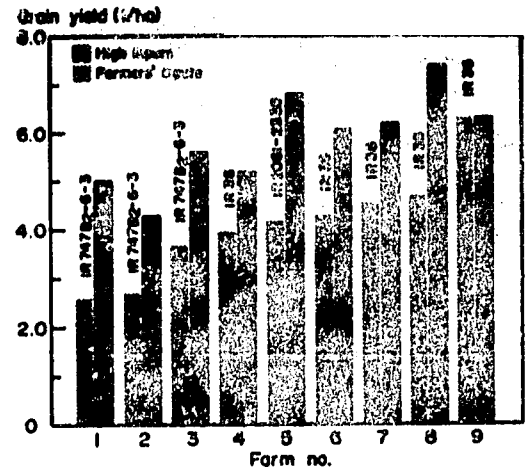
[a]DT = days after transplanting, DS = days after seeding, DAPI = days after panicle initiation. [b]Test levels of nitrogen: intermediate: I-1 = 40 kg N/ha, I-2 = 70 kg N/ha, high (H) = 100 kg N/ha. F = farmers' timing of N application; R = researchers' timing: basal N application 25 DS and 5-7 days before panicle initiation.

farmers' levels and practices. The data from one farm were excluded because of severe typhoon damage.

Yields with farmers' and researchers' timing of nitrogen application were similar at all the test levels of nitrogen application under farmers' levels of insect and weed management practices (Table 17). However, at high levels of insect and weed control, the yield with the researchers' timing was 0.4 t/ha higher than that with the farmers' management of the nitrogen rate but 0.3 or 0.2 t/ha lower than that with the farmers' practices at other nitrogen levels. Because all the trials were hit by at least three strong typhoons from late booting to ripening stages, it is not possible to draw firm conclusions about the experimental results. Further research is needed.

Iloilo sites, dry season. During the 1978 dry season, two complete factorial trials, two minifactorial trials, and five supplemental trials were conducted on communal pump-irrigated fields in Iloilo. Three farms (5,8, and 9 in Fig. 7) used transplanting and the rest practiced direct seeding. The average levels of fertilizer applied by the cooperating farmers were 87 kg N/ha, 10 kg P_2O_5/ha, and 5 kg K_2O/ha. To protect their crops from insects, farmers used an average of four foliar insecticide applications. Only one farmer used granular insecticide to supplement foliar sprays. All farmers controlled weeds by hand pulling, and six combined chemical weed control and hand weeding.

Grain yields with farmers' inputs ranged from 2.6 to 6.3 t/ha (Fig. 7) and averaged 4.1 t/ha (Table 13). With high inputs, yields ranged from 4.3 to 7.4 t/ha, and averaged 5.9 t/ha. The average yield gap was 1.8 t/ha. An outbreak of brown planthopper on three farms growing a



7. Variations in yield gap between farmers' fields in farm yield-constraints studies in Iloilo, Philippines, 1978 dry season.

susceptible variety prevented the farmers and researchers from obtaining high yields. Further yield reduction on two of the three farms was attributed to low fertilizer levels.

Only the data from the complete factorial and minifactorial trials were used in calculating the relative contributions of the test factors to the yield gap. Farmers' yields from these experiments averaged 5.0 t/ha, and grain yields with the high inputs averaged 6.7 t/ha, generating a yield gap of 1.7 t/ha (Table 14). Improved insect control contributed the most — 0.6 t/ha (60%) — to the yield gap, while improved fertilizer management contributed 0.5 t/ha (50%). The high level of weed control gave a negative contribution to the yield gap, indicating that the farmers controlled weeds adequately.

Average grain yields at different levels of inputs are shown in Table 18. The farmers' fertilizer levels and the first intermediate level

Table 18. Grain yield at different levels of inputs. Iloilo, Philippines, 1978 dry season.

Farmer	Grain yield[a] (t/ha)								
	Fertilizer				Insect control			Weed control	
	F	I-1	I-2	H	F	I	H	F	H
Portal	5.2	5.4	6.2	6.2	5.6	5.7	5.9	5.8	5.8
Dorsog	5.3	5.2	5.5	5.8	5.3	5.1	5.9	5.3	5.8
Av	5.2	5.3	5.8	6.0	5.4	5.4	5.9	5.0	5.7

[a]F = farmers' level, I = intermediate, H = high. Data are averaged over all levels of other test inputs.

Table 18. Grain yields with farmers' and test levels of fertilizer, and farmers' and high levels of weed and insect control in experiments in farmers' fields, Iloilo province, Philippines, 1979 dry season.

Farmer	Weed and insect control level	Nitrogen applied (farmers' level)			Grain yield* (t/ha)			
		Rate (kg/ha)	Timing* First	Timing* Final	Farmers'	I-1	I-2	H
Pertal	Farmers'	104	17 DS	41 DS	4.6	5.2	5.8	6.0
	High				5.2	5.2	7.0	6.2
Dereng	Farmer's	101	13 DT	43 DT	4.7	4.9	6.0	5.2
	High				6.0	5.4	6.1	7.4

*DT = days after transplanting, DS = days after seeding. Test levels of nitrogen: I-1 = 80 kg N/ha, I-2 = 100 kg N/ha, H = 180 kg N/ha. Total N application 25 DS or DT and 5-7 days before panicle initiation.

(I-1) produced similar yields even though the nitrogen applied at the farmers' level was twice that at I-1. The second intermediate fertilizer level (I-2) gave a 0.6 t/ha yield advantage over the farmers' levels with the application of similar amounts of nitrogen fertilizer. However, the rates of P_2O_5 and K_2O used at I-2 were considerably higher than those at farmers' levels. Yields further increased by 0.2 t/ha with the high fertilizer level (H). The results are in good agreement when the yields with fertilizer at the test levels are compared with those with insect and weed control at either the farmers' levels or the high level (Table 19).

Because of a high incidence of stem borers and leaf rollers in some areas, the high level of insect control produced 0.5 t more yield than the farmers' or intermediate levels.

To further investigate the earlier findings that some farmers in the study area were applying fertilizer inefficiently, a separate experiment was conducted on four irrigated farms during the dry season. The experimental procedures were essentially the same as those used in the Nueva Ecija sites. The input levels and timing of N application used by the researchers and farmers are given in Table 15.

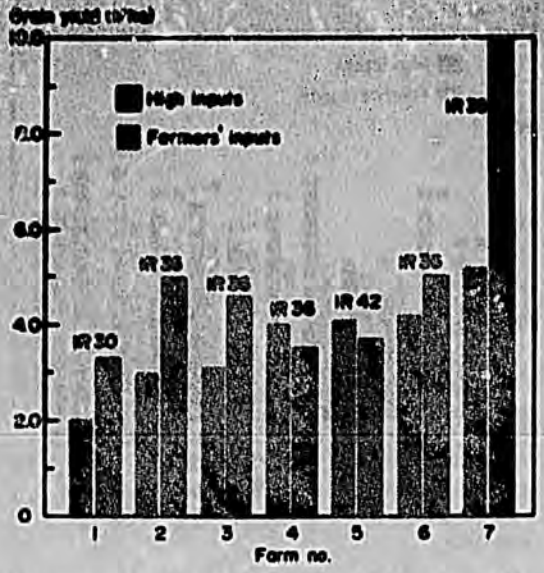
As shown in Table 16, yields from researchers' timing of nitrogen application were 0.6 t/ha higher than those from the farmers' practice at both the high and the farmers' nitrogen levels. These results confirm earlier evidence that farmers were applying fertilizers in a technically inefficient manner. Low yields with both timings of nitrogen application were primarily from poor protection against brown planthopper at the farmers' levels. The treatment with high input level managed at recommended cultural practices substantially outyielded all the other treatments, while the no-fertilizer treatment gave the lowest yield of 2.1 t/ha.

Iloilo sites, wet season. All farmers in the cooperating wet season experiments on nine Iloilo farms practiced direct seeding on puddled soil. The farmers' average levels of fertilizer were 35 kg N/ha and 4 kg P_2O_5/ha. No farmer applied potassium. One farmer applied neither fertilizer nor insecticide. The other farmers used foliar insecticides; one farmer used granular insecticides.

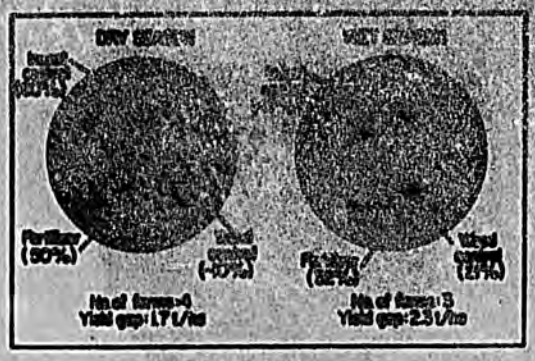
Farmers' yields varied from 2.0 to 5.3 t/ha (Fig. 8), and averaged 3.7 t/ha (Table 13). Yields with high inputs ranged from 3.3 to 10.1 t/ha, and averaged 5.1 t/ha. The low yields with high inputs may be attributable to poor water supply and lodging.

The contributions of the three factors to the yield gap were determined from three trials. Farmers' yields from the farms ranged from 3.2 to 5.3 t/ha, and averaged 4.3 t/ha (Table 14). Yields with high inputs ranged from 4.6 to 10.1 t/ha, and averaged 6.6 t/ha. The average yield gap was 2.3 t/ha, 47% (1.6 t/ha) of which was contributed by improved insect control, 32% (1.1 t/ha) by fertilizer, and 21% (0.7 t/ha) by improved weed control (Fig. 9).

A separate experiment was conducted on three farms to determine whether the farmers were still getting low yield response from their nitrogen fertilizer applications. The experimental procedures were the same as those used at the Nueva Ecija sites except that current



8. Variations in yield gap between farmers' fields in farm yield-constraints studies in Iloilo, Philippines, 1978 wet season.



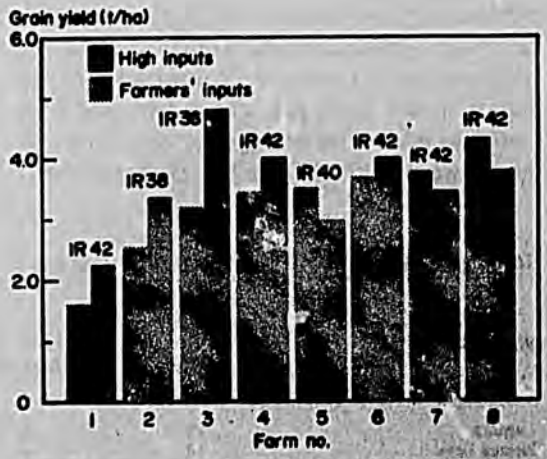
9. Relative contribution of insect control, fertilizer, and weed control to improved rice yields in farmers' fields, Iloilo, Philippines, 1978.

farmers' levels and insect control practices, instead of the previous wet seasons' farmers' practices, were followed.

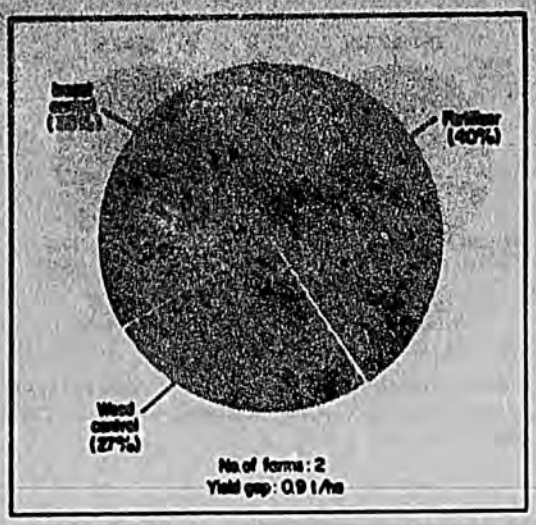
At the farmers' insect and weed management levels, the yields obtained with the researchers' timing of nitrogen application were no higher than those obtained with farmers' practices, particularly at the H and I-2 nitrogen levels (Table 17). However, when insect and weed control were at the high level, the researchers' timing of nitrogen application outyielded the farmers' regardless of the nitrogen levels.

Laguna sites, wet season. In wet-season experiments on 8 Laguna farms, the average fertilizer level applied by the farmers was 70 kg N/ha, 3 kg P_2O_5/ha, and 7 kg K_2O/ha. Nitrogen was split into two or three applications. Yields at the farmers' levels of inputs varied from 1.6 to 3.8 t/ha (Fig. 10), and averaged 3.2 t/ha (Table 13). Yields at the high-input level ranged from 2.3 to 4.8 t/ha and averaged 3.7 t/ha. The average yield gap was 0.5 t/ha. High fertilizer input contributed 40% of the yield gap, and improved insect control contributed 33% (Fig. 11). Improved weed control contributed only 27%. In one case, yields with improved insect control and high fertilizer were significantly higher than the farmers' yields. The results suggest that actual farm yields can be increased through increased use of fertilizer, that farmers' insect control measures are ineffective, and that the farmers' weed control methods are generally adequate.

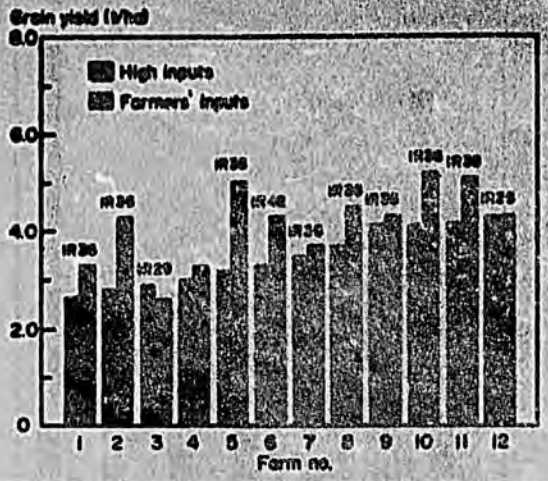
Table 17 shows that with all other inputs at farmers' levels, researchers' timing of fertilizer application did not produce higher yields than the farmers' timing. With the high levels of weed and insect control, improved timing of fer-



10. Variations in yield gap between farmers' fields in farm yield-constraints studies in Laguna, Philippines, 1978 wet season.



11. Relative contributions of insect control, fertilizer, and weed control to improved rice yields in farmers' fields. Laguna, Philippines, 1978 wet season.



12. Variations in yield gap between farmers' fields in farm yield-constraints studies in Camarines Sur, Philippines, 1978 wet season.

tilizer application increased yields only at the higher nitrogen levels.

Camarines Sur, 1978 wet season. The average level of fertilizer used by the Camarines Sur farmers on 12 irrigated farms was 55 kg N/ha, 9 kg P_2O_5/ha, and 5 kg K_2O/ha. Farmers' yields varied from 2.7 to 4.2 t/ha (Fig. 12) and averaged 3.5 t/ha (Table 13). With high levels of inputs, grain yield ranged from 2.6 to 5.2 t/ha and averaged 4.2 t/ha. The average yield gap was 0.7 t/ha. Typhoons late in the season caused substantial yield losses on all farms. Inadequate fertilizer application also contributed to low yields on some farms. The contribution of test inputs to the yield gap was determined from only two trials. The average increase from high inputs was 0.4 t/ha (Table 14). Bacterial blight, especially prevalent with high fertilizer levels in one field, caused the low yield gap. Improved insect control, as well as adequate and improved fertilizer application, were the main contributors to the overall yield gap. The high weed control did not produce higher yields than farmers' weed control levels.

Yields from researchers' timing of fertilizer application were not higher than those from the farmers' timing at both the high and farmers' levels of weed and insect control (Table 17).

SUPPLEMENTARY STUDIES

Yield losses from weeds, wet season. Wet-season experiments were conducted in many farmers' fields in Nueva Ecija, Laguna, Camarines Sur,

Table 20. Yields with farmers' and high level of weed control in farmer's fields. Philippines, 1978 wet season.

Province	Sites (no.)		Yield[a] (t/ha)		
	Irrigated	Rainfed	Farmers' weed control	High weed control	Difference
Laguna	15	0	3.1	3.4	0.3
Nueva Ecija	10	4	3.7	4.0	0.3
Camarines Sur	14	0	3.9	4.3	0.4
Iloilo	16	1	3.6	3.9	0.3

[a]Fertilizer, insect control, and other cultural practices were at farmers' levels. The high level of weed control consisted of a series of hand weedings, except in Iloilo, where herbicides and spot hand weeding were used.

and Iloilo provinces, Philippines, to determine yield losses caused by weeds. A weed-free treatment consisting of a series of hand weedings on the test plot was superimposed on the farmers' levels of inputs and practices. In Iloilo, where most farmers practiced direct-seeding on puddled soil, a combination of granular and liquid herbicides, and hand weeding was used to suppress weeds in the test plots.

Weeds reduced farmers' yields by 0.3 t/ha in Laguna, Nueva Ecija, and Iloilo, and by 0.4 t/ha in Camarines Sur (Table 20).

Consequences of new technology

Agricultural Economics Department

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SOURCES OF INCREASED RICE PRODUCTION: PHILIPPINES AND INDONESIA

Rice production increased at an annual rate of 3.8% between 1965 and 1975 in the Philippines and at 5.4% between 1967 and 1974 in Indonesia. The increase proceeded at different rates in the regions of the two countries and was caused by different input factors. To determine the causes for increased production, consistent time series data for 9 regions in the Philippines and 12 regions in Indonesia were gathered. The causes of growth for the major regions of each country were then quantified.

The relationship that total output in period t is equal to total crop area multiplied by yield per unit area was used:

$$P_t = A_t \times Y_t \qquad (1)$$

where P_t is total rice output in period t,
A_t is total rice area in period t, and
Y_t is yield per unit area in period t.

Transforming equation 1 into logarithmic form results in

$$ln\ P_t = ln\ A_t + ln\ Y_t \qquad (2)$$

Differentiating equation 2 with respect to t gives

$$\frac{d\ ln\ P_t}{dt} = \frac{d\ ln\ A_t}{dt} + \frac{d\ ln\ Y_t}{dt} \qquad (3)$$

That gives the growth rate in production disaggregated into growth from area and from yield. The rates of change between 5-year averages centered on the stated years, as estimates of the rates of growth of production, area, and yield, were calculated. That removed the short-term fluctuations caused by weather.

Distribution of production growth in the Philippines. For the Philippines as a whole, rice production increased at an annual rate of 3.1% from 1955 to 1975 (Table 1). Between 1955 and 1965 the annual rate of increase was 2.4%; from 1965 to 1975 it was 3.8%. In 1955–65 area and yield were equally important, each growing at 1.2%. In 1965–75 yield increased at 2.7% and area at only 1.1%.

The Central Luzon region contributed the largest share of national rice output, but its relative importance declined from 28% of total rice production in 1955 to 22% in 1975. In 1955 western Visayas was the second most important region, accounting for 14.5% of total production. In 1975 it contributed only 11.8% and was replaced as the second largest rice-producing region by southern and western Mindanao with 14% of the output.

The increase in rice area, from 237,000 ha in 1955 to 495,000 in 1965, accounted for the importance of southern and western Mindanao in that period. Although little area increase occurred in the region in 1965–75, it maintained its relative importance as the second largest rice-producing region through a large increase in yield — 1.2 t/ha in 1965, 1.7 t/ha in 1975. Yield increases in western Visayas and

Table 1. Annual compound growth rates in production, area, and yield of paddy in the Philippines and its regions, 1955–75.

Area	Annual growth rate[a] (%)								
	1955-65			1965-75			1955-75		
	Production	Area	Yield	Production	Area	Yield	Production	Area	Yield
Philippines	2.4	1.2	1.2	3.8	1.1	2.7	3.1	1.2	1.9
Ilocos	6.2	2.8	3.4	2.3	1.3	1.0	4.2	2.0	2.2
Cagayan Valley	3.5	2.8	0.7	5.5	3.0	2.5	4.5	2.9	1.6
Central Luzon	1.0	−1.2	2.2	2.5	1.7	0.8	1.7	0.3	1.4
Southern Tagalog	3.9	3.0	0.9	3.2	−0.2	3.4	3.6	1.4	2.2
Bicol	5.8	1.6	4.2	3.5	0.7	2.8	4.7	1.1	3.5
Eastern Visayas	−0.7	0.6	−1.3	2.9	−1.9	4.8	1.1	−0.7	1.8
Western Visayas	0.4	−2.9	3.3	4.4	1.8	2.6	2.4	−0.6	3.0
Northern & eastern Mindanao	−2.8	0.6	−3.4	8.5	4.5	4.0	2.7	2.5	0.2
Southern & western Mindanao	6.3	7.6	−1.3	3.7	0.1	3.6	4.9	3.8	1.1

[a]Calculated from 5-year averages centered on the years shown, except the rate for 1975, which is from 4-year averages.

in most other regions from 1955 to 1975 varied in magnitude from region to region. Some growth occurred because of area expansion and some because of yield changes.

In 1955–65 eastern Visayas and northern and eastern Mindanao showed decreases in production, traceable to yield reductions (Table 1). Five regions had output growth rates exceeding 3%/year, largely because of rapid expansion in rice area. In that period the annual growth rate of yield exceeded 2% in 4 regions, but in 1965–75 it exceeded 2% in 7 regions and 3% in 2.

Philippine sources of increased production. The contribution of area and yield to production increases was further disaggregated (Table 2). The contribution of area was divided into increases from irrigated and from nonirrigated land. The contribution of yield was partitioned into increases from changes in the *quality of land* (the proportion of irrigated land) and from an item termed *residual*, which represents the contribution of new varieties, higher levels of modern inputs, and other unspecified factors.

In 1955–65 increase in irrigated land area was a dominant factor in six of the nine regions (Table 2), and technology, reflected in the residual, was dominant in the three others. Increased irrigation accounted for most of the increased production, except in Ilocos, Cagayan Valley, and southern and western Mindanao. In five regions the [illegible] of irrigated rice land actually [illegible]. However, the [illegible] in average yields that resulted solely from the increased proportion of irrigated land was relatively small in all regions except Bicol.

In 1965–75, growth in irrigated land area was most important in three regions, and the effect of technology was most important in size. Although the data needed for a direct measurement of the inputs associated with modern technology for each region are not available, the evidence suggests that 1) the widespread acceleration in rice output in 1965–75 in the Philippines resulted largely from modern technology, and 2) irrigation was relatively less important, except in Ilocos, Cagayan Valley, and Central Luzon.

Growth in rice production in Indonesia. The trends in production, area harvested, and yield per hectare, as well as sources of increased production of rice in Indonesia, for the 12 (out of 27) provinces that contribute 90% of Indonesia's rice production were analyzed. The annual rice production growth rate in Indonesia was 6.3% in 1967–71 and 4.1% in 1971–74.

Production in all provinces studied increased between 1967 and 1974 (Table 3). Central Java and West Nusa Tenggara had the highest growth rate of 6.7%/year, largely because of a growth rate in yield of about 5%/year. The provinces of Aceh, West Sumat-

Table 2. Estimated proportion of increased rice production output attributed to area and yield (by region), Philippines, 1955–75.*

Area	Annual rate of production growth (%)		Percentage points attributed to: Area, Irrigated		Area, Nonirrigated		Yield, Land quality		Yield, Residual	
	1955-65	1965-75	1955-65	1965-75	1955-65	1965-75	1955-65	1965-75	1955-65	1965-75
Philippines	2.4	3.8	1.6	1.1	−0.4	0	0.6	0.4	0.6	2.3
Ilocos	6.3	2.3	0.9	1.7	1.9	−0.4	−0.1	0.3	3.5	0.7
Cagayan Valley	3.5	5.5	1.8	3.8	1.0	−0.8	0.5	1.0	0.2	1.5
Central Luzon	1.0	2.5	1.0	1.2	−1.3	0.5	0.1	0.1	2.1	0.7
Southern Tagalog	3.9	3.2	2.5	0.4	0.5	−0.8	0.9	0.4	0	2.0
Bicol	5.8	3.5	3.2	0.2	−1.6	0.5	1.7	−0.1	2.8	2.0
Eastern Visayas	−0.7	2.9	1.5	−0.3	−0.9	−1.6	0.4	0.2	−1.7	4.0
Western Visayas	0.3	4.4	−0.1	0.6	−2.8	1.2	0.2	0.2	3.1	2.4
Northern & eastern Mindanao	−2.8	8.5	1.2	3.0	−0.6	1.5	0.1	0.8	−3.5	2.4
Southern & western Mindanao	6.3	3.7	4.9	0.5	2.7	−0.4	0.7	0.5	−2.0	3.[illegible]

*Each figure is a 5-year av centered on the years shown, except that for 1975, which is a 4-year av.

ra, and South Sumatra also had a respectable growth rate of 4.2%/year, with both land area and yield per hectare contributing.

Harvested area in all provinces increased in 1967–74. The growth rate in total rice area in the outer islands (provinces other than Java and Bali) was no higher than that in the inner islands. The highest rates of increase in area were 2.5%/year in South Kalimantan and 2.4%/year in Aceh; East Java and West Java followed with 2%, and Central Java with 1.5%.

The period studied was divided into two subperiods: 1967–71 and 1971–74. The pattern of growth in output differed considerably from province to province. Except in South Sumatra, Lampung, South Kalimantan, and West Nusa Tenggara, there was a slackening in the production increase in total paddy in the 1971–74 period. The annual production increase rate decreased especially sharply in North Sumatra and South Sulawesi.

All provinces in Java, North Sumatra, and South Sulawesi had lower growth rates in yield in the later period. In North Sumatra, East Java, West Java, Central Java, and South Sulawesi, the growth rates in the later period were only about 30% of those in the earlier period.

Most of the provinces studied had lower growth rates in total paddy area during 1971–74. Only East Java and South Kalimantan had higher growth rates in this period.

Sources of increased production in Indonesia. The contribution of upland and wetland rice areas can be identified separately, and the yield increase can be attributed to either a higher proportion of irrigated area or a higher use of yield-increasing inputs. Fertilizer applied per hectare of rice is determined from extension information. The contribution of fertilizer to output was estimated by assuming that 1 kg fertilizer (NPK) produces 10 kg of paddy rice. The contribution of new varieties is assumed to be the added yield from fertilizer made profitable by their adoption.

Wetland paddy was the most important source of increased production in all provinces in both periods, but its contribution decreased in several provinces in the later period (Table 4). The contribution of dryland paddy was zero or negative in all provinces in both periods except in South Sumatra, Lampung, Bali, and West Java in 1971–74. Part of the reason might have been the Indonesian government's emphasis on wetland paddy production in the BIMAS program for increasing rice production in Indonesia. There have been no programs for dryland paddy.

Wetland paddy contributed most of the increase in rice production. The sources of output growth were studied in detail. For the 12 provinces being considered, the contribution of area to wetland paddy increase declined from

Table 3. Annual compound growth rate of production, area, and yield of paddy in selected provinces of Indonesia, 1967–71 and 1971–74.[a]

Area	Annual growth rate (%)								
	1967-71			1971-74			1967-74		
	Production	Area	Yield	Production	Area	Yield	Production	Area	Yield
Indonesia	6.3	1.8	4.4	4.1	1.1	3.0	5.4	2.3	3.0
Aceh	5.0	3.7	1.4	3.4	0.7	2.6	4.3	2.4	1.9
North Sumatra	8.8	3.6	5.1	0.6	−1.5	1.4	5.2	1.4	3.5
West Sumatra	4.5	2.2	2.3	3.7	0.2	3.5	4.2	1.3	2.8
South Sumatra	3.2	0.7	1.4	5.4	0.5	4.8	4.2	0.6	3.5
Lampung	3.1	1.3	1.7	9.0	0.9	8.2	5.6	1.1	4.4
South Kalimantan	5.4	2.0	3.3	6.7	3.1	3.7	5.9	2.5	3.5
South Sulawesi	6.9	1.0	6.0	1.1	−1.2	1.9	4.4	0.1	4.2
West Nusa Tenggara	4.4	1.7	2.7	9.9	1.7	8.0	6.7	1.7	4.9
West Java	6.7	2.1	4.5	4.7	1.8	3.0	5.9	2.0	3.8
Central Java	9.5	1.9	7.4	3.2	0.9	2.3	6.7	1.5	5.2
East Java	5.2	1.7	3.3	4.6	2.3	2.3	4.9	2.0	2.9
Bali	5.5	2.5	2.9	3.8	0.6	3.2	4.7	1.7	3.0

[a]Computed on a 5-year average centered on the years shown, using the formula $\log g = 1/t \log (X_t/X_0)$.

Table 4. Rates of increase of wetland and dryland rice production in the total harvested in Indonesia's rice production, 1967–71.

Area	Rate of increase (%)					
	1967-71 production			1971-74 production		
	Total	Wetland	Dryland	Total	Wetland	Dryland
Indonesia	6.3	6.5	−0.2	4.1	4.3	−0.2
Aceh	5.0	5.0	0	3.4	3.8	−0.4
North Sumatra	8.8	8.9	−0.1	0.8	1.5	−0.8
West Sumatra	4.5	5.2	−0.7	3.7	4.0	−0.3
South Sumatra	3.2	3.8	−0.7	5.4	5.2	0.2
Lampung	3.1	3.8	−0.7	9.0	8.7	0.3
South Kalimantan	5.4	5.9	−0.5	6.7	7.2	−0.5
South Sulawesi	6.9	7.2	−0.3	1.1	1.6	−0.5
West Nusa Tenggara	4.4	5.1	−0.7	9.9	10.1	−0.2
West Java	6.7	7.0	−0.3	4.7	5.0	0.3
Central Java	9.5	9.5	0	3.2	3.2	0
East Java	5.2	5.1	0.1	4.6	4.6	0
Bali	5.5	5.8	−0.3	3.8	3.6	0.2

2.6% to 2.0%/year between the 2 periods (Table 5). The irrigated area increased at less than 1%/year, while the nonirrigated wetland area increased at 1.9% and 1.4%. In Central Java and Bali, the contribution of area decreased from the first to the second period, but in East and West Java it increased. In five of the eight outer island provinces, the contribution of area declined. Irrigated area was an important cause of area growth in most provinces in the 1967–71 period; it was not important in 1971–74, except in Lampung, East Java, South Sulawesi, and West Nusa Tenggara.

Between 1967–71 and 1971–74, the contribution of yield increased in five of the eight outer island provinces but decreased in Java. Fertilizer contributed about 0.5%/year to yield increase in the outer islands over both periods and 1.3–2.0%/year to yield increase in Java. The residual, which includes the effect of irrigation on yield and other technical changes, declined in all three Java provinces and in half of the outer island provinces.

ALLOCATION OF RESEARCH INPUTS TO RICE ENVIRONMENTS

The potential impact of research on rice production and rice-based cropping patterns can be fully realized only if the research efforts are

Table 5. Contribution of irrigation and fertilizer to increased production of wetland paddy in selected provinces of Indonesia, 1967–71 and 1971–74.

Area	Production increase (%)		Contribution (%) to increased production											
			Area						Yield					
			Irrigated		Nonirrigated		Total		Fertilizer		Residual		Total	
	1967-71	1971-74	1967-71	1971-74	1967-71	1971-74	1967-71	1971-74	1967-71	1971-74	1967-71	1971-74	1967-71	1971-74
Indonesia	7.2	4.6	0.7	0.6	1.9	1.4	2.6	2.0	1.3	1.1	3.4	1.4	4.7	2.5
Aceh	5.4	4.0	1.6	0.2	2.2	0.5	3.8	0.7	0.6	0.7	1.1	2.6	1.7	3.3
North Sumatra	10.9	1.7	2.3	0.2	3.9	0.7	6.2	0.9	0.6	0.6	2.4	0.2	4.8	0.8
West Sumatra	5.5	4.1	2.0	0.4	1.3	0.4	3.3	0.8	0.7	0.4	1.5	2.9	2.2	3.3
South Sumatra	5.8	7.3	0.8	0.9	3.5	4.1	4.3	5.0	0.8	0.6	0.8	1.6	1.6	2.2
Lampung	6.9	13.8	3.2	4.3	4.2	5.3	7.4	9.6	0.7	0.5	−0.1	3.4	0.6	3.9
South Kalimantan	6.4	7.7	1.1	1.7	1.5	3.1	2.6	4.8	0.1	0.3	3.7	2.8	3.8	3.1
South Sulawesi	7.7	1.6	3.1	5.9	−1.2	−4.9	1.9	0.2	0.3	0.5	5.7	0.8	6.0	1.3
West Nusa Tenggara	5.6	10.7	0.4	2.2	2.7	0.2	3.1	2.4	0.4	1.6	2.2	6.8	2.6	8.4
West Java	7.4	5.2	1.8	1.6	1.4	1.4	3.2	3.0	1.4	1.7	2.8	0.6	4.2	2.3
Central Java	9.7	3.2	0.9	0.3	1.3	0.7	2.2	1.0	1.9	1.3	5.6	1.0	7.5	2.3
East Java	5.2	4.6	1.9	2.5	0	0.2	1.9	2.7	2.0	1.4	1.4	0.7	3.4	2.1
Bali	5.9	3.6	3.4	0.2	0.2	0.1	3.6	0.3	0.2	1.0	2.1	2.4	2.3	3.4

concentrated on the right problems. Scientists believe that research findings are environment specific, that is, results that increase the productivity of rice grown under well-controlled irrigated conditions may not be of much value for rice grown in dry upland conditions. Researchers must therefore decide in which environments their efforts are most likely to be productive. Economists can determine how much effort should be devoted to each environment if they know the biologists' hypotheses about possible gains in the various environments.

The benefits to be derived from research on irrigated, rainfed, upland, and deepwater rice in the main rice-growing countries of South and Southeast Asia are examined in this section.

In theory, if the productivity of research resources is to be maximized, expenditures should be allocated so that the increase in productivity obtained from each *additional* dollar spent on research for each rice environment is equated. The analysis should take into account the area over which the new technology is suitable, the expected productivity gain, the farmers' costs involved in using the new technology, or the reduction in cost achieved by the technology, the probability of success, and the time period from the start of research until the productivity gain is achieved. With this information it is possible to calculate the net present value of research for the ith type of rice environment as:

$$NPV(T_i) = (1 + r)^{-t} [\sum_k (\Delta Q_k P_k - C_p) A_i + \sum_m (\Delta A_m P_m - C_a) Q_i]$$

where:

$NPV(T_i)$ = net present value of potential new technology for environment i,
r = social rate of time discount (interest rate),
t = years between research input and production increase,
ΔQ_k = change in value of output made possible by the research,
P_k = probability of success in achieving ΔQ_k production change,
A_i = area over which the technology is successful,
C_p = cost to the farmer of using the technology,
ΔA_m = new production area suitable for production made possible by research,
P_m = probability of success in achieving ΔA_m area change,
C_a = cost to the farmer of extending production to the new area, and
Q_i = value of output per hectare of area.

With this information for each type of environment, research resources can be allocated in proportion to the net present value of potential new technology for each environment.

Information for this kind of analysis is difficult to obtain, but a simplification has been implemented. A group of IRRI scientists estimated the anticipated increases in rice yield and cropping intensity that would be possible from *reasonable* research and extension inputs into each environment of South and Southeast Asia. It was assumed that the increases in yield could be realized over a 20-year period. The probability of success, the direct cost of technology for each area, and the time required to achieve success were assumed to be identical for all environments.

Total production increase was assumed to be attributable to the gain in production from yield increases, cropping intensification, and new irrigation development. Gains in yield and cropping intensity are shown in Table 6. The first two columns of Table 7 show the change in the proportion of land area in specific categories due to the expansion of irrigation. Irrigated area was assumed to grow at 1.5%/year. The gross area in rice increased by 3 million ha because of increase in the area double-cropped, but the area in rainfed rice declined by 6 million ha as land was converted from rainfed land to irrigated rice land.

The increase in rice production in the 1990s from expansion of irrigated land, assuming no change in the 1970s yield level, is projected to be 17.8 million (Table 7). If the value of rice is assumed to be $100/t, the undiscounted benefit in the 20th year will be $1.78 billion. Irrigated rice accounts for 52% of the total research and extension benefits that result from an increase in yield. Rainfed rice accounts for 38%, and

Table 6. [illegible] on rice and for cropping systems for specified rice environments in South and Southeast Asia, 1970s and 1990s.

Environment	Yield (t/ha)			Rice cropping intensity (crops/yr)			Upland cropping intensity (crops/yr)		
	1970s (1)	1990s (2)	Change (3)	1970s (4)	1990s (5)	Change (6)	1970s (7)	1990s (8)	Change (9)
Irrigated	3.0	4.1	1.1	1.2	1.6	0.4	0.3	0.5	0.2
Shallow rainfed	1.8	2.6	0.8	0.7	1.0	0.3	0.4	0.5	0.1
Medium-deep rainfed	1.0	1.8	0.8	0.8	0.9	0.1	0.3	0.5	0.2
Deepwater	1.0	1.5	0.5	0.9	1.0	0.1	0.3	0.4	0.1
Upland	1.0	1.5	0.5	0.8	0.8	0	0.5	0.8	0.3

deepwater and upland rice contribute the balance.

Projected undiscounted benefits from rice crop intensification (Table 8) in the 20th year are $8.10 billion and $3.40 billion from upland crops, where upland crops have a net value (gross value less cash costs) of $75/t.

The discounted benefits over the 20-year period are summarized in Table 9.

Cost differences. The preceding analysis assumed that the probability of success, the direct cost of technology for each area, and the time required to achieve success are the same for all environments. This assumption may not be reasonable. In fact, it seems reasonable to expect that research effort in the irrigated environment would have a greater probability of success, but the cost of installing the irrigation adds to the total cost society must bear to achieve the gains. This section shows the results of calculations that take into account these costs.

Fertilizer use is also likely to be higher in irrigated areas. This analysis assumed the use of 120 kg fertilizer/ha on 36 million ha of irrigated area and 36 kg/ha on an equivalent rainfed area. Fertilizer is expected to cost $200/t (at constant 1975 prices). In both rainfed and irrigated areas, labor will be needed to obtain the additional output. Additional labor requirements are calculated at 30 days/additional ton of rice. The added labor cost for the irrigated area is higher.

The estimated annual returns and costs for expansion of production in the irrigated and rainfed environments are budgeted in Table 10. The annual changes in yield, production, and land area are based on data in Tables 6 and 7. Some of the assumptions about investment costs and current expenses are based on research discussed in the Consequences section of the 1977 Annual Report. It is assumed that, by the mid-1990s, $100 million will be spent on research and extension for irrigated rice and another $100 million on research and extension for rainfed rice, based on an annual increase of 8% over the next 20 years, close to the rate of growth in fertilizer cost. The data show the

Table 7. Estimated contribution of research and extension to projected increase in rice production due to yield increase in specified environments, South and Southeast Asia, 1970s to 1990s.

Environment	Gross area[a] (million ha)		Yield increase (t/ha)	Undiscounted benefits from irrigation[b] (million t)	Undiscounted benefits in 20th year from research and extension due to yield		
	1970s (1)	1990s (2)	(3)	(4)	Million t (5)	Billion $ (6)	% (7)
Irrigated	27	36	1.1	27.0	39.6	3.96	52
Shallow rainfed	29	25	0.8	−7.2	20.0	2.00	26
Medium-deep rainfed	13	11	0.8	−2.0	8.8	0.88	12
Deepwater	7	7	0.5	0	3.5	0.35	5
Upland	8	8	0.5	0	4.0	0.40	5
Total	84	87		17.8	75.9	7.59	100

[a]Irrigated area is assumed to increase at 1.5/annum and gross land area at 0.2%/annum. Land moves from rainfed to irrigated.
[b]Col. 4 equals col. (2-1) above × col. 1 of Table 6. Benefits are for the 20th year.

Table 10. [illegible]

Environment	Area harvested at 1970s intensity[a] (million ha)		Anticipated increase in intensity				Unilateral benefits in 2000 year from research and extension due to intensification			
			Ratio[b]		Million ha		Billion $[c]		%	
	1970s (1)	1980s (2)	Rice (3)	UC (4)	Rice (5)	UC (6)	Rice (7)	UC (8)	Rice (9)	UC (10)
Irrigated	23	30	0.4	0.2	12.0	6.0	4.92	1.35	61	54
Shallow rainfed	41	38	0.3	0.1	10.8	3.8	2.81	0.70	35	21
Medium-deep rainfed	16	14	0.1	0.2	1.4	2.8	0.25	0.38	3	11
Deepwater	8	8	0.1	0.1	0.8	0.8	0.12	0.08	1	3
Upland	10	10	0	0.3	0	3.0	0	0.38	0	11
Total	98.0	98.0					8.10	3.40	100	100

[a]Computed by adjusting gross area in Table 7 to rice cropping intensity existing in 1970s shown in col. 4 of Table 6. [b]From col. 6 and 8, Table 6. [c]Converted to dollars: 1 t of paddy rice is valued at $100; 1 t of upland crop is valued at $75.

investment requirement for fertilizer, irrigation, research, and extension.

Gross increased returns contributed 60% in the irrigated area and 40% in the rainfed area, but the capital investment for irrigation and fertilizer for the irrigated area is much larger. Thus, the rate of return on investment was larger for the rainfed area than for the irrigated. Despite that, 55% of net value of additional rice generated by research and extension efforts was from the irrigated environment and 45% from the rainfed.

Contributions of research by country. While the figures given indicate the potential payoff from research on rainfed rice in South and Southeast Asia as a whole, the results for individual countries are very different. Questionnaires were sent to a group of rice scientists from each country asking them for information on the present yields of irrigated, upland, deepwater, and rainfed rice, and for their estimates of the potential yields in each category. *Unofficial* data for each of the countries were used to compute the potential benefits from research and extension in each country. The procedure outlined was used, but benefits from cropping intensification were not considered. The share of benefits of each rice crop environment is presented in Table 11.

The results indicate that Asian countries fall into two categories: those with a high potential for benefits from investment in rainfed rice research, and those with a high potential for benefits from investment in irrigated rice research. Bangladesh, Burma, Thailand, and Nepal fall into the first category; Indonesia, the Philippines, and Sri Lanka into the second. In India, the potential benefits from both irrigated and rainfed areas are considerable and are similar to those for South and Southeast Asia as a whole. If India were divided into regions, however, the same concentration of potential benefits from certain types of research in certain regions would probably be observed.

Clearly, each country must pursue a research strategy appropriate to its environment(s). The

Table 9. Summary of present value discounted vs added benefits from research and extension due to yield increase and cropping intensity increase for specified environments in South and Southeast Asia, 1970s and 1980s.

Environment	Benefits (billion $) from			Total benefits	
	Yield increase	Rice cropping intensity	Upland cropping intensity	Billion $	%
Irrigated	7.89	9.50	3.69	21.38	58
Shallow rainfed	3.98	5.58	1.39	11.00	29
Medium deep rainfed	1.76	0.48	0.76	2.99	8
Deepwater	0.72	0.24	0.18	1.14	3
Upland	0.80	0	0.76	1.55	4
Total	15.14	10.10	6.78	38.06	100

Table 10. Annual production increases and costs estimated to be required to achieve the production increases, [illegible] and economic effects on irrigated and rainfed rice in South and Southeast Asia.

	Irrigated rice		Rainfed rice	
Area in 20th year (million ha)	36.0		36.0	
Increased production (million t in 20th yr)	55.0		55.4	
Value of production increase[a] (million $ in 20th yr)		5,500		5,540
New irrigated area (ha/yr)	450,000		—	
Capital cost of new irrigated area[b] (million $ ev/yr)		675		0
Current operating cost for new irrigation[c] (million $ ev/yr)		5		0
Additional fertilizer required to obtain increase (kg/ha)	120		36	
Cost of additional fertilizer[d] (million $ in 20th yr)		864		259
Additional labor used at 20 days/t (days in 20th yr)	2,694		1,782	
Cost of additional labor[e] (million $ in 20th yr)		2,694		1,782
Nonresearch cost of production increase (million $)		4,232		2,041
Research and extension investment (million $/yr)		100		100
Net value of research and extension (million $/yr in 20th yr)		4,572		2,799

[a]Yield and intensity increases on rice crop only. [b]New irrigation costs $1800/ha, operating costs, $11/ha. [c]Fertilizer cost, $300/t. [d]Assuming $1/day for labor.

estimates given in Table 11 might be modified somewhat by taking the cost of irrigation into account. However, this factor was not pursued because irrigation cost data were not available.

ANALYSIS OF A RICE RESERVE STOCK PROGRAM

Most governments in Asia have policies designed to influence rice production, consumption, and trade. A decrease in rice prices tends to cause a sharp decline in farmers' incomes, often to a level below subsistence; an increase in rice prices tends to increase consumers' costs. Thus, an overriding objective of rice policy in Asian countries has been to maintain a sufficient supply of rice for consumers at a stable price, sufficient to maintain the subsistence income levels of producers.

Many rice-importing countries have adopted rice self-sufficiency as a national goal. However, self-sufficiency in rice cannot provide price stability in the short run, because weather causes year-to-year fluctuations in rice production. Thus, self-sufficiency in a normal year may be accompanied by a shortage in a poor year and a surplus in a good year. A reserve stock is a policy instrument used to maintain short-run price stability.

This study is concerned only with reserve stocks that can be classed as reserves from the good years that can be used as a buffer during the poor years.

With favorable levels of production in 1975, 1976, and 1977, Philippine farm prices fell significantly below the government's floor price. For this situation, the question of whether or not it would be practicable to set aside part of

Table 11. Estimated contribution of research and extension to expected growth in rice production for specified environments in selected countries in South and Southeast Asia, 1970s to 1990s (*unofficial* data based on personal communications with rice scientists in the named countries).

Environment	Share of benefits from research-extension [a](%)								
	South and Southeast Asia	Nepal	Thailand	Bangladesh	Burma	India	Philippines	Indonesia	Sri Lanka
Irrigated	52	20	22	23	25	46	74	76	79
Shallow rainfed	26	67	49	41		10	11	10	8
Medium-deep rainfed	12	0	24	22	53[b]	26	2	0	5
Deepwater	5	0	4	4	19	4	1	6	—
Upland	5	13	1	10	3	15	12	8	4
Total	100	100	100	100	100	100	100	100	100
Implied annual growth in rice production	2.4	3.0	4.1	1.9	3.2	3.6	2.9	4.2	3.4

[a]Benefits are due to yield increase only. [b]Includes shallow and medium-deep rainfed areas.

the surplus production as a reserve against future shortfall in production was investigated.

Instituting and operating stock programs is not easy. A number of questions immediately arise. How large a reserve stock is needed to maintain an acceptable range of price fluctuation between the floor and ceiling prices? What is the cost of maintaining a reserve stock program? Would it cost less to rely on imports in years of low production? What is the effect of a reserve stock program on producers and consumers?

The study was aimed at:

- determining acceptable price fluctuation ranges;
- determining the size of reserve stock needed to maintain price fluctuations within the acceptable range;
- determining the cost of keeping such a reserve stock;
- assessing the gains and/or losses to consumers and producers of operating such a reserve stock.

A simulation model for comparing and evaluating alternative strategies of reserve stock management was constructed. Alternative sets of decision rules on the acquisition and release of stocks were developed. The reserve stock schemes were evaluated by taking into account the costs, benefits, stabilization effects on rice price, and distributional impact of operations.

The model. For a given year, price is determined at the intersection of the supply and demand curves of rice in the market. Price instability is caused by the relative changes in supply and demand. Because rice is a staple food, demand changes are slow. But sharp changes in its supply can be brought about by the vagaries of environmental factors.

The level of storage activity in a given year is determined by production and storage rules; it is constrained by storage capacity and the amount of rice stored in previous years. Storage rules relate the accumulation and release of stocks to the available supply. If price rises above a certain level, rice is withdrawn from storage to bring price down to the prespecified level; if price is below a certain level, rice is stored to bring price up to the prespecified level.

Theoretically, with reserve stocks, price fluctuations can be narrower. However, actual fluctuations would not really be confined to the specified range because the actual amount of rice stored in a given year can never exceed the available storage capacity, and the amount taken from storage cannot exceed that available in storage. The available storage space and the amount of rice in storage depend on the maximum available storage capacity and the level of storage activity in previous years. Hence, reserve stock operation can dampen price fluctuation but not necessarily eliminate it.

The cost components of a reserve stock operation comprise the fixed cost of constructing storage facilities and the operational costs. They include a) one-time costs, such as the cost of loading and unloading, and b) costs proportional to the length of time stocks are stored, such as interest on invested money or losses in quantity and quality.

Reserve stock operation benefits are measured through the concept of consumer and producer surpluses relative to a base situation. In this study, the base situation is a closed economy in which there is no foreign trade and no reserve stock operation. Referring to Figure 1, assume that the desired price range is set at P_1^* to P_2^*.

During a stock accumulation year, consumers lose, while producers gain, because if there is no storage when supply is plentiful, say at Q_1, price would be P_1. However, if the quantity, $Q_1^*Q_1$ is stored, then the price will go up to P_1^*. Consequently, consumers will not only have to pay a higher price but also consume less. The loss in consumer surplus is area $P_1^*P_1BA$. Producers will enjoy a higher price for their produce and increased income. The gain in producer surplus is area $P_1^*P_1BC$. The gain in producer surplus is greater than the loss in consumer surplus by area ABC. This difference is termed gross benefits to society because the cost of storage has not been taken into account.

During a year of stock release it is the other way around — consumers gain, while producers lose, because when supply is short, say at Q_2, price will be at P_2. But if stocks are released, supply will increase, say to Q_2^*, and price will

decrease. Therefore, consumers will be paying a lower price and consuming a larger quantity, while producers will receive less. The gain in consumer surplus in this case is area $P_2P_2^*EH$, while the loss in producer surplus is area $P_2P_2^*FH$. The gross benefit to society is area HFE.

To determine which group gains through reserve stock operation, it is necessary to evaluate the sequence of accumulation and release over years and the level at which the prices are set.

Reserve stock management simulation model. Figure 2 presents the flow chart of the rice reserve stock management simulation model. The model is designed to use the market price level to activate adjustments of stocks (as far as possible) until the desired price level is achieved. Random disturbances to represent weather and other noncontrollable effects are included in the forecasting of production. The model will do 300 iterations of 15-year sequences.

For every 15-year sequence the program draws random numbers representing deviation from normal production. It then reads in initial values of exogenous variables, together with the target lower and upper price bounds. Normal production is then computed and multiplied by the deviation index to get actual production for a particular year. Assuming all production is sold, the price is computed using the price equation, which is transformed from the demand function.

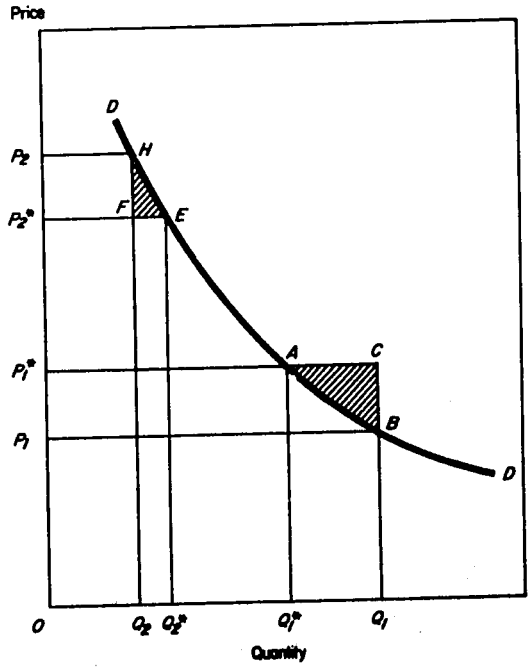
The program then compares the computed market price with the upper and lower price bounds. Three situations are possible. The computed market price is 1) between the lower and upper price bound, 2) higher than the upper price bound, or 3) lower than the lower price bound.

In the first situation no adjustment in stocks is made.

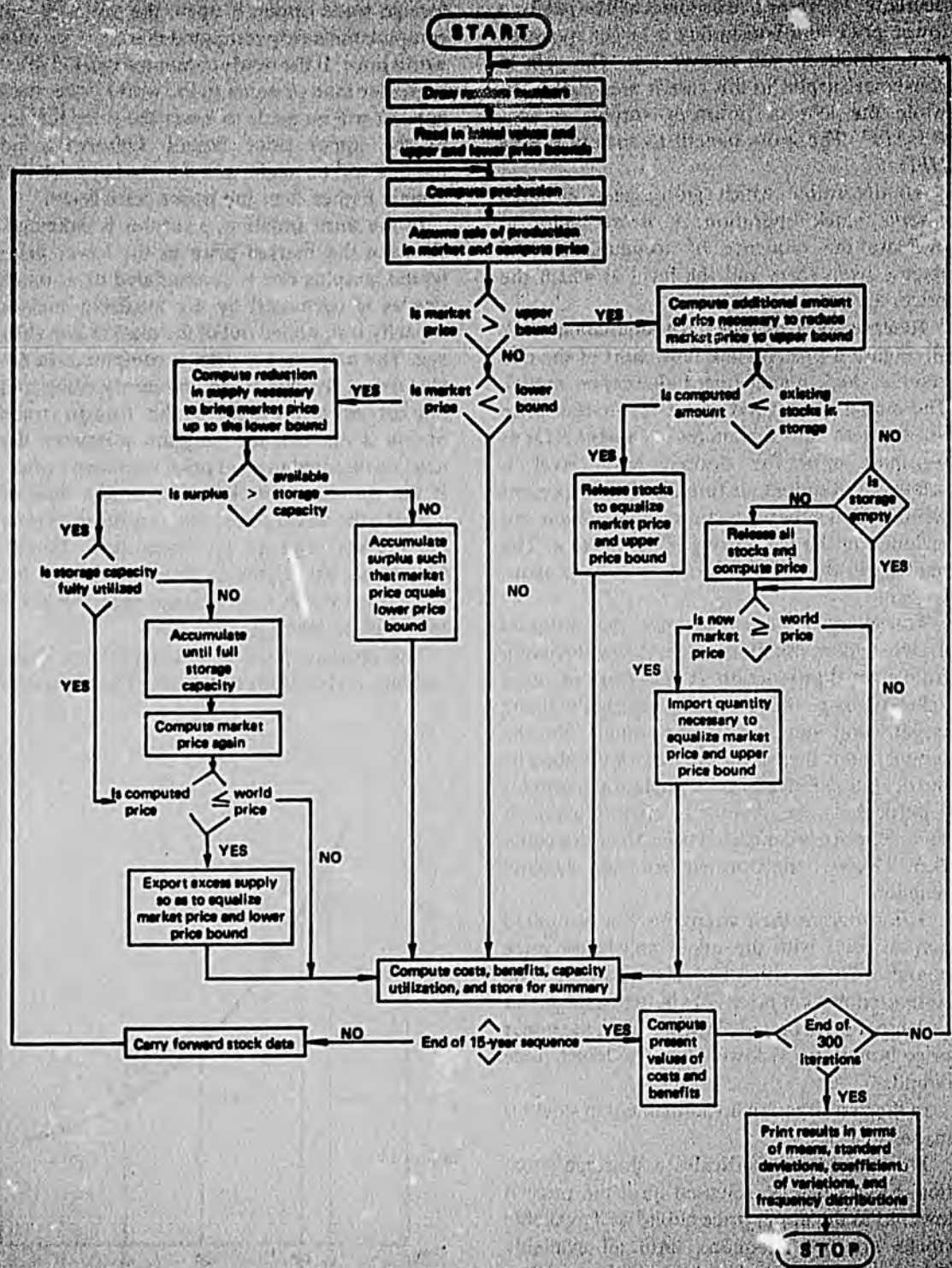
The second case indicates a shortage situation. Stocks will be released until the price is lowered to the upper price bound or if available stocks are not adequate, until all available stocks are released. The new market price is computed. In the absence of foreign trade, the newly computed market price will prevail. If the foreign trade option is open, the program will compare the newly computed market price with world price. If the newly computed market price is greater than or equal to the world price, then imports will be made to lower the price further to the upper price bound. Otherwise, no imports will be made, and the market price will remain higher than the upper price bound.

In the third situation, a surplus is indicated. To raise the market price to the lower price bound, surplus rice is accumulated or as much rice as is permitted by the available storage capacity is siphoned out of the market into storage. The new market price is computed. In the absence of foreign trade, the newly computed market price prevails. If the foreign trade option is opened, the program compares the newly computed market price with world price. If the computed market price is less than or equal to the world price, export is made to raise the market price to the lower price bound. Otherwise, no export is undertaken, and the market price will remain lower than the lower price bound level.

The program goes on to compute the costs, benefits, and capacity utilization. The stock data



1. Economics of reserve stock operation. IRRI 1978.



2. Flow chart of rice reserve stock management simulation model. IRRI, 1978.

are carried forward to the second-year simulation. Production is computed for the second year and the procedure is repeated for 15 years. The 15-year sequence is repeated 300 times, and means, standard deviations, coefficients of variation, and frequency distribution of the results are computed.

One important assumption made in the foreign trade option in the program is that the Philippines is a marginal importer. That is, it imports only when domestic resources are inadequate, and the world market can supply any quantity it decides to import. It exports when needed to maintain the lower price bound and the world market can absorb any quantity it decides to export. Imports are made only to meet current needs and not for storage purposes.

Data and parameters. The data and parameters of the simulation model include 1) production function and random deviation indices, 2) demand and price equations, 3) storage rules, 4) world rice price, 5) cost of storage, and 6) storage capacity.

Production function. Based on time-series data from 1956–57 to 1975–76, a national production function for paddy was estimated using ordinary least squares regression. The variables in the production function were irrigation, fertilizer, and a dummy variable for poor weather (Table 12). Without the weather dummy, the equation could explain 87% of the variation in palay output; with it, the equation could account for 92%. Equation 2 was used in the simulation.

Random production effects. Random production deviation indices were constructed by substituting the actual value of irrigated rice area and fertilizer used in the estimation of the production function into the equation to obtain the yearly predicted output. Dividing the actual production by the predicted production resulted in a set of 20 production indices. In the simulation 15 sequentially ordered draws were made from these indices to represent deviation from normal production. For each simulation run, the draw was repeated 300 times to obtain a representative sample.

Irrigated rice area and fertilizer were assumed to be exogenously determined. Irrigated area took the value projected in the *Five-Year Philippine Development Plan, 1978–82.* The Plan projects irrigated rice area only to 1987. Later data projections were based on the trend in the Plan projections.

Because the Plan has no projections on fertilizer supply, the following equation, which resulted from a regression of the time series data from 1956–57 to 1975–76, was used:

$$\text{Ln fertilizer} = 0.23 + 0.09t \quad r^2 = 0.94.$$

In addition to using the production function and projections of input growth, simulations were also run assuming a normal production growth of 4%/year.

Demand and price equations. The demand for rice was estimated by ordinary least squares, with rice availability (production plus imports) as the dependent variable and prices of rice, corn, and wheat, personal disposable income, and population as the independent variables for 1955 to 1977 (Table 13).

Table 12. Estimates of production function for the Philippines, 1956–57 to 1975–76.[a] Dependent variable is the logarithm of production.

	Equation no.	
	1	2
R^2	0.87	0.92
Constant	5.99845	6.17633
Ln irrigated rice area	0.18863 (1.632)	0.15389 (1.668)
Ln fertilizer	0.22327 (4.040)	0.24079 (5.521)
Bad weather dummy		−0.11412 (3.417)

[a]Figures in parentheses are *t*-values.

Table 13. Estimates of the rice demand function for the Philippines, 1957–76.[a] Dependent variable is the logarithm of rice availability.

	Equation no.			
	1	2	3	4
R^2	0.92	0.93	0.92	0.93
Constant	−3.618	−3.189	−2.537	−3.248
Ln rice price	−0.412 (2.254)	−0.410 (2.329)	−0.448 (2.510)	−0.455 (2.671)
Ln corn price	0.574 (2.761)	0.568 (2.887)	0.567 (2.736)	0.578 (2.926)
Ln wheat price	0.084 (0.963)	0.080 (1.016)		
Ln income	−0.079 (0.130)		0.130 (0.236)	
Ln population	1.048 (1.180)	0.933 (6.262)	0.520 (0.[illegible])	1.017 (8.217)

[a]Figures in parentheses are *t*-values.

Income was not statistically significant. The estimated price elasticity of demand for rice was approximately −0.4. The cross price elasticity of rice with corn and with wheat were 0.57 and 0.08. When the price of wheat was excluded from the estimation, the price elasticity of rice demand did not change significantly. That indicates low substitution between rice and wheat in the Philippines.

In the simulation, equation 4 was transformed into one with price as the dependent variable. Population was assumed to take the value projected in the Plan. Corn price was assumed to maintain its 1973–77 average price level. Because production was expressed in palay, while demand was in terms of milled rice, a milling recovery was necessary. The milling recovery rate was assumed to be 67.45% by weight. This is the official rate adopted by the Philippine Bureau of Agricultural Economics.

Storage rules. In 1978 the Philippine Government had a ceiling price equal to $0.286/kg of milled rice and a floor price of $0.149/kg of palay. The difference between the floor price and ceiling price covered transport cost, milling cost, milling recovery, and profit. The target prices of the government were taken as the lower price bound in the model. Converting $0.286/kg of milled rice to constant 1972 prices gave $151/t. Two alternative selling prices (upper price bound) were tried: 10% and 20% above the lower price bound.

World rice price. The world rice price was determined by calculating the mean and standard deviation of the price of 5% broken Thai rice from 1963 to 1977. For the simulation a price was selected from the distribution, derived at random.

Cost of storage. The following data used in the simulation model are from the Philippine National Grains Authority. Handling cost from farm to warehouse is $0.84/t, assuming 4 movements. Handling cost from warehouse to dealer is $0.84/t. Cost of maintaining stocks in storage was $1.41/t per year. Loss of stock was assumed to be 2%/year. Annual interest rate on money tied up on stocks was 12%. The fixed cost of constructing warehouses was $45.44/t.

Because this study abstracts from location, the transport cost is excluded. It should be noted, however, that the exclusion will considerably bias the total storage cost downward and should therefore be considered when deciding where to hold the reserve stock.

Simulation analysis. Four basic models were considered in the simulation analysis.

- The *free market without trade* (FMxT) model is basically a closed economy, with the added assumption of no reserve stock. This model serves as the basis for comparison.
- The *free market with trade* (FMwT) model assumes no reserve stock, but foreign trade is available for regulating domestic prices. The basic assumption in this model is that once a decision to import or export is made, the world market will be able to supply or absorb whatever quantity is necessary.
- The *reserve stock without trade* (RxT) model also assumes a closed economy but with the existence of reserve stock for regulating market prices to the extent possible.
- The *reserve stock with trade* (RwT) model assumes both the existence of reserve stock and foreign trade. The assumption concerning foreign trade in this model is similar to that of the FMwT model.

Historical data indicate that the standard deviation from trends of Philippine rice production is approximately 300,000 t. The storage capacities considered in the simulation are 150,000 t, 300,000 t, and 600,000 t, which correspond to 0.5, 1.0, and 2.0 standard deviation from the trend.

A simulation run is always assumed to have full initial storage, whatever the storage capacity is.

Ten programs were simulated using the four basic models. The basic features of the different programs are illustrated in Table 14. Some runs were made on the assumption of a 4% rate of growth of rice output. These are identified as RxT (2.1), FMwT (2.1), and RwT (2.1), using the earlier notation.

Stabilization effects. Without foreign trade, the existence of a reserve stock reduces both the expected price and the probability of extreme price fluctuations. However, the reductions are not large. Expected price goes down from $195

Table 14. Basic features of programs simulated, [illegible]

Model[a]	Size of reserve stock (thousand t)	Target price range[b]	Foreign trade
FMxT (1.1)	0	none	Not available
FMwT (1.1)	0	$151-$189	Available
RxT (1.1)	300	151- 189	Not available
RxT (1.2)	300	151- 192	Not available
RxT (1.3)	600	151- 192	Not available
RwT (1.1)	180	151- 189	Available
RwT (1.2)	300	151- 193	Available
FMwT (2.1)	0	151- 189	Available
RwT (2.1)	300	151- 189	Available
RxT (2.1)	300	151- 189	Not available

[a]FM = free market, x = without, T = foreign trade, w = with, R = reserve stock. [b]At constant 1972 prices.

to $193/t, while the probabilities of prices going out of the range $151–189/t increase by 9% (Table 15).

The existence of a large reserve stock stabilizes prices further by reducing the probability of extreme price fluctuations. Models RxT (1.2) and RxT (1.3) have the same assumed target prices, but the larger reserve stock in RxT (1.3) decreases the probability of prices falling below $151 or going above $189 by 5%.

The availability of foreign trade opportunity greatly alters the expected rice price and its frequency distribution. The expected price drops from more than $190/t in the FMxT and RxT models, to $173/t in the FMwT model (1.1). The probability of extreme price fluctuations also goes down from more than 50% to less than 20%.

When foreign trade opportunity is available, the existence of reserve stock does not bring significant additional stabilization effects. RxT (1.1) assumes a reserve stock of 150,000 t and RwT (1.2) assumes a reserve stock of 300,000 t. The expected price and the percentage of frequency distribution of rice price remain nearly the same as those in FMwT (1.1).

Compared with model FMxT (1.1) model FMwT (2.1) exhibits a decreasing trend in the yearly expected prices because, with the assumption that production increases at a trend rate of 4% per annum, production grows faster than population. In model FMxT (1.1), production growth just keeps pace with growth in demand.

Distributional impact. In discussing distributional impact, model FMxT (1.1) serves as the base case with which the others are compared. Table 16 summarizes the expected benefits and losses from the various programs.

Without foreign trade the existence of reserve stock benefits consumers at the expense of the producers; see models RxT (1.1), RxT (1.2), and RxT (1.3). In most cases, however, the gains and losses are large only for the first 2 years. In most programs the chances of either the consumers or producers gaining or losing eventually balance out at a probability of less than 10%.

Gross benefits to society, defined as the sum of consumer and producer benefits, are higher for the case where the target price range is smaller. The larger reserve stock of RxT (1.3), compared with that of RxT (1.2), also results in higher gross social benefits.

The existence of foreign trade opportunity results in higher gross social benefits — as compared with no foreign trade — by increasing the expected gains of consumers at the expense of

Table 15. Expected rice price levels of various models, average for 1978–82.

Model[a]	Mean	SD	C.V.	Frequency distribution (%)		
	($/t)[b]			<$151	$151-$189	>$189
FMxT (1.1)	194	29	0.15	5	36	59
RxT (1.1)	193	28	0.14	1	44	55
RxT (1.2)	193	28	0.14	1	46	53
RxT (1.3)	192	38	0.14	1	51	48
FMwT (1.1)	173	15	0.09	2	82	16
RwT (1.2)	172	25	0.09	2	83	15
RwT (2.1)	173	15	0.09	0	84	15
RxT (2.1)	158	26	0.16	36	55	9
FMwT (2.1)	159	15	0.09	14	83	4
RwT (2.1)	158	14	0.09	12	86	2

[a]FM = free market, x = without, T = foreign trade, w = with, R = reserve stock. [b]At constant 1972 prices.

Table 16. Summary of expected gains and losses of various programs compared with the FMxT program. IRRI, 1978.

Program*	Av annual benefit (million $)		
	Consumer benefits	Producer benefits	Gross social benefits
RxT (1.1)	6.39	-5.85	0.54
RxT (1.2)	6.53	-5.98	0.55
RxT (1.3)	12.24	-11.56	0.68
FMxwT (1.1)	111.15	-103.67	7.48
RxwT (1.1)	111.42	-103.95	7.47
RxwT (1.2)	110.61	-103.13	7.48
RxT (2.1)	2.31	-1.49	0.82
FMxwT (2.1)	-7.07	10.34	3.27
RwT (2.1)	-6.25	9.96	3.71

*R = reserve stock, x = without, T = foreign trade, FM = free market, w = with.

producers. Unlike in the without-trade model, where the chances of either consumers and producers gaining or losing balance out eventually after the first few years, in the model with foreign trade, the chances of consumers gaining remain constantly high — more than 50%. The probability of producers gaining remains at less than 10% throughout. The existence of reserve stock when foreign trade opportunity is present does not significantly alter the expected benefits or losses to consumers, producers, and society.

At the faster rate of output growth, the existence of a reserve stock favors producers more than consumers. Although the present value of producer benefits is negative, the detailed analysis shows that the benefits are negative only for the first few years and then become positive. The probability of producers receiving positive benefits from reserve stock operation increases from 5% in 1978 to 91% in 1992.

In model FMwT (2.1), which assumes the existence of foreign trade but no reserve stock, the probability of producers having positive benefits is lower than in model RxT (2.1), but the probability of producers suffering losses is higher than in RxT (2.1). The probability of positive producer benefits in RwT (2.1) is the same as in RxT (2.1), and the probability of producers losing is higher than in RxT (2.1) but lower than in FMwT (2.1). This suggests that although reserve stock operation increases price stability only slightly in the presence of foreign trade, it provides an added protection to the producers.

Cost comparison. Table 17 summarizes the total variable cost and stocking agency benefits of the different programs. Total variable cost, as defined, includes handling cost of stocks, interest on money tied up in stocks, and maintenance cost of stocks in storage. The stocking agency benefits are the revenue from sales of stocks and money needed for the purchase of stocks together with total variable cost.

Without foreign trade, the higher the degree of price stability achieved, the higher the variable cost involved. Since the degree of price stability is higher in model RxT (1.3) than in model RxT (1.2), while the degree of price stability is higher in RxT (1.2) than in RxT (1.1), the magnitude of program variable cost also follows the same order.

The expected stocking agency benefits are positive in the three reserve stock-without-trade models. A closer look at the yearly stocking agency benefits reveals, however, that only in the first 2 to 3 years is there a large positive expected benefit. This may also be the result of the full initial storage assumption. However, the chances of the stocking agency selling or purchasing stocks eventually balance out at less than 10% probability.

The models assume the stocking agency to be the sole dealer in exports and imports in the presence of foreign trade. The stocking agency benefits if it imports rice at a price lower than the selling price, or if it exports rice at a price higher than the buying price. In the presence of foreign trade, the yearly probability of agency benefits is higher than the probability of negative benefits at roughly 2.5:1.0.

Table 17. Summary of expected total variable costs and expected stocking agency benefits. IRRI, 1978.

Program*	Av annual amount (million $)	
	Variable costs	Stocking agency benefits
RxT (1.1)	0.27	1.77
RxT (1.2)	0.54	1.77
RxT (1.3)	1.36	3.40
FMwT (1.1)	0.27	7.35
RwT (1.1)	0.41	7.76
RwT (1.2)	0.54	8.57

*R = reserve stock, x = without, T = foreign trade, FM = free market, w = with.

DYNAMICS OF AGRARIAN CHANGE

Last year changes in land tenure and labor contract relations in response to population pressure and technological change in a village in Laguna province were reported. In that village (Barrio P) an increase in economic rent (the functional share of land) arising from technological change and the pressure of population on limited land was not paralleled by an increase in the rent actually paid to landlords, partly because of social inertia and partly because of land-reform regulations. The surplus of the economic rent over the actual rent was captured by most tenants as a part of their operators' farm income. Some of the tenants captured the surplus more explicitly by subrenting the land they held under lease, thus giving rise to a multistage landlordism.

It was hypothesized that the economic forces that gave rise to multistage landlordism could also induce polarization of barrios into a system of large-scale commercial farms and landless workers. The increase in economic rent and the difficulty of adjusting actual rent to the economic rent under the land-reform laws could make it more attractive for large tenants to capture the economic rent of land by direct cultivation rather than by subleasing it in small parcels. In fact, Laguna province has a few cases in which large-scale commercial farms were developed through the purchase of tenancy titles. Such cases, however, are exceptional.

The purpose of the study is to investigate one such case of polarization in a village community and to identify the underlying economic and social factors. The methodology of intensive village survey applied to Barrio P was used for another barrio in Laguna (Barrio S) where polarization was in progress. The survey was conducted in September 1977. Data on the situation in 1967, as remembered by the respondents, were also collected to identify changes in the past decade.

Characteristics of the village. Barrio S is on the east shore of Laguna de Bay, a lake lying south of Manila. The barrio houses stretch narrowly along a municipal road, surrounded by 200 ha of village lowland paddy fields. Barrio S belonge to a rice area settled only in the 1930s. The area was part of a large land grant by the Spanish Crown, transferred in the form of rice fields to a few Filipino landlords around the beginning of the 19th century. The landlords gradually opened marshy jungles and installed drainage and irrigation facilities. Barrio S began as haciendas of two landlords in the 1930s. Its development was completed in the 1940s. As the haciendas created infrastructure, marginal areas were settled by small holders and squatters.

Agriculture in Barrio S is characterized by a rice monoculture, with duck raising as a sideline. The major area of the barrio is a highly productive rice field of about 200 ha. Average paddy yields in 1977 were 2.6 t/ha for the wet season and 4.0 t/ha for the dry season, substantially higher than the national average of about 1.7 t. However, because the area is very low and is subject to flooding, the coefficient of variation of yields across farms was 54% for the wet season and 30% for the dry season.

In 1967 no farmer had tried modern rice varieties, but in 1977 all farmers planted them. The diffusion of such varieties was accompanied by the application of fertilizers and pesticides and by the adoption of improved cultural practices. As a result, the average paddy yield per hectare has increased by about 35% since 1967.

Another major technological change was adoption of hand tractors for land preparation. Some of the areas were formerly uncultivated during the wet season because carabaos were unable to work in the deep mud. In 1977 24 tractors cultivated the major area in the barrio. Two carabaos were used for cultivating the edges of paddy fields.

The barrio had a high proportion of landless farm workers. Of 124 households, 56% belonged to the landless worker class. Except for two full-time raisers and four urban employees, the landless made a living primarily by supplying labor for agricultural production. The wage earnings from hired agricultural work were about 30% of the income of all households in the barrio and about 60% of the income of landless worker households (Table 18).

Land holdings and land tenure system. The

[illegible]

Source	All households		Farmers		Landless workers	
	$	%	$	%	$	%
Farming	[illegible]	40	[illegible]	66	0	0
Rice	[illegible]	8	[illegible]	7	[illegible]	11
Others	[illegible]	48	612.11	73	[illegible]	11
Total	47.80	8	[illegible]	7	41.80	9
Nonfarm enterprise						
Wage earning						
Farm	[illegible]	31	119.57	14	[illegible]	57
Nonfarm	81.80	13	[illegible]	8	[illegible]	23
Total	274.57	44	168.57	20	261.80	80
Total	624.08	100	836.46	100	461.43	100

[illegible]

[illegible] 2 large commercial farms.

rice farms in Barrio S in 1976 covered 205 ha owned by 31 landlords and characterized by absentee landlordism. The degree of skewness in the distribution of ownership was high (Table 19). Only 3 ha was owned by a barrio resident, who operates a large-scale commercial farm, to be discussed later. The area owned by residents of Laguna province was about 8%, and nearly 70% was owned by 9 landlords living in Manila. Only 13% of the total area was owned by 29 landlords with holdings below 3 ha, and more than 70% was owned by only 5 Manila landlords. Such a pattern of land ownership in Barrio S contrasts sharply with that in Barrio P, in which most land was owned by relatively small landlords living in the same municipality.

Operational landholdings. The size distribution of operational landholdings was also very skewed in Barrio S (Table 20). In 1977, 50 farmers, who accounted for 94% of all farms in the barrio, operated less than 35% of the total rice area, while the 3 large farms of over 10 ha each covered 135 ha or 66%. One of the large farms (14 ha) was under the direct administration of a landlord who lived in Manila and managed the farm through a farm manager or supervisor. Two others — 80 ha and 41 ha — were operated as large-scale enterprises by tenant farmers living in the barrio. The skewness in the farm size distribution had worsened from 1967 to 1977. Especially noteworthy are the rapid increase in the number of farms below 1 ha — which tripled in 10 years — and the decrease in the number of farms in the 1- to 3-ha class. Such trends reflect the transfers of land from small and medium-size family farms to large-scale commercial operations.

Land tenure system. This barrio had traditionally consisted of two large-scale farms under the direct administration of hacienda owners, and a large number of small family farms under share contracts with the hacienda owners. Two tenant farmers later gradually accumulated landholdings through both direct renting from landlords and purchase of tenancy titles from other tenants.

In 1967 the area under the 4 large enterprises and the 32 small share-tenants added up to 94% of the total area. The area cultivated by small

Table 19. Distribution of landlords owning rice land in 2 barrios, Laguna province, Philippines, 1977.

	Barrio S ("polarized")		Barrio T ("fragmented")	
	Landlords (no.)	Area owned (ha)	Landlords (no.)	Area owned (ha)
Landlord's residence				
The same barrio	1	3.0	4	2.4
The same municipality (except the barrio)	0	0	24	[illegible]
Laguna province (except this municipality)	9	16.4	7	11.7
Batangas province	11	42.8	14	17.6
Quezon or Rizal province	1	8.5	5	15.7
Manila or Baguio	9	137.5	2	4.2
Total	31	[illegible]	[illegible]	[illegible]
Land owned by landlord				
Less than 1 ha	4	2.0	[illegible]	[illegible]
1 to 2.9 ha	[illegible]	[illegible]	[illegible]	[illegible]
3 to 6.9 ha	7	[illegible]	11	[illegible]
More than 7 ha	5	151.4	1	[illegible]
Total	41	[illegible]	[illegible]	[illegible]

Table 20. Farm size distribution in barrio S, Laguna, Philippines, 1967 and 1977.

Farm size (ha)	1967				1977			
	Farms		Rice area		Farms		Rice area	
	No.	%	Ha	%	No.	%	Ha	%
Below 1	7	16	4.2	2	21	40	10.6	5
1 – 1.9	14	31	17.7	9	13	24	17.2	8
2 – 2.9	13	29	28.7	15	11	21	24.7	12
3 – 4.9	5	11	16.0	9	5	9	17.5	9
5 – 9.9	2	4	13.0	5	0	0	0	0
10 and above	4	9	115.0	60	3	6	138.0	66
Total	45	100	191.6	100	53	100	208.0	100

farmers under leasehold tenancy was negligible. From 1967 to 1977 tenancy underwent a major change. All share-tenants were converted into leaseholders under Presidential Decree No. 2 and No. 27 after the declaration of martial law in 1972. One of the large farms under the direct administration of landlords was put under the management of a large tenant operator.

The number of farms under the extralegal arrangements of subtenancy increased. Subtenancy can be classified into three categories (Table 21). First, the sublessor and the sublessee share the output and the cost equally. Six of 12 farms under subtenancy in 1977 were of this type. Second, the sublessor receives a fixed rent from the sublessee. In the 4 farms belonging to this category fathers subleased tenanted land to their sons. Third, subrenting takes a form in which the sublessor puts his land in pawn to the sublessee. That is, the sublessee advances credit to the sublessor and receives the right to cultivate the land until the loan is repaid.

Subtenancy is illegal under the land-reform laws, and the contract is usually made without the formal consent of the landowner. If a sublessee proves to the Regional Office of Agrarian Reform that he is the actual cultivator of the land, he can obtain a formal title of leasehold tenancy. In practice, therefore, the subtenancy contracts are usually limited to friends and relatives, whose moral obligations prevent them from taking such legal action.

As in the case of the barrio reported on last year, the fact that subtenancy is increasing despite the risk involved indicates that the rent actually paid by tenants to landlords is less than the economic return to land. Hence, there is a substantial surplus available to the tenants for whom rents were fixed by law with the conversion from share to leasehold tenancy. Such a tendency is reinforced by increased competition for farmland and by increased productivity of the land. It is commonly belived that large-scale farm operation is more efficient than small-scale farming and can lead to greater yields and higher income. The study of a barrio with both systems provides an opportunity to examine this hypothesis in a homogeneous natural environment.

Farm organization. To test the hypothesis we contrasted the two large leasehold tenant-operated farms with 42 small leasehold farms.

Table 21. Distribution of farms under subtenancy contracts, barrio S, Laguna, Philippines, 1977.

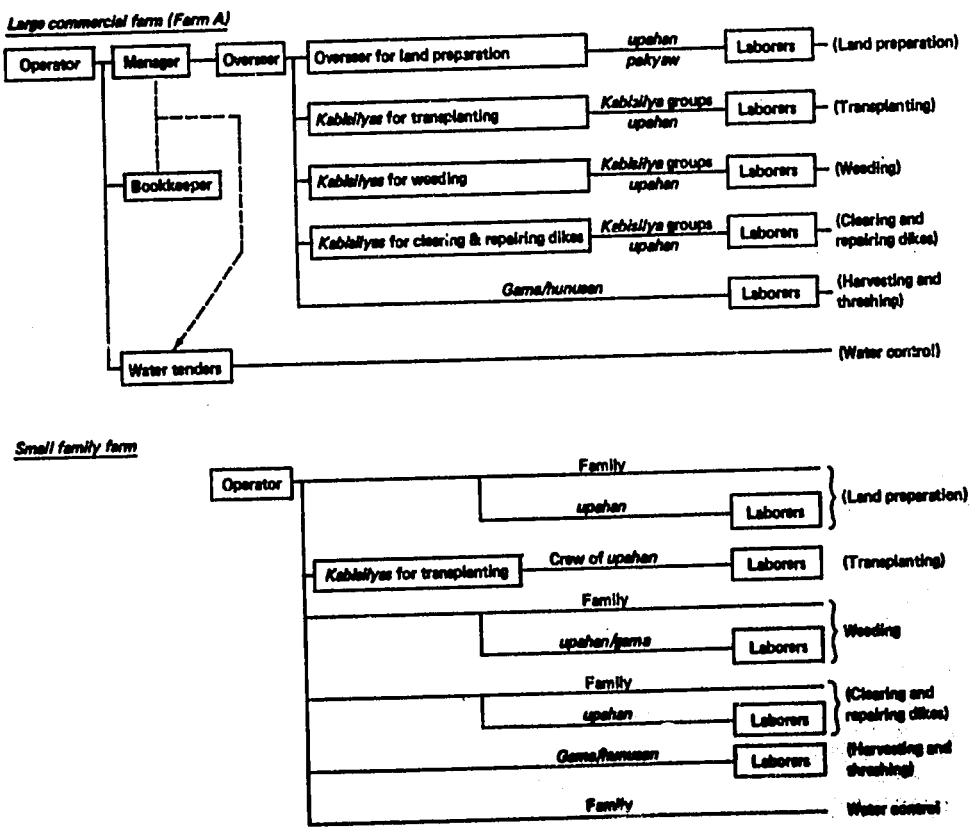
Subtenancy class	1966			1977		
	Farms (no.)	Area (ha)	Area (ha) per farm	Farms (no.)	Area (ha)	Area (ha) per farm
With share rent	3	3.0	1.0	6	6.3	1.1
With fixed rent	—	—	—	4	1.4	0.4
By pledging	—	—	—	2	0.9	0.5
Total	3	3.0	1.0	12	8.6	0.7

Figure 3 shows the contrasting organizational characteristics of the two farm types in the barrio.

On the small farms, it is common for the operators and their families to do all activities related to seedbed preparation, fertilizer and chemical applications, and water control. Farmers who own tractors use family labor supplemented by labor hired at a fixed wage rate for land preparation. Farmers who do not own tractors usually contract their land preparation on a custom basis at a fixed cost per hectare (*pakiyaw*). Rice planting depends primarily on a crew of fixed-wage laborers organized by a *kabisilya*. The *kabisilya* receives $0.07 for each worker mobilized. Harvesting and threshing are done by labor hired on a harvest-share basis (*hunusan* or *gama*) (see subsequent section for definitions). Weeding is done partly by family and partly by fixed-wage (*upahan*) or *gama* labor. The relationships between the small farmers and the laborers are direct, except in transplanting, for which employment is made through a *kabisilya*.

In contrast, the large farms have a management hierarchy. Employment contracts and supervision are done through a manager-foreman system. The farmer employs a manager who is responsible for overall coordination and supervision. On one intensively studied farm, the farmer's wife keeps records of farm expenses. Under the manager, an overseer hires and supervises laborers. The overseer employs the laborers through another overseer for land preparation operations; through a *kabisilya* for rice planting, weeding, and maintenance of ditches and banks; and through the *hunusan* and the *gama* systems for harvesting and threshing. The farm also employs two persons full-time for the control of the irrigation systems.

Inputs and rice yields. Despite the organizational differences, large and small farms differed



1. Organizational charts of large and small farms in barrio S, Laguna, Philippines, 1977.

Table 22. Capital asset holdings, large and small farms in 1 Laguna barrio, Philippines, 1977.

Capital asset holding	2 large commercial farms		42 small family farms	
	Total	Per 100 ha	Total	Per 100 ha
Farmland (ha)	131	—	70	—
Hand tractors (no.)	8	6.1	14	20
Carabao (no.)	1	0.7	1	1
Power threshers (no.)	3	2.3	1	1
Sprayers (no.)	7	5.3	21	30
Rotary weeders (no.)	25	19.0	73	104

in farming practices. Both completely adopted modern varieties and straight-row planting, carried out about the same intensity of weeding, and applied an average of 4 bags (200 kg) of fertilizer/ha.

Nor was there much difference in the degree of mechanization. Two of the large farms owned five and three hand tractors, while less than one-third of the small farms owned a tractor. However, the number of tractors per hectare was larger for the small farms (Table 22). Large and small farms relied heavily upon custom tractor work, and nearly 100% of the area was cultivated by tractors in both cases.

The same situation applied to chemical application and weeding. The only major difference in the use of machinery between large and small farms was that threshing on the small farms was done mostly by hand-beating on bamboo tables, while all the threshing operations for the large farms were performed by mechanical threshers.

As a result, there was little difference between the farm types in the levels of labor inputs applied per hectare for rice production in the 1977 dry season (Table 23). Large farms relied much more heavily on hired labor. Total labor input per hectare was 20% higher; but the difference was due primarily to a difference in the use of labor for management. If management is excluded the difference in the levels of labor inputs per hectare (107 days for large farms and 102 days for small farms) becomes insignificant.

At the same levels of input use, the large and small farms showed no difference in the level of paddy yield (t/ha):

	Large farms	Small farms
1977 wet season	2.9	2.6
1977 dry season	4.0	4.0
Av	3.4	3.3

Cost-return structure. The economic advantages of large farms over small farms can be evaluated by comparing the relationships between farm output values and input costs. Table 24 makes the comparison by estimating the distribution of farm outputs among various factors used for rice production, and the surplus (net profits) left to the farm operators.

The cost-return structure measured in terms of the factor shares of rice output per hectare was similar for the large-scale commercial farms and the small family farms operating under leasehold tenancy. As shown in Table 23, the average labor input per hectare was higher on

Table 23. Labor inputs for rice production per hectare of large and small farms in barrio S, Laguna, Philippines, 1977 dry season.

Tasks	Large farms			Small family farms		
	Labor-days/ha		Hired labor share (%)	Labor-days/ha		Hired labor share (%)
	Total (1)	Hired (2)	(2) ÷ (1)	Total (3)	Hired (4)	(4) ÷ (3)
Land preparation	12.0	12.0	100	10.5	7.3	70
Transplanting	9.6	9.6	100	9.5	8.9	94
Weeding	34.0	34.0	100	35.1	18.4	52
Harvesting & threshing	30.0	30.0	100	34.4	30.8	90
Seedbed preparation & care	2.0	2.0	100	1.8	0.3	19
Fertilizer & chemical application	3.0	3.0	100	2.8	0.5	18
Clearing and repair of dikes	16.0	16.0	100	7.9	1.9	24
Management	16.0	14.0	88	3.0	0	0
Total	122.6	120.6	98	104.8	68.1	65

large farms because of their larger labor requirement for management. However, the labor requirements were compensated for by the lower wage rates resulting from the large farmers' stronger bargaining power. Thus, the level of labor cost was the same as that for the small farms (see the section Dynamics of agrarian change).

The somewhat higher capital cost per hectare for the large farms reflects a higher capital intensity. The lower capital level of the small farms was, to a large extent, cancelled by the higher land rent paid to the landlords. The large farms and the small farms with leasehold titles did not significantly differ in the level of operators' surpluses. Hence, the data fail to support the hypothesis of higher productivity by large-scale rice farms.

The cost-return structure of small farms operating under subtenancy arrangements is in sharp contrast with that of the small farms under leasehold tenancy. There was no operators' surplus because the subtenants had to pay a large share of output to the intermediate landlords (sublessors).

Such contrasts in the cost-return structures between the leasehold tenants (both large and small) and the subtenants show clearly that large operators' surpluses exist in the barrio after the introduction of modern technology and land reform. The surpluses appear as the difference between the economic rent and the actual rent paid to landlords. In the face of growing population and technological change, this difference generated by the institutional rigidity of land rental rates and fixed by law generates pressure for changes elsewhere in the system.

Labor use and contracts. The forms of labor used for rice production in this area are:

- family labor;
- exchange labor;
- *upahan* – daily labor hired at a certain wage rate;
- *hunusan* – the labor employed specifically for harvesting and threshing in return for a share (usually one-sixth) of paddy output;
- *gama* – an arrangement similar to *hunusan* except that workers also weed the field without receiving wages. In the *gama* system the weeding labor is a free service of workers to establish a right to participate in harvesting and receive one-sixth of the harvest.

Hunusan is the traditional form of labor contract for harvesting. The *gama* system — of recent origin — can be considered an institutional innovation that permits the employer to reduce the wage rate for harvesting to a level equal to the marginal productivity of labor. In earlier days when the rice yield per hectare was low and labor was more scarce, the one-sixth share of output under the *hunusan* system might have represented a wage rate equal to the marginal product of harvesters' labor. However, as the productivity of rice farming increased and the labor supply became more abundant because of growing population, a one-sixth

Table 24. Payments and shares of output paid to factors of production on 2 large and 42 small farms[a] in barrio S, Laguna, Philippines, 1977 dry season.

Factor	Factor payments (kg/ha)			Factor shares (% of output)		
	Large farms leasehold	Small farms		Large farms leasehold	Small farms	
		Lease-hold	Sub-tenancy[b]		Lease-hold	Sub-tenancy
Rice yield (paddy)	3960	3996	3866	100	100	100
Current inputs	540	477	544	14	12	14
Land (total)	697	873	1742	18	22	45
Landlord	697	873	662	18	22	17
Sublessor	0	0	1080	0	0	28
Labor	1143	1086	1215	29	27	31
Capital[c]	531	339	383	13	8	10
Operator's surplus[d]	1049	1228	−18	26	31	0

[a]The 2 large farms total 121 ha. The 42 small leasehold farms total 65.8 ha. The 5 subtenanted parcels total 3.3 ha. [b]Excluding the subtenanted farms in which the 2 contracting parties are relatives. [c]Sum of paid or imputed rental of carabao, tractor, and other machines. [d]Residual.

share of output has become substantially larger than the marginal product of labor for harvesting.

Thus, the perceived need is to reduce the harvester's share or replace share harvesting by daily wage labor. However, some difficulty is associated with changing a custom such as the one-sixth share for harvesting, and even though labor is normally abundant, there is a risk that an individual farmer may not find sufficient daily wage workers at the time he needs them for harvest.

The *gama* system is another way of reducing the wage rate, because the one-sixth of output covers the costs of both weeding and harvesting in this system. Because *gama* is more congruent with the traditional *hunusan* system, it creates less social friction. The availability of labor at harvesting is guaranteed by contract. *Gama* is more secure for the employee because it assures his employment. Because of its advantages, the *gama* system has diffused rapidly throughout Laguna in the past decade.

In our former study barrio, nearly 100% of harvesting was carried out by *gama* labor. In barrio S, however, *gama* is not so commonly practiced. Out of 53 farms in the barrio, only 7 depended exclusively on *gama*, 15 used both *gama* and *hunusan*, and 25 used only *hunusan*. Only 13% of the rice area was harvested by *gama* labor in the 1977 dry season. The percentage in *gama* was lower on large commercial farms than on small family farms.

Table 25. Comparison between the imputed value of harvesters' shares and the imputed cost of *gama* and *hunusan* labor per hectare. Laguna, Philippines, 1977 dry season.[a]

	Large commercial farms	Small family farms
Gama system		
Gama labor (days/ha):		
Weeding	17.4	19.5
Harvesting, threshing	18.9	36.3
(1) Imputed cost of *gama* labor[b] ($/ha)	49.8	81.0
Actual share of harvesters (kg/ha)	338.8	554.4
(2) Imputed value[c] ($/ha)	50.3	82.3
(2) – (1)	0.5	1.3
Hunusan system		
Hunusan labor (days/ha):		
Harvesting, threshing	34.0	30.9
(3) Imputed cost of *hunusan* labor ($/ha)	55.5	50.5
Actual share of harvesters (cavans/ha)	374.0	404.8
(4) Imputed value[c] ($/ha)	55.5	60.1
(4) – (3)	0	9.6

[a]Data are for *gama* and *hunusan* laborers. [b]Using market wage rates (daily wage = $1.10 for weeding, $1.60 for harvesting and threshing). [c]Using market prices ($0.15/kg).

The *gama* system was less commonly used by large farmers because they adopted a more direct method of reducing payments to harvesters by reducing the sharing rates. The traditional output-sharing rates for harvesters in Barrio S were one-sixth for the dry season and one-fifth for the wet season.

In 1975 the two tenant farmers operating the large commercial units reduced the sharing rates to one-eighth in the dry season and to one-seventh in the wet season. Their action met substantial resistance from workers. When the two announced the reduction of sharing rates, some of their fields were destroyed during the night. However, they were successful in changing an established custom in the village because of the strong bargaining power of their monopolistic position in labor use — they used 70% of the landless worker labor in the village.

The reduction in harvesters' out-sharing rates initiated by the operators of the large commercial farms was implemented by the small farmers. As a result, the average percentage shares of harvesters under both the *gama* and the *hunusan* systems were higher on the small farms than on the large farms.

Imputation of labor costs for rice harvesting by applying market wage rates shows that, regardless of whether *gama* or *hunusan* was used by the large farmers, the share paid was approximately equal to what would have been paid at the *upahan* daily wage rate. The same applied to small farmers using *gama*. However, the actual share was substantially higher than the imputed cost for small farmers using *hunusan* (Table 25).

These results, together with the use of the alternative harvesting systems, suggest that: 1) the large farms were successful in reducing the share for harvesters to a level equal to the marginal productivity of harvesting labor (provided the market wage rates used for imputation equal the marginal value product of the labor) primarily by reducing the sharing rates of the *hunusan* system; and 2) the small farms made

power between the agreement of large and small firms.

Cropping systems program

Environmental description

Multiple Cropping Department and Cropping Systems Component of Agricultural Economics and Plant Pathology Departments

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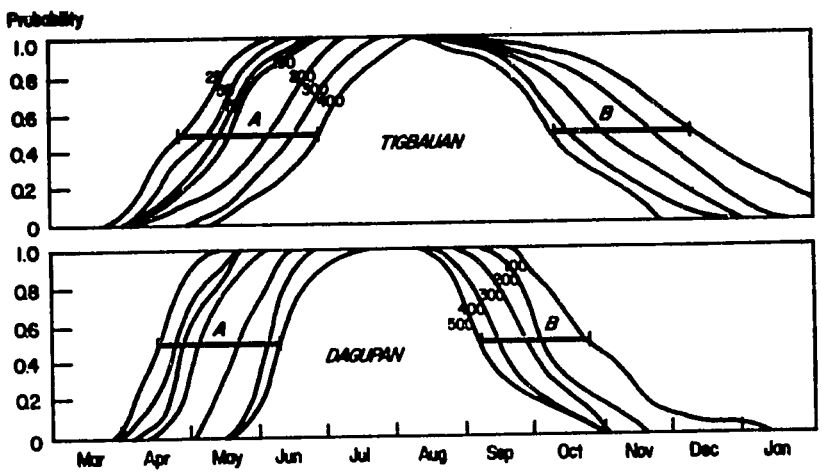
RAINFALL

Multiple Cropping Department

The probability of a certain cumulative amount of rain on a given date at various sites was evaluated to define the start of the wet season. To indicate the end of the wet season the probability of the site's still receiving a certain amount of rain after a given date was used. For each year the rainfall accumulation criteria of 25, 50, 75, 100, 200, 300, and 400 mm were used for onset and 500, 400, 300, 200, and 100 mm for termination. The dates by which these criteria were satisfied in each year of the rainfall record were ranked and plotted to obtain the empirical cumulative distributions (Fig. 1). Several sites showed wide variations in rainfall duration and dates and rates of onset and termination in the wet season (Table 1).

The rainfall characteristics of IRRI cropping systems sites in Pangasinan (Dagupan) and Iloilo (Tigbauan) provinces differ in rate and time of onset and termination of the rainy season. The expected onset (at 100 mm rain) is 12 days earlier in Pangasinan than in Iloilo, but termination (100 mm remaining) averages 40 days earlier in Pangasinan.

Onset and termination are substantially more variable in Iloilo than in Pangasinan, as indicated by the slope of the cumulative probability distributions on the standard deviations (Fig. 1). The average onset can be read off the figures



1. Empirical cumulative probabilities for the onset (25, 50, 75, 100, 200, 300, 400 mm cumulative rain) and termination (500, 400, 300, 200, 100 mm remaining rain) of rains in Iloilo (Tigbauan) and Pangasinan (Dagupan) research sites. Philippines, 1978. A = onset, B = termination.

Table 1. Wet-season rainfall characteristics for selected sites in the Philippines.

Site	Onset			End			Length (days)
	Date[a]	Rate[b]	SD[c]	Date[d]	Rate[e]	SD[f]	
Ibe	30 May	35	12	17 Oct	37	25	139
Duet	23 Apr	88	24	6 Mar	47	21	316
Tigbauan	13 May	60	22	13 Dec	61	36	213
Aparri	23 May	90	18	4 Feb	75	28	256
Laoag	14 May	40	13	28 Oct	40	22	165
Dagupan	1 May	55	12	4 Nov	46	17	186
Ambulong	18 May	88	17.4	7 Dec	71	25	203
Baler	14 Apr	43	16.1	11 Mar	68	14	329

[a]Accumulated rainfall R_a = 25 mm at P = 0.50. [b]Days between R_a = 25 and R_a = 400 at P = 0.50. [c]Standard deviation of day on which R_a = 200 (days). [d]Remaining rainfall R_r = 100 at P = 0.50. [e]Days between R_r = 500 and R_r 100 at P = 0.50. [f]Standard deviation of day on which R_r = 200 (days).

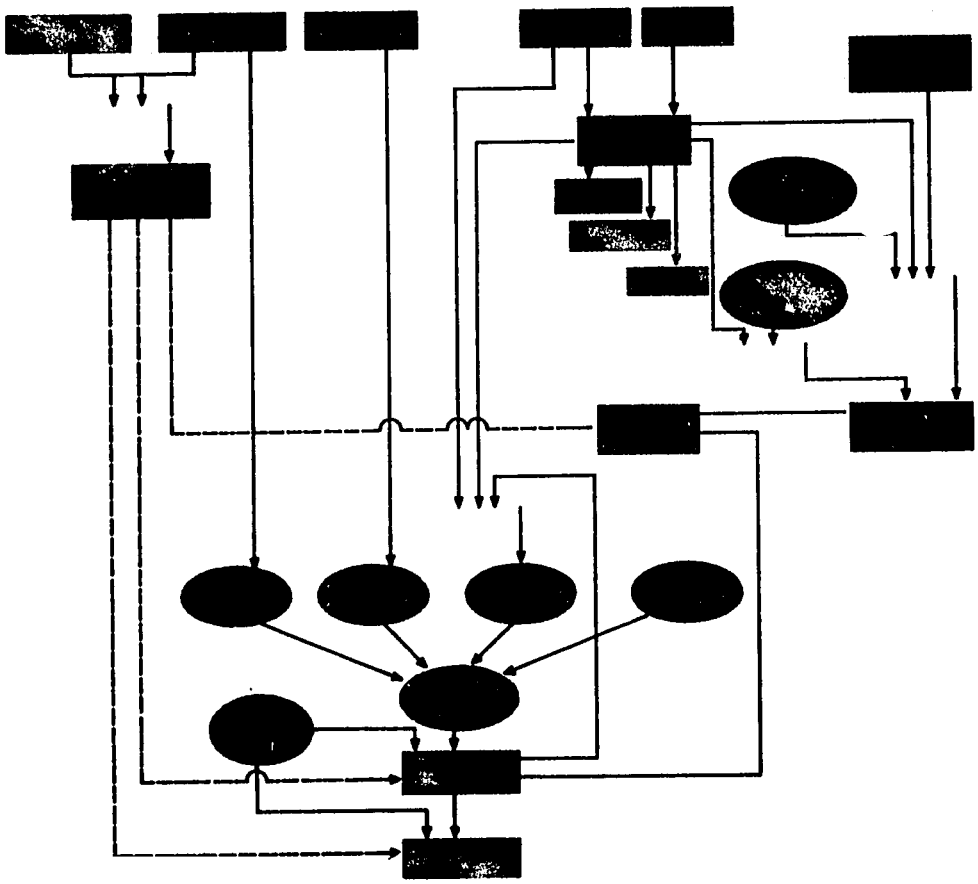
by observing, for example, the distance between the 25- and 400-mm criteria at $P = 0.40$, as indicated by bar *A*. Onset from 25 to 400 mm accumulated rainfall takes about 55 days in Pangasinan and 50 days in Iloilo. Among Philippine sites tested, this period ranged from 35 to 90 days. A similar analysis of the curves for 500 to 100 mm of rain still to be received (bar *B*) shows that termination is considerably more rapid in Pangasinan (46 days) than in Iloilo (61 days). Among the sites studied, this period ranged from 37 to 75 days.

ENVIRONMENT SIMULATION MODEL

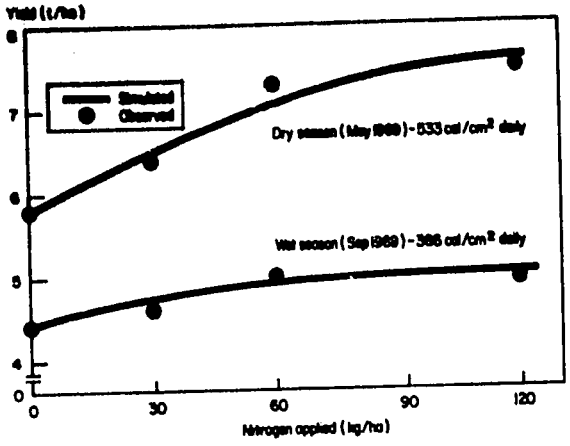
Multiple Cropping Department

Techniques of systems analysis can assist in the process of matching cropping systems with environment. In 1978 development of a simulation model of a rice-based cropping system was started. The core of the model — shown as a flow chart in Figure 2 — is a single crop. The model requires daily inputs of the weather elements shown in the top boxes. Soil management characteristics are included in the model as parameters, with emphasis on an agronomic level of understanding of crop growth.

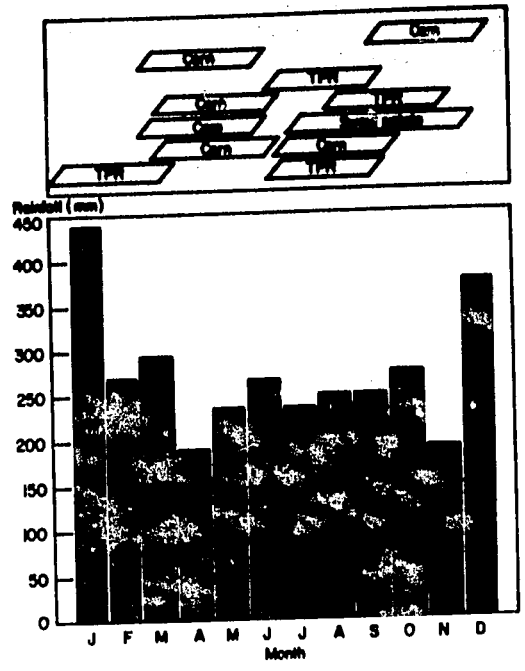
In the model a growth envelop is described by a Gompertz equation, which is modified by the environmental factors of temperature, radiation, and water and nitrogen supply. With the use of actual weather data, the adequacy for growth of each of the inputs is compared daily with the requirement for unconstrained growth,



2. Flow chart of a simulation model of rice growing on a puddled soil. IRRI, 1978.



3. Comparison of simulated and observed yields of irrigated rice. Observed yields were reported in the 1969 IRRI Annual Report. IRRI, 1978.



4. Rainfall and cropping pattern, Agusan del Sur province, for the 1977–78 crop year. TPR = transplanted rice.

and actual growth in relation to deficiencies in every or all inputs is estimated. The technique for simulating these effects is to compute indexes — each scaled between zero and unity — with zero representing no growth, and unity representing unconstrained growth. The *growth index* is computed as the product of these indexes, and is found to reflect the effects and interactions of the four factors.

The phasic development section of the model allows accurate estimation of anthesis date and consequent allocation of growth into grain production. In conditions of stress after anthesis the model provides for mobilization of carbohydrate reserves into grain.

The model was tested against 1969 yields of irrigated rice at IRRI, and good agreement for a range of levels of nitrogen nutrition in both the wet and dry seasons was found (Fig. 3).

ENVIRONMENTAL DESCRIPTION FOR CROPPING PATTERN DESIGN

Cropping Systems Component of Agricultural Economics Department

During 1978 a short form was devised to describe environments for the purpose of cropping pattern design. The form was tested in a collaborative project with the Philippine Government in which new cropping patterns were being designed for resettlement areas in Agusan del Sur, Bukidnon, and Capiz provinces. The form served the need for a first approximation of which crops and management techniques to consider, and how they should be combined to most efficiently use farmers' resources.

PHYSICAL DETERMINANTS OF CROPPING SYSTEMS

Cropping Systems Component of Agricultural Economics Department

Short-form data for the resettlement site in Agusan del Sur illustrate physical determinants of cropping systems. Farmers grow about 60 different cropping patterns that range in complexity from single crops of lowland rice, dryland rice, corn, mung bean, sweet potato, or cassava to complex double crops of wet-seeded rice, and corn intercropped with sweet potato followed

Table 2. Land types and cropping patterns for Agusan del Sur [illegible]

Cropping pattern[a]	Plots (no.)	Relative elevation of plots	Soil texture	Soil moisture	Distance from house
Fallow-TPR	16	Low	Light	Wet	Far
TPR-fallow	7	Low	Light	Wet	Medium
TPR-TPR	110	Low	Heavy	Wet	Near
Fallow-DLR	9	Low	Medium	Dry	Near
DLR-fallow	11	High	Light	Medium	Near
DLR-DLR	22	Low	Light	Medium	Far
Fallow-corn	13	High	Medium	Medium	Far
Corn-fallow	26	Medium	Medium	Medium	Far
Corn-corn	76	Medium	Medium	Dry	Far
Abaca	56	High	Heavy	Dry	Medium
Banana	31	High	Light	Dry	Medium

[a]TPR = transplanted rice, DLR = dryland rice.

by a corn and dryland rice intercrop. The main cropping patterns are shown in Figure 4. Researchers will attempt to grow three crops of rice where farmers are growing two transplanted crops, and two rice crops where farmers are growing one.

To identify possible rules that farmers follow in placement of crops, the frequency of cropping patterns associated with certain land characteristics was recorded. The slope, elevation, soil texture, moisture, and distance from house of 377 plots planted to 11 major cropping patterns were analyzed. The plots accounted for 87% of annual crops and 62% of perennial crops. Table 2 shows the land types where farmers prefer to grow each cropping pattern. Slope ratings of flat, moderate, and steep were correlated with elevation ratings of low, medium, and high, and are not shown in Table 2.

Sufficiency of moisture appeared as the major consideration for growing wetland and dryland rice. Wetland rice was planted on relatively low, wet soils at low elevations: a single crop where soils were light and two crops where heavy soils retained moisture longer. Low, flat areas with light soils and medium moisture supported two dryland rice crops; at higher elevations or on drier soils a single crop of dryland rice was grown.

Farmers regarded drainage as important for corn. Two corn crops were grown at medium elevations with medium-textured dry soils. Perennial crops of abaca and banana are grown at high elevations with dry soils, with abaca preferred on heavy soils.

Distance of plots from homes affected the choice of crops from the standpoint of convenience in applying inputs and removing produce. Two crops of transplanted rice had the highest labor and material input requirements, and the data indicate that homes were located near the plots growing two rice crops.

ECONOMIC DETERMINANTS OF CROPPING SYSTEMS

Cropping Systems Component of Agricultural Economics Department

Taken together, the data from the three resettlement sites indicated that labor and power availability in relation to farm size are important determinants of cropping systems. Compared with farmers at the IRRI cropping systems research sites in Batangas, Iloilo, and Pangasinan, farmers at the three resettlement sites had more land and farmed it less intensively. A significant portion of land was left idle at each site: 1.9 ha in Bukidnon, 1.9 ha in Agusan, and 0.9 ha in Capiz (Table 3). The larger the mean farm size, the lower was the labor input per crop (Table 4).

Despite their idle lands, farmers cropped the cultivated land rather intensively, producing nearly 2 crops/year. The Agusan farmers spread labor over the relatively large farms by planting 30% in perennial crops; the Bukidnon farmers compensated by using more hired power, particularly tractors, and material inputs (Table 4). Relative labor scarcity in Bukidnon, reflected in higher wage rates, made it relatively more

Table 3. Land availability and use in 3 resettlement sites in an IRRI-Philippines collaborative project, 1977–78.

Site	Farm size (ha)	Cultivated crop: Owned (%)	Yield (t/ha)	Crops/yr	Rice (%)	Corn (%)	Perennial crops (%)
Bukidnon	6.4	88	4.0	1.7	16	74	6
Agusan del Sur[a]	5.5	88	3.6	1.5	38	32	30
Agusan del Sur[b]			2.2	1.7	54	46	—
Capiz	2.8	68	1.9	1.8	68	13	2

[a]Annual and perennial crops. [b]Annual crops only.

profitable to replace labor with mechanical power and materials.

Consumption demand and differential costs of production lead to different prices of corn and rice at the resettlement sites (Table 5). The relatively higher price of rice in Bukidnon, where little rice is grown, largely reflected the cost of importing rice into the area. Conversely, low Capiz prices partly reflected relative abundance of rice in the area and lower costs of production resulting from higher yields and low wage rates. Corn prices in Bukidnon, which were higher than elsewhere even though corn is Bukidnon's major crop, reflected the higher costs of corn production caused by high wage rates and lower productivity per hectare.

The total value of crops produced per farm was highest in Bukidnon, but net returns above cash costs per farm were lowest because of high cash costs for corn production (Table 6). In terms of total farm income, the relatively high net returns of Capiz farmers were partly offset by their lower off-farm income. Despite different resource conditions across the three sites, and different production activities, farm families in all three appeared equally well-off.

The relationships observed between farmers' systems and environmental conditions provided information for the initial design of patterns. Differential adoption rates of new patterns will provide information on their suitability.

Table 5. Crop production and prices at 3 resettlement sites in an IRRI-Philippines collaborative project, 1977–78.

Site	Rice yield (t/ha)	Corn yield (t/ha)	Rice price ($/t)	Corn price ($/t)
Bukidnon	1.0	.6	147	110
Agusan del Sur	1.1	.7	115	107
Capiz	1.5	1.2	87	100

DISEASES IN DRYLAND RICE-BASED CROPPING SYSTEMS

Cropping Systems Component of Plant Pathology Department

Rice. During the 1978 dryland rice crop in Batangas province, leaf blast (*Pyricularia oryzae* Cav.) was observed on the local variety Dagge and the introduced variety C171-136. Infection ranged from light to moderately heavy, and was lighter on C171-136 than on Dagge. The disease could have started from a portion of the field where the shading and windbreak effects of neighboring plants of *Gliricidia sepium* prolonged the dew period and favored blast development.

Although Dagge had a blast score of 4 (based on the 1976 Standard Evaluation System for Rice scale) in the variety trial where the plants were at maximum tillering, it had a score of 5 in farmers' fields with plants at early tillering.

Table 4. Labor and purchased inputs at 3 resettlement sites in an IRRI-Philippines collaborative project, 1977–78.

Site	Labor: Total days/ha per crop	Hired (%)	Wage rate ($/day)	Inputs purchased ($/farm): Total loans	Hired labor	Hired power	Materials
Bukidnon	21	46	0.87	115	64	129	91
Agusan del Sur	47	30	0.84	5	22	30	34
Capiz	60	43	0.54	60	46	16	19

[illegible]

Site	Yields of crops and farm income at 0 [illegible]	Net returns* /farm	[illegible]	[illegible]	[illegible]
Bukidnon	[illegible]	[illegible]	71	[illegible]	[illegible]
Agusan del Sur*	367	[illegible]	[illegible]	[illegible]	[illegible]
Capiz	438	[illegible]	43	[illegible]	[illegible]

*Returns on crops net of costs for hired labor, rented power, and material inputs (variable cash costs). [illegible] potential crops, which account for 30% of cultivated area.

buildup of inoculum on the early plantings caused the heavier infection on younger plants. However, the disease spread no further and plants fully recovered.

Moderately light to moderately heavy infection of leaf smut (*Entyloma oryzae* H. and P. Sydow) was also observed on Dagge and C171-136, but it was confined to the lower leaves and considered insignificant.

Corn. Less than 1% incidence of corn downy mildew (*Sclerospora philippinensis* Weston) was observed on an introduced variety in Batangas. The presence of the disease suggests that the conidia of *S. philippinensis* existed at the site. The absence of infection on Tinumbaga, a local variety planted in most fields, suggested its resistance to the disease or insufficient spore density in the immediate environment.

Infection of both Rhizoctonia sheath blight (*Rhizoctonia solani* Kuhn) and Curvularia leaf spot (*Curvularia* sp.) on Tinumbaga was light.

Bush sitao. Fusarium root rot (*Fusarium solani* f. sp. *phaseoli*) was important in Batangas in 1978. In two fields 90% of the plants were destroyed. Symptoms appeared when the plants were at the 6- to 7-trifoliolate-leaf stage. The fields had been previously planted to corn and sorghum and then left fallow for 5 months. It appears that planting nonhost crops followed by fallowing may not control Fusarium root rot.

Root rot due to *Sclerotium rolfsii* Sacc. was also observed, but incidence was only 1%.

Peanut. Leaf rust (*Puccinia arachidis* Sped.) infection of peanut ranged from moderately heavy to severe in Batangas when the crop was between pod filling and maturity. Yield loss due to the disease was not assessed.

Mung bean and cowpea. Mung bean and cowpea had mainly powdery mildew (*Erysiphe polygoni* D. C.) and leaf rust (*Uromyces* sp.). Powdery mildew infection was severe on mung bean, and rust on cowpea. Both diseases occurred after pod filling.

DISEASES IN WETLAND RICE-BASED CROPPING SYSTEMS

Cropping Systems Component of Plant Pathology Department

Rice. Brown spot [*Cochliobolus miyabeanus* (I. & K.) Drechsler ex Dastur], a minor disease, was observed on wetland rice at two sites in Pangasinan province. Infection ranged from light to moderately heavy—lesion types 1 to 5 by the 1976 Standard Evaluation System for Rice. The inoculum could have originated from an area where rice is continuously cropped. The disease was observed as early as when the seedlings were still in the seedbed, and infection was generally common on nitrogen-deficient plants. Although infection on the second rice crop was slightly higher, the plants recovered. Brown spot also occurred in Iloilo province; severity of infection and lesion type were similar to those in Pangasinan.

Leaf blast was observed on a weed (*Echinocloa colona*) infesting most dry-seeded rice fields in both Iloilo and Pangasinan. IR36, which was planted in the fields, did not show any blast infection; its blast resistance was confirmed. At one Iloilo site severe leaf blast was observed on a local variety.

Bacterial blight *Xanthomonas oryzae* (U. & I. Dowson) occurred in research plots and in some farmers' fields at one Iloilo site. Its occurrence appeared related to nitrogen fertilizer level because only the greener, taller plants were infected. About 50% of the plants

[illegible] were affected. The presence of [illegible] in the last crop [illegible] could have [illegible] the [illegible] in the next rice crop, in which a 5–10% brusk infection was observed at the early tillering stage.

Corn. Downy mildew at various levels of incidence was observed on corn planted before wetland rice in Pangasinan. Fields with plants at the late whorl to tasseling stage (10–12 leaves) had less than 5% infection, but those with plants at 4- to 5- and 6- to 7-leaf stages had 80 and 40% infection. A buildup of inoculum from diseased plants in early plantings caused a higher disease incidence in later plantings. The fields were planted to the local variety Macapuno.

Blighting of the 2 to 3 uppermost leaves of corn plants at late whorl to maturity stage was also observed in Pangasinan. The symptoms started from the tip of the leaves and extended down to the leaf sheath. Less than 1% of the plants in a field were infected. Microscopic examination confirmed the bacterial nature of the disease.

Mung bean. In Pangasinan, infection of powdery mildew was moderately light to heavy during the late growth stage of mung bean planted after the [illegible] in CES 14 and in Cas 10-11, a [illegible] variety with some resistance to both powdery mildew and Cercospora leaf spot (*Cercospora* sp.).

The occurrence of a light to moderately heavy infection of Cercospora leaf spot could be an indication of the high relative humidity in the area.

In Iloilo, powdery mildew and Cercospora leaf spot were also observed. Regardless of the cropping pattern, airborne diseases, such as powdery mildew and Cercospora leaf spot, are present whenever mung bean is grown.

In Pangasinan, mung bean plants that exuded a white foamy substance on some portions of the peduncle were observed. Less than 1% of the plants in a field exhibited the symptom, and infected plants in a field were localized. The presence of a disease was not confirmed.

Other dryland crops. The following diseases were also observed at the Iloilo and Pangasinan sites: Cercospora leaf spot and rust of cowpea; black spot (*Cercospora* spp.), rust, and mottle of peanut. In most cases, the infections were light to moderate and occurred at the mature seed stage. Their effect on grain yield was negligible.

Cropping systems program

Design of cropping patterns

Multiple Cropping Department and Cropping Systems Components of Entomology, Agricultural Economics, and Plant Pathology Departments

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CUTOFF DATES FOR CROP SCHEDULING

Multiple Cropping Department

The rainfall probabilities described earlier (*see* Environmental description) were used to determine cutoff dates for purposes of crop scheduling. Assuming that 360 mm is lost as evapotranspiration in an 80-day rice crop, 100 mm is used during land preparation, and 100 mm of extractable water remains in the profile before land preparation, the crop water requirements to be met by rainfall are about 400 mm. This assumption is supported by data from on-farm testing of cropping patterns and production programs, which show that about 400 mm rain is required to achieve 4 t/ha from a second rice crop. Rainfall probabilities show that this requirement can be met 4 out of 5 times by transplanting rice before 30 September in Iloilo and before 30 August in Pangasinan.

To achieve double rice cropping, the first crop would have to be transplanted before 25 June in Iloilo and before 25 May in Pangasinan. Or the crop would have to be direct seeded (wet or dry) before the end of May in Iloilo and by 1 May in Pangasinan. Turnaround period between crops is 15 days.

Tests in 1978 revealed that, because of the slow land preparation, wet seeding of rice in puddled fields over a wide area requires about 300 mm of accumulated rainfall. Wet seeding could, therefore, be practiced before the end of May in less than 1 of 2 years in Iloilo. In Pangasinan wet seeding would be possible before 25 May in only 1 of 9 years.

However, 75 mm of accumulated rain was generally sufficient to obtain emergence and sustain early growth of dry-seeded rice. The chances for satisfying this requirement before the end of May (cutoff date for two-crop system) in Iloilo are 10 to 1; in Pangasinan the 74-mm rainfall can be expected in 3 of 5 years before the 25 May cutoff.

Landscape position modified field water regimes substantially (Table 1). Bottomlands were wet seeded an average of 2 weeks before paddies on the plain and plateau landscape position. The plain maintained standing water an average of 3 weeks longer than the plateau and side slope paddies.

Reduction of the field duration of the transplanted second rice crop to 75 days and of the direct-seeded second rice crop to 95 days shifts the second rice crop transplanting dates to 5

Table 1. Effect of landscape position on 3 rainfed field characteristics governed by water regimes. IRRI, 1978.

Landscape position	Av week of first crop establishment (wk no.)	Flooded days of first rice crop (av no.)	Av wk during which the field last held standing water (wk no.)
Bottomland	25	78	46
Plain	27	76	45
Plateau	27	76	41
Side slope	28	61	41

Table 2. Critical dates for the dry-seeded rice (DSR)-transplanted rice (TPR) pattern for selected sites in the Philippines, 1978.

Site	Seeding DSR[a]	Planting TPR[b]	Harvest TPR[c]	Remaining rain ≥100 mm[d]
Iba, Zambales	11 Jun	24 Sep	19 Dec	17 Oct
Deet, Camarines Norte	15 May	7 Sep	2 Dec	6 Mar
Tigbauan, Iloilo	30 May	22 Sep	17 Dec	13 Dec
Aparri, Cagayan	10 Jun	3 Oct	28 Dec	4 Feb
Laoag, Ilocos Norte	27 May	19 Sep	14 Dec	28 Oct
Dagupan, Pangasinan	12 May	4 Sep	30 Nov	4 Nov
Ambulong, Batangas	30 May	22 Sep	17 Dec	7 Dec
Baler, Quezon	22 Apr	15 Aug	9 Nov	11 Mar

[a]Cumulative rainfall exceeds 75 mm, $P = 0.80$. [b]115 days after DSR seeding. [c]85 days after TPR planting. [d]At $P = 0.80$.

October and first-crop direct-seeding dates to 15 June in Iloilo. In Pangasinan the second-crop transplanting date shifts to 5 September and the first-crop direct-seeding date to 15 May. These dates increase the chances for satisfying the 75-mm accumulated rain required for dry-seeded rice to nearly 100% for Iloilo and 90% for Pangasinan.

With the use of cumulative rainfall probabilities, critical dates for dry seeding (Table 2) and wet seeding (Table 3) of rice were evaluated for selected sites in the Philippines. It was assumed that dry seeding (DSR) takes place on or before the date that 75 mm of rain has accumulated, that seeding on puddled soil (WSR) takes place after 300 mm of rain has accumulated, and that the second rice crop can be transplanted 115 days after the first-crop seeding. The harvest date of the second crop can then be checked against the end-of-season date (remaining rain = 100 mm) to roughly determine the feasibility of double rice cropping under rainfed conditions in each site.

CROPPING INTENSITY TRENDS

Cropping Systems Component of Agricultural Economics Department

Cropping intensity trends were surveyed in Manaoag, Pangasinan, and among cropping systems research cooperators in Iloilo.

Pangasinan trends. Most farmers in Manaoag have upland and lowland areas. On the lowland they plant one or two crops of wetland rice, often preceded by corn or followed by mung bean. On the upland they plant dryland rice, with other crops grown at the same time or later. During 1978 cropping intensity in upland rainfed areas declined, mainly at the expense of nonrice upland crops. Cropping intensity in lowland areas increased, mainly by the addition of upland crops before and after rice. Overall cropping intensity and area of rice planted did not change.

Cropping intensity is high in Manaoag. It was 197 in a 1974–75 baseline survey and has remained at about that level among 36 farmers surveyed in 1977 and 1978 (Table 4). The adoption of new cropping patterns depends upon their profitability when compared with present technology. This is examined during cropping pattern testing, and is reported in the section Testing of cropping patterns, of this report.

Iloilo trends. In 1974 about 18% of farmland in Iloilo was double-cropped. A third of that was in a small irrigated area where two rice crops were grown. The multiple cropping index on a sample of 46 farmer cooperators in cropping systems studies since 1975 has increased to about 180.

Thirty-one percent of cooperators' farmland is now irrigated and 2 rice crops are grown; 57% of land is rainfed lowland and about half of that is double-cropped, some in rice-rice. The technique of direct seeding early maturing varieties is closely associated with increased multiple cropping on irrigated and rainfed lowland (Table 5). Direct seeding is commonly used for rice followed by an upland crop, but infrequently used for single rice crops.

With 1 carabao about 2 months are required to prepare and plant an average 2-ha farm. As a result size of the power base is a major determinant of farmers' capacity to multiple crop. Table 6 shows the relationship between number

Table 3. Critical dates for the wet-seeded rice (WSR)-transplanted rice (TPR) pattern for selected sites in the Philippines, 1978.

Site	Planting WSR[a]	Planting TPR[b]	Harvest TPR[c]	Remaining rain ≥100 mm[d]
Iba, Zambales	5 Jul	28 Oct	22 Jan	17 Oct
Daet, Camarines Norte	7 Jul	30 Oct	24 Jan	6 Mar
Tigbauan, Iloilo	5 Jul	28 Oct	22 Jan	13 Dec
Aparri, Cagayan	29 Jul	21 Nov	15 Feb	4 Feb
Laoag, Ilocos Norte	18 Jun	11 Oct	4 Jan	28 Oct
Dagupan, Pangasinan	13 Jun	6 Oct	31 Dec	4 Nov
Ambulong, Batangas	9 Jul	1 Nov	25 Jan	7 Dec
Baler, Quezon	30 May	22 Sep	17 Dec	11 Mar

[a]Total rain >300 mm at $P = 0.80$. [b]115 days after WSR seeding. [c]85 days after TPR planting. [d]At $P = 0.50$.

Table 4. [illegible]

Land type	Total farmland* (%)			Multiple crop index* (%)			Farmland (%) in use		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
Rainfed lowland	62	21	21	218	198	188	82	81	87
Irrigated lowland	7	64	61	204	200	236	88	88	83
Upland	11	15	18	174	169	141	21	32	37
Total	100	100	100	212	198	208	61	61	61

*Large areas of rainfed lowland became irrigated in 1977. Minor shifts in area by land type resulted from changes in the cement and area of irrigation pumps and land transactions by sample farmers. *Multiple cropping intensity = planted area ÷ total farmland × 100.

Table 5. At the cropping systems research site in Iloilo, Philippines, farmers widely practiced direct seeding of early-maturing varieties during the 1977–78 crop year with a resulting increase in multiple cropping in irrigated and rainfed areas.

Water regime	Area planted to various crops and crop sequences (%)					
	Rice, rice, rice	Rice, rice	Rice, other crops	Rice	Other crops	Total
Irrigated 12 wk*	1	22				23
Irrigated 8 wk*		8		1		9
Rainfed		10	17	28	2	57
Dryland			4		7	11
Total	1	40	21	29	9	100
Early-maturing varieties (%)	91	89	51	35		71
Wet-seeded rice (%)	90	94	69	54		81

*Period of irrigation beyond the rainfall period.

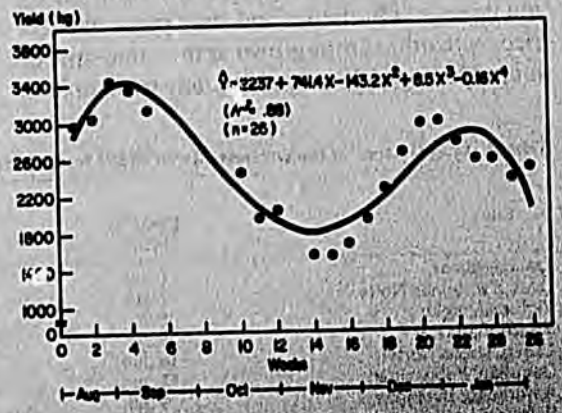
of carabaos owned by Iloilo farmers, area double-cropped, and turnaround time between crops. Accelerating turnaround requires additional hired power and the decision to muitiple crop is therefore tied to yield expectations.

Yield expectations. To examine rice yield expectations, 2-year data from 2 rainfed wetland rice areas with similar rainfall patterns were examined. To estimate the relationship between yield and week of harvest, average weekly yields of 500 rice plots in farmers' fields in Pangasinan and Iloilo in crop years 1975–76 and 1976–77 were used (Fig. 1).

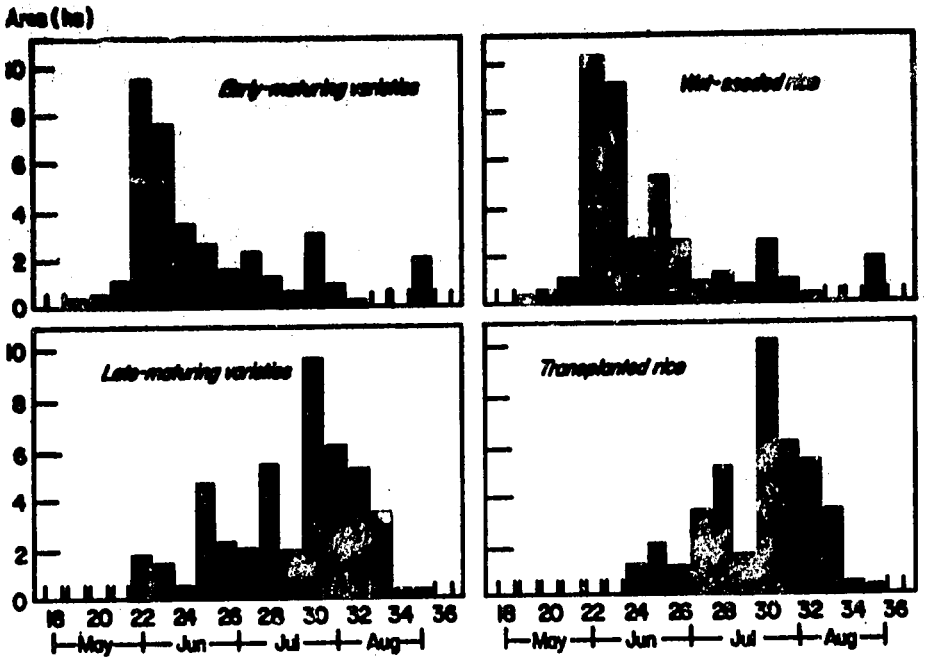
The data suggest that the highest total production on lowland can be expected from direct seeding of an early-maturing improved variety in mid-May for harvest in early September, and transplanting of a second crop for harvest in late December. A corroborative study in Iloilo showed that during 1976 farmers shifted from early-maturing varieties and direct seeding to later maturing varieties and transplanting about the end of June (Fig. 2).

Table 6. Number of carabaos per farm, area double-cropped, and turnaround days, Iloilo, Philippines, 1977–78.

Carabaos (no./farm)	Area of farm double-cropped (%)	Turnaround time (range in days)
0	18	25–31
1	29	19–29
2	42	14–26



1. Rice yield by week of harvest on 500 plots of 96 farmers in 1975–77, Pangasinan and Iloilo, Philippines.



2. Area of rice planted by 46 Iloilo farmers, by week of planting, varietal maturity period, and method of planting. Iloilo province, Philippines, 1978.

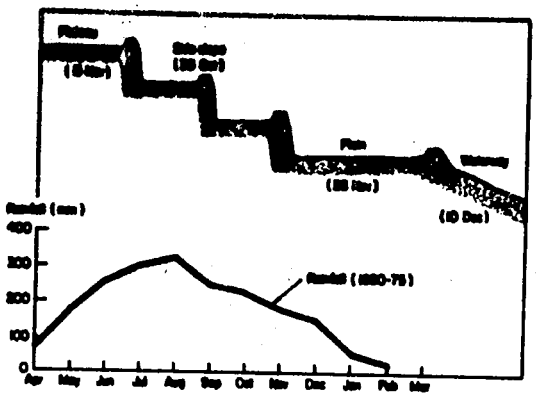
Power base and yield expectations are major factors in farmers' cropping strategies, but water-holding capacity of specific plots complicates decision making. Half of purely rainfed Iloilo farms are composed of a mix of landscape positions. Second crops must be planted earliest on side slopes, and can be planted latest on waterways (Fig. 3); usually more of the latter is double-cropped. In crop year 1977–78, double-cropping was done on 12% of rainfed side slopes, 28% of plateaus, 77% of plains, and 83% of waterways.

DISEASE AND INSECT CONTROL

Cropping Systems Components of Entomology and Plant Pathology Departments

Methodology in determining insect control recommendations. The challenge of insect control in cropping systems is determination of control regimes that meet farmers' requirements. Work on a methodology to systematize the determination procedure continued. The four-step methodology follows an overall scheme of description, design, testing, and preproduction evaluation.

I. Description
   A. Determining the need for insect control
      1. Quantifying yield loss by crop growth stage and translating such loss into economic terms through field trials.
      2. Pinpointing responsible target insects through population sampling.
   B. Understanding the target farmer
      1. Assessing the quality and quantity of resources used in insect control on existing cropping patterns through economics farm record-keeping data.
      2. Learning which insect control tactics farmers comprehend (chemical control, biological control, cultural control, host-plant resistance) through farmer interviews.
      3. Appreciating the factors currently limiting farmer adoption of technology.



3. Farmers' consensus on latest feasible planting dates of second rice crops by landscape position, rainfed lowland, Iloilo, Philippines, 1977–78.

II. Design — technology assessment
   A. Relying on proven technologies (i.e. those that have been tested in the country, mostly at experiment stations, and form the basis of national recommendations).
   B. Selecting the most appropriate technology to test at the sites as determined from the results of the descriptive phase and its economic analysis.

III. Testing—verification of the technology, at the sites, by researchers
   A. Testing the technology on each crop under the conditions in which it is grown in actual cropping patterns in farmers' fields to determine environmental interactions.
   B. Testing the technology at the management level as determined by the other team members.

IV. Preproduction evaluation
   A. Evaluating the farmers' performance in executing the technology.

The methodology developed is highly flexible. It can be adapted for any crop, requires little data gathering, and can be performed and interpreted by staff with minimal training. The methodology assumes that, if available, appropriate insect-resistant varieties will be used. Focus is, therefore, on management decisions regarding insecticide usage and cultural control techniques that use less cash and labor resources.

The methodology is applied for each crop in the patterns tested at a site, even rice-rice. Large plots (exceeding 50 m²) are grown in farmers' fields with management practices recommended by a research team. To determine site interactions, treatments are replicated across, not within, farms and a minimum of four farms (replicates) is suggested. Pest populations are monitored during the crop season by standard sampling procedures. Broad-spectrum insecticides are applied at high dosages to determine the impact of damage by eliminating pests as much as possible. Combinations of treatments covering the various plant growth stages permit partitioning of yield loss among growth stages to show the optimal timing of recommended insecticides. The trials are repeated 2–3 years for each crop at each site to establish treatment reliability. Provisional pest

Table 7. Experimental design and methodology used to determine insect control recommendations for first-crop, wet-seeded rice (IR36).[a] Iloilo, Philippines, 1978.

Treatment	Insecticide	Yield[b] (t/ha)
Complete protection	a. 1.0 kg a.i. carbofuran granules/ha, soil incorporated before seeding b. 0.75 kg a.i. endosulfan/ha, sprays at 45 and 55 DE[c] c. 0.75 kg a.i. carbaryl/ha, sprays at postflowering and premilky stage	4.5 a
No protection at vegetative stage	b and c only	4.0 b
No protection at reproductive stage	a and c only	4.6 a
No protection at ripening stage	a and b only	4.3 ab
Untreated control	None	3.8 c
Recommended practice	Economic thresholds (0.75 kg a.i. carbaryl/ha for caseworm and rice bug = 3 sprays)[d]	4.4 a

[a]Av of 5 fields. Randomized complete block design, unreplicated within fields. [b]Means followed by a common letter are not significantly different at the 5% level. [c]Days after emergence. [d]Insecticide cost = $20/ha, 0.1 t rice costs $15.

control recommendations for each crop are specified at the beginning of cropping pattern testing for each site. The recommendations are revised each year on the basis of the results of the loss trials.

Insect control on rice. The growth stages (and the expected insects) for rice in the Philippines are seedbed (armyworm, caseworm), vegetative (whorl maggot, caseworm, stem borer), reproductive (stem borer, leaf folder), and ripening (rice bugs). There is no seedbed stage in direct-seeded rice.

Partitioning of the yield loss among the growth stages involves two check plots: a plot protected at all growth stages with high levels of insecticides to determine the yield potential of the crop free of insect damage, and an untreated check plot. In additional plots for each growth stage, all growth stages except one are protected. This is illustrated by the first-crop, wet-seeded rice in Iloilo province (Table 7). The performance of the recommended insect control practice is measured against that of the other treatments.

The 1978 recommendation for first-crop, wet-seeded rice in Iloilo was to apply insecticide only when the economic thresholds were surpassed. It was necessary to spray with carbaryl (0.75 kg a.i./ha) once (during the vegetative stage) for caseworm and twice (ripening stage) for rice bug.

The total yield loss (the difference between the complete-protection and untreated checks) was significant — 0.9 t/ha (4.5 t/ha – 3.6 t/ha). The yield loss of 0.5 t/ha (4.5 t/ha – 4.0 t/ha) during the vegetative stage was significant. A yield loss of 0.2 t/ha (4.5 t/ha – 4.3 t/ha) during the ripening stage was not significant even though rice bugs surpassed the economic threshold.

The yield from the recommended-practice plot was significantly higher than that from the untreated check and was statistically equal to the yield of the complete-protection plot. The value of the rice saved ($120.55/ha) was 6.1 times the cost of the insecticide ($19.73). It was concluded that the recommended insect control was optimal for first-crop, wet-seeded rice in Iloilo.

Insect and disease control for mung bean. The same basic methodology was used for mung bean to determine insect and disease control recommendations for Pangasinan province in the 1978–79 crop year. The two growth stages for mung bean are preflowering and postflowering. The recommended insect control for crop year 1977–78 was 0.25 kg a.i. monocrotophos/ha at 2 and 12 days after emergence (DE) (preflowering) and 0.75 kg a.i. endosulfan/ha at 35 and 45 DE (postflowering). The recommended disease control measure was 2 applications of 0.5 kg a.i. thiophanate-

Table 8. Experimental design and methodology for determining insect and disease control recommendations for 3 mung bean[a] planting dates after rice. Pangasinan, Philippines, 1977–78.

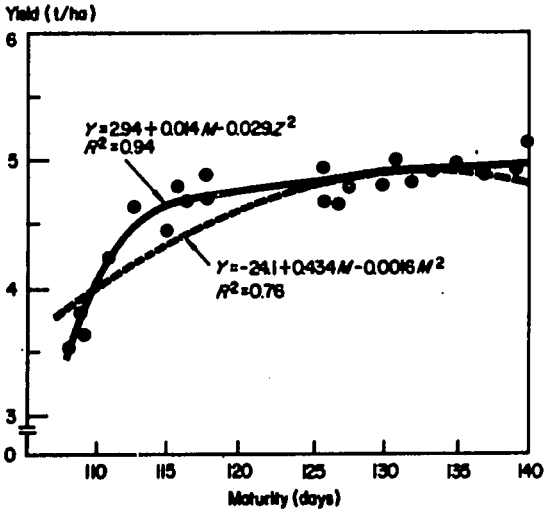
Treatment	Insecticide	Fungicide	Yield[b] (t/ha)		
			Nov	Dec	Jan
1. Complete protection	a. Preflowering protection 0.50 kg a.i. monocrotophos/ha 2, 12, and 25 DE b. Postflowering protection, 1.0 kg a.i. endosulfan/ha 35 and 45 DE	0.50 kg a.i. benomyl/ha 30 and 37 DE	1.23 a	1.61 a	1.16 a
2. Recommended practice[c]	a. Preflowering 0.25 kg a.i. monocrotophos/ha 2 and 12 DE b. Postflowering protection, 0.75 kg a.i. endosulfan/ha 35 and 45 DE	0.50 kg a.i. thiophanate-methyl, 30 and 35 DE	1.16 ab	0.58 b	1.00 a
3. Recommended practice	2a and 2b	None	1.06 b	0.40 bc	0.82 b
4. Recommended practice[d]	2a only	None	0.87 c	0.82 a	0.43 b
5. Untreated control	None	None	0.40 d	0.04 d	0.11 c

[a]CB514. Av of 4 fields/planting date. Randomized complete block design, unreplicated within fields. DE = days after emergence. [b]Duncan, means followed by a common letter are not significantly different at the 5% level. [c]1977 recommendation based on [illegible] and fungicide protection. [d]Designed to partition the yield loss due to insect damage among the preflowering and postflowering stages.

methyl/ha 7 days apart when powdery mildew disease exceeded 10% of the leaf area. The insect and disease control recommendations were tested over three planting dates, representing different cropping patterns of mung bean after single- or double-cropped rice (Table 8).

The results of the November planting revealed that insects caused a yield loss of 0.83 t/ha (1.23 t/ha–0.40 t/ha), none of which could be attributed to diseases (1.16 t/ha vs 1.05 t/ha). The recommended insecticide regime gave optimal insect control (1.23 t/ha vs 1.16 t/ha). Seventy-two percent of the yield loss was due to preflowering insect pest damage (1.05 t/ha– 0.40 t/ha = 0.65 t/ha; 0.87 t/ha– 0.40 t/ha = 0.47 t/ha; 0.47 + 0.65 = 72%) and 18% occurred during the postflowering stage.

The December planting had no significant yield loss from diseases (0.58 t/ha vs 0.40 t/ha); however, the recommended insect control regime was suboptimal (1.61 t/ha vs 0.58 t/ha) and resulted in a yield loss of 1.03 t/ha. The loss was due to postflowering insects — omitting postflowering protection gave a yield equal to that of the untreated plot. *Heliothis* pod borer was particularly abundant in the December planting.



4. Mean grain yield vs maturity of 22 selected entries from the fifth international rice yield nurseries (IRYN-E, IRYN-M). IR36, currently used extensively in cropping systems research at IRRI, had a mean maturity of 118 days and yield of 4.8 t/ha in the yield nursery.

Powdery mildew heavily damaged the January planting. Lack of fungicide resulted in a 48% yield loss (1.00 t/ha– 0.52 t/ha); however, the recommended pesticide protection was adequate (1.16 t/ha vs 1.00 t/ha). The *Heliothis* population was low in the January planting; only 22% of the loss from insects was attributed to postflowering pest damage (0.52 t/ha– 0.11 t/ha = 0.41 t/ha; 0.43 t/ha– 0.11 t/ha = 0.32 t/ha; 0.32 t/ha + 0.41 t/ha = 78%; 100% – 78% = 22%).

As a result of the study, the postflowering insect control practice for the 1978–79 crop year was revised to include 2 prophylactic treatments of 0.75 kg a.i. carbaryl/ha at 25 and 35 DE to control pod borers. A new powdery mildew-resistant mung bean variety (CES 1D-21), which was identified in 1977–78 variety trials, eliminates further foliar fungicide application.

INFLUENCE OF THE RICE VARIETY'S MATURITY ON YIELD

Multiple Cropping Department

Yield and crop duration (maturity) are major considerations in the selection of rices for cropping patterns. The relationship between these factors were explored using data from the 1977 early and medium (fifth) international rice yield nurseries (IRYN-E, IRYN-M). Twenty-two entries in both nurseries were tested at 20 sites. To select the appropriate set of entries for analysis, the overall mean yield of each variety was plotted against its mean maturity, and a curve was constructed of line segments connecting the earliest maturing entry with successive later maturing but higher yielding entries. The entries falling within 0.33 t/ha of the curve were used in the analysis. They were assumed to be the most advanced entries from varietal improvement programs and, except for check entries, would not be available to farmers on a large scale in the near future. It was also assumed that within each maturity interval, the selected entries reflected the current maximum attainable yields.

A quadratic model, $Y = a + bM + cM^2$ — where Y is yield (t/ha) and M is maturity (days) — was used to estimate one equation to

describe the relationship between yield and maturity, and a grafted polynomial model, $Y = a + bM + cZ^2$ — where Y is yield (t/ha), M is maturity (days) and $Z = M - C$ when M is less than a fixed value C, but zero otherwise — was used to estimate a second equation. The second equation was fitted by incrementing C over a range of maturity values to minimize the residual sum of squares. The value found for C was 114 days (Fig. 4).

R^2 for the grafted polynomial model was significantly greater than the value for the quadratic model, indicating a better fit to the data points. In addition, the grafted polynomial model also produced a better biological fit: its yield estimates in the maturity range of 110 to 115 days are in accord with observed yields, and it does not predict declining yield potential for rices of greater than 136 days maturity.

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

Cropping systems program

Testing of cropping patterns

Multiple Cropping Department, Cropping Systems Components of Agronomy, Agricultural Economics, and Entomology Departments, and Rice Production Training and Research Office

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Cropping systems research at sites in Iloilo and Pangasinan provinces entered a third year of cooperation with the Philippine Bureau of Plant Industry. Only patterns that previous testing had indicated as promising were tested.

PANGASINAN TESTS

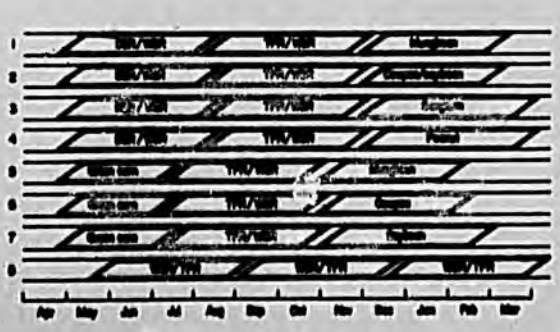
Multiple Cropping Department and Cropping Systems Components of Agronomy, Agricultural Economics, and Entomology Departments

Of 12 cropping patterns tested in Pangasinan during crop year (CY) 1976–77, 8 patterns (Fig. 1) warranted retesting in CY 1977–78.

Figure 2 presents monthly rainfall totals from April to March for 1976 and 1977 and mean totals based on 26 years of data. The deviations in 1977 rainfall relative to the previous years' and the long-term point out the decision-making problems farmers face.

Patterns 1 to 4 were tested in rainfed and partially irrigated fields. The latter received irrigation water to supplement rainfall from June until mid-December in some fields, but irrigation after mid-October became progressively unreliable. The rice-rice-upland crop (R-R-UC) patterns proposed for 52 farmers' fields were completed as designed only on 16 fields.

Patterns 5 to 7 were tested on rainfed and pump-irrigated fields and on soils with moderately rapid drainage. Where used, the pump irrigation system moistened the soil, reduced draft power requirements, and facilitated rapid emergence and early growth of corn. Of the 17 farmers' fields for which green corn-rice-upland crop (GC-R-UC) patterns were proposed, only on 14 were the patterns strictly followed.



1. Cropping patterns tested in Pangasinan, Philippines, in crop year 1977–78. DSR = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice.

Pattern 8 was designed for fields located near free-flowing wells in the shallow water table sector, where three successive rice crops (R-R-R) appeared agronomically feasible. Of the nine farmers' fields for which R-R-R patterns were proposed, eight followed the patterns.

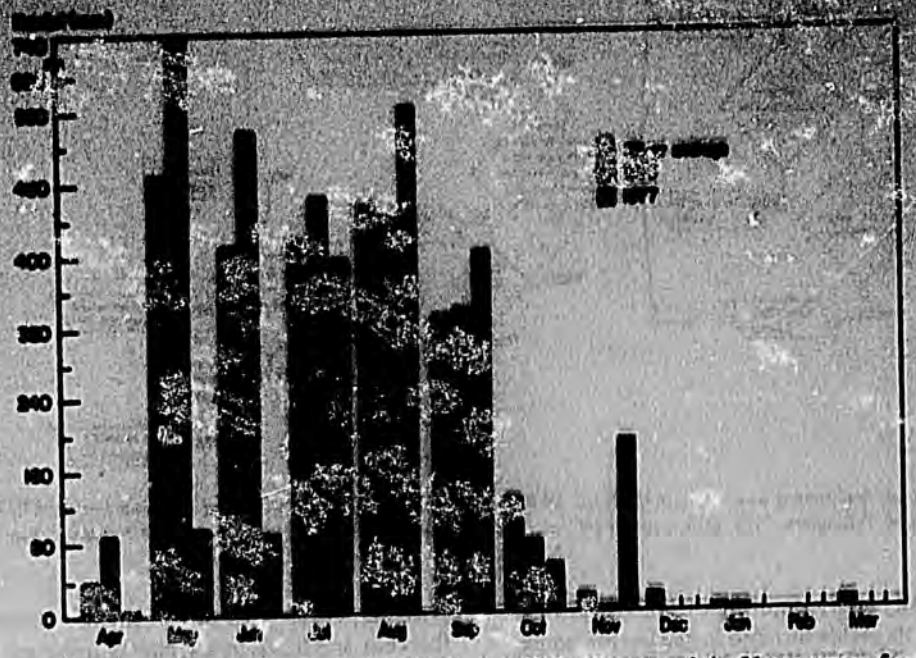
The high frequency of completion of GC-R-UC and R-R-R patterns indicated that the two were agronomically adapted to the fields where they were tested, and that farmers could meet their cultural requirements.

Because of limited success with the R-R-UC patterns, data were examined to determine the reasons for the low completion rate. Of the possible patterns in the R-R-UC group, those with dry-seeded rice (DSR) as a first crop and transplanted rice (TPR) as a second crop were emphasized because comparisons of the water requirements for these two crops with historic rainfall data had indicated that early DSR crops were necessary if second TPR crops were to be successful (*see* Environmental description). The 52 farmers who agreed to test R-R-UC patterns also agreed to dry-seed the first crop and transplant the second. IR36, which previous tests at the sites had shown to be well adapted to planting methods for both DSR and TPR, was used for both crops. The initial 52 farmer-cooperators were reduced to 48. Of the 32 who transplanted a second rice crop, 16 planted a succeeding upland crop.

Farmers gave several reasons for inability to complete the proposed DSR-TPR-UC pattern:

- late seeding of DSR because land preparation could not be started until after rains began.
- poor germination of seeds distributed by the project for the TPR crop, which required a second nursery planting,
- competition with other activities for labor,
- high risk of water shortage for the TPR and UC, and
- lack of access to fields by draft animals because intervening fields contained rice crops.

Table 1 shows that 21 of 24 DSR fields planted after 31 May deviated from the DSR-TPR-UC pattern, and 12 of 23 fields planted before 1 June completed DSR-TPR-UC pat-



2. Monthly rainfall distribution for April 1976–March 1977 for Lingayen and the 26-year average for Dagupan City, Pangasinan, Philippines.

terns. Considering reasons given for noncompletion (but assuming availability of viable TPR seeds), a simple decision diagram that leads to DSR-TPR-UC, DSR-TPR, or DSR-UC patterns is presented in Figure 3. The rice yield levels shown are averages obtained from CY 1977–78 pattern tests. For upland crops relative yields are shown; these are based on project site variety trial yields of 0.8 t/ha for mung bean, 0.6 t/ha for cowpea, and 2.4 t/ha for sorghum.

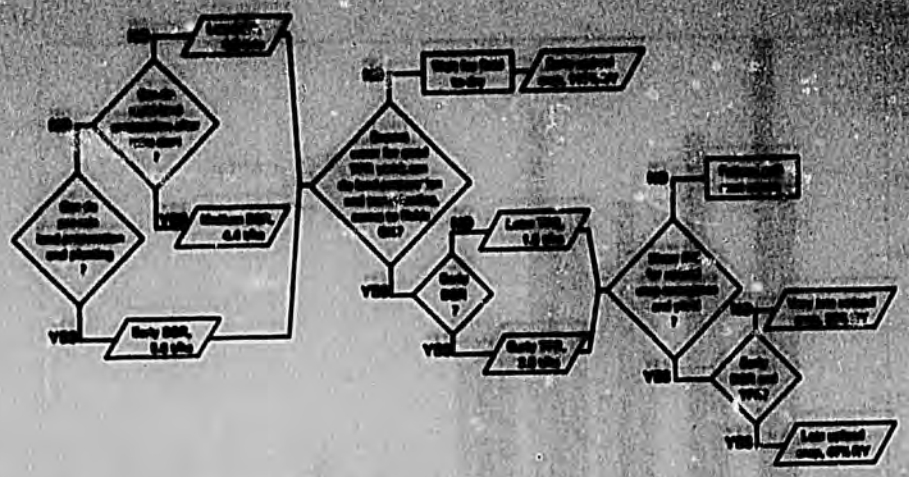
Early planted DSR had higher yields than later planted crops, but the reason for the difference was not clear. Delayed DSR plantings also affected the yield of the following TPR and UC through the water regime differences (Fig. 3).

A 1 June planting of a DSR with a field duration of 115 days (IR36) would be harvested on 24 September (Fig. 4) and a second crop could be planted on 1 October if 1 week is required to prepare the field. On the basis of rainfall records, 400 mm of rain was expected to fall between 1 October and the end of the wet season in 1 of 10 years. But in CY 1977–78, there was only 240 mm of sporadic rainfall between 1 October and the date by which a transplanted IR36 crop would have been close to harvest. Eight fields partially irrigated between mid-November and mid-December produced TPR yields 1.5 t/ha higher than fields relying on rainfall or irrigation that ceased before mid-November. Farmers who attempted a late-planted second rice crop obtained low yields regardless of irrigation class and were unable to plant a following upland crop. Farmers who decided to plant an upland crop after a single rice crop had to wait for the fields to dry sufficiently to protect upland crop from later damage from excessive moisture.

Table 1. Distribution of 48 patterns, as affected by time of seeding dry-seeded rice, Mangalag, Pangasinan, Philippines, crop year 1977–78.

Time of seeding	Farmer (no.)		
	DSR-TPR-UC	DSR-TPR	DSR-UC
Before 12 May	1	—	—
13-31 May	3	1	1
22-31 May	6	6	4
1-7 Jun	2	6	3
8-15 Jun	1	1	4
Beyond 16 Jun	—	—	1
Total	13	14	13

DSR = dry-seeded rice, TPR = transplanted rice, UC = upland crop.

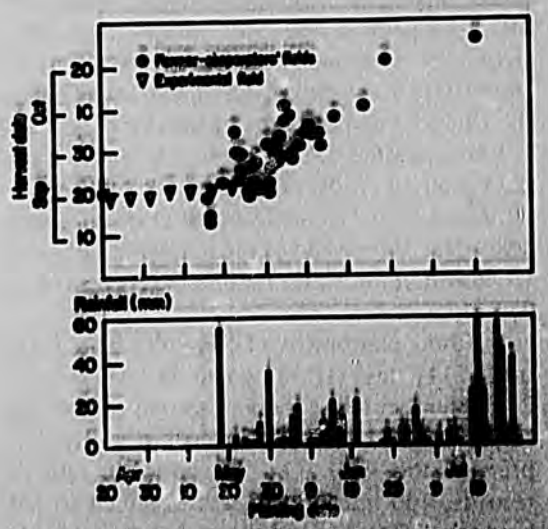


3. Schematic for determining which pattern (DSR-UC, DSR-TPR, or DSR-TPR-UC) will be planted in a rainfed or partially irrigated Panguinan field. Philippines, 1978. DSR = dry-seeded rice, TPR = transplanted rice, UC = upland crop, RY = relative yield.

Apparently early planting of DSR is critical not only to its yields but also to the performance of the crop following it. It was obvious, however, that most farmers waited until rains began before preparing DSR fields. The effects of soil moisture on energy requirements and tillage quality have been well established in tillage studies by agricultural engineers and soil physicists. Field conditions will still favor planting delays at the start of the season, even if mechanical tillage equipment becomes available, because of power input differences before and after the soil becomes wet.

The availability of water to the second rice crop in both DSR-TPR-UC and GC-TPR-UC patterns is critical to the performance of that crop. Besides the difference in irrigation duration cited earlier, soil texture, landform, and water table depth have been suspected to alter water availability. To more clearly isolate differences between the factors, a regression model was used to remove the influence of a flooded day (F) from the yield variability in 45 cases where a second rice crop had been grown in DSR-TPR-UC or GC-TPR-UC patterns. The salient statistics on four models are presented in Table 2.

A water table (W) dummy was used to distinguish between fields in a sector of the project area (Cuarteyan) where the water table remains within 2 m of the surface throughout the year and fields in a sector (Lipit-Pao) where the table drops to below 3 m during the dry season. A soil texture (T) dummy was used to distinguish between fields that had clay, silty clay, or clay loam textures and fields that had silty clay loam, silt loam, loam, or sandy loam textures. A landform (L) dummy was used to dis-



4. Planting date vs harvest date of dry-seeded rice in farmers' cooperators' and experimental fields, rainfall, and [illegible] during the planting period (Apr.–Jul.), 1978.

[illegible]

Variable	Estimated coefficient	t-value	Probability
	Model 1		
F	94.3	2.38	0.023
F^2	−0.583	−0.89	0.487
Intercept	1261.2	3.69	0.0008
R^2	0.479	—	0.0001
	Model 2		
W	−1334.0	−3.82	0.0003
F	92.8	2.70	0.010
F^2	−0.156	−0.22	0.830
Intercept	1730.7	5.44	0.0001
R^2	0.621	—	0.0001
	Model 3		
L	−383.0	−1.06	0.295
F	89.5	2.24	0.031
F^2	−0.484	−0.56	0.577
Intercept	1542.1	3.57	0.0003
R^2	0.483	—	0.0001
	Model 4		
T	−816.1	−2.32	0.026
F	95.4	2.51	0.016
F^2	−0.623	−0.80	0.431
Intercept	1565.8	4.46	0.0001
R^2	0.539	—	0.0001

*F = flooded day, i.e., simply a day in which there is standing water on the field. See text for a description of the independent variables. *W* = 1 for deep water table and 0 for shallow water table, *T* = 1 for light-textured soils and 0 for heavy-textured soils, *L* = 1 for nonwaterways.

tinguish between fields located in broad, natural drainageways through which water from surrounding higher fields flows, and fields that would not receive appreciable runoff from surrounding fields.

The negative coefficient for the water table dummy variable indicates that yield would be 1.3 t/ha lower in the deep water table sector after adjusting to a common number of flood days. The moisture-sustaining effect of the shallow water table and the higher natural soil fertility (higher soil organic matter) are two possible factors contributing to the higher yields in the shallow water table sector.

The negative coefficient for the landform dummy variable suggests (with weak statistical significance) that apart from the influence of landform on the number of flooded days, lower yields should be expected in nonwaterway positions. The additional water from surrounding fields, which accompanies lower positions, not only leads to a greater number of flooded days, but also maintains more nutrients and moisture. Differences in natural fertility may also explain part of the yield increase.

The negative coefficient for the textural dummy indicates that light soil texture would decrease yields apart from influencing the number of flooded days. The beneficial effects of heavy texture may be due to reduced deep percolation and higher natural fertility. The addition of more than 2 variates to the model, including interactions among *F*, *L*, *W*, and *T*, showed that the 4 explanatory variables acted additively and independently in accounting for yield variability in the second crop in the set of 45 observations.

ILOILO TESTS

Multiple Cropping Department and Cropping Systems Components of Agronomy, Agricultural Economics, and Entomology Departments

During 1977–78 three general cropping patterns were tested in Iloilo (Table 3). In the first pattern, the first crop was either DSR or WSR, the second crop was either WSR or TPR, and the following upland crop was either mung bean or cowpea. The second pattern consisted of WSR or TPR followed by an upland crop (sorghum, peanut, mung bean, or cowpea). The third pattern had green corn as the first crop, followed by either WSR or TPR, and then either mung bean or cowpea as a third crop. The three patterns were allocated to a total of 96 fields distributed on plateaus, plains, side slopes, and bottomlands.

The CY 1977–78 rainfall had a delayed onset, an extremely high peak, and an early end (Fig. 5). Only 4 months had more than 200 mm of rain compared with 5 months in the long-term means. May rainfall was half the long-term average and June, July, August, and September were all wetter than in the preceding year or the 25-year means.

Measured by the criteria of 75 mm and 100 mm remaining for the start and end of the growing season (see Environmental description), the

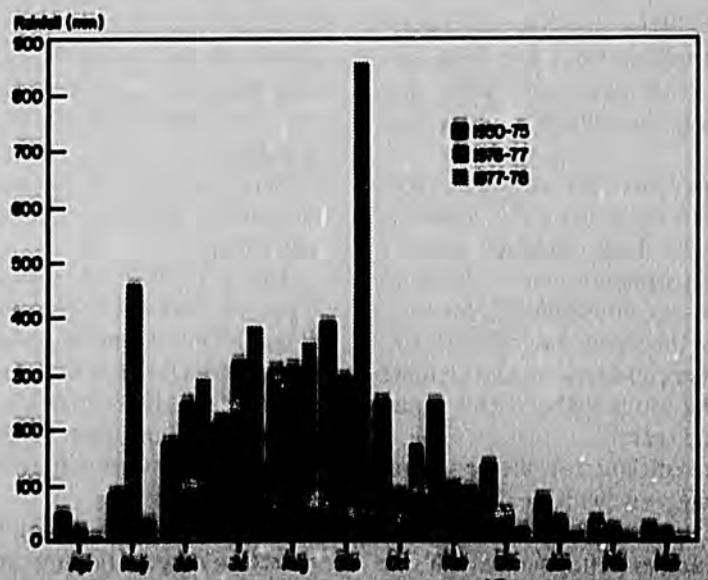
[illegible]

[illegible]	Plain	Plateau	Side slope	[illegible]	[illegible]
[illegible]	4	1	1	—	6
[illegible]	6	1	1	6	14
[illegible]	—	—	—	4	4
[illegible]					
[illegible]	2	3	3	—	8
[illegible]	2	3	3	—	8
[illegible]	2	3	3	—	8
[illegible]	2	3	3	—	8
[illegible]	2	3	3	—	8
[illegible]	2	3	3	—	8
Green corn-rice-upland crops					
[illegible]	2	5	3	—	10
[illegible]	2	5	3	—	10
Total					96

[illegible] = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice, M = mung bean, CP = cowpea, S = sorghum, SB = soybean, P = peanut, SP = sweet potato.

CY 1977–78 growing season was only 151 days long compared with the long-term average of 212 days. The delayed, but abrupt, onset of rain greatly affected first-crop planting dates.

The distribution of the 96 first crops actually grown, after 2 cooperators' fields were shifted from plateau to plain position, is summarized in Table 4. All green corn plots were shifted to WSR, entirely eliminating the green corn-rice-upland crop pattern group. Of the seven DSR fields planted, six were on plateau and side slope positions where water took longer to accumulate. Rapid water accumulation on the plains prompted farmers to puddle and wet-seed or transplant the first crop instead of dry seeding it. Over all landscape positions, most (72%) of the first crops were established as WSR but the proportion of TPR was greater within the side slope position. Partly because seedling production could not be easily coordinated so that



5. Comparison of 1977–78 monthly rainfall with that of 1976–77 and the 25-year average, Tigbauan, Iloilo, Philippines.

Table 4. Summary of the first crops actually grown, Iloilo, Philippines, crop year 1977–78.

Pattern component*	Fields (no./landscape position)				Total
	Bottom-land	Plain	Plateau	Side slope	
GC	—	—	—	—	0
DSR	—	1	4	2	7
WSR	10	25	22	12	69
TPR	—	2	4	14	20
Total	10	28	30	28	96

*GC = green corn, DSR = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice.

seedlings of an optimum age were ready for transplanting as soon as fields were puddled, only 20 fields were transplanted, and those were predominantly on the side slopes.

The average week when the rainfed first crop was established varied by landscape position (Table 5). Fields in the bottomlands were planted as early as the second week of June (week 24) or about 1 week after the first rains. Most crops were established in the bottomlands during weeks 25 and 26. Fields in the plateau and plain positions were planted between weeks 25 and 31, with a peak in week 27. The difference in planting dates related to earliness of water accumulation. In general, water accumulates in the order 1) bottomlands, 2) plain, 3) plateau, and 4) side slopes.

Yields obtained from rainfed first rice crops in the different patterns varied by landscape position, as expected. Among landscape positions, bottomlands produced the highest mean yield (6.1 t/ha), and side slopes the lowest (4.6 t/ha). Yields from plateaus averaged 5.1 t/ha; those from plains, 4.9 t/ha. The differences in first rice crop yields were in accord with differences in water regimes as described for CY 1976–77 (1977 Annual Report) and the number of flooded days during the time the crop was in the field (Table 5).

Depending on the pattern, rice or upland crops were designed as second crops for the four landscape positions (Table 3). Because of low October rainfall, 42% of the rice crops proposed for plain, plateau, and side slope positions were replaced with upland crops (Table 6). Most of the shifts to upland crops were in the plateau and side slope positions where water receded rapidly. On the other hand, a few fields in plains, plateaus, and side slopes that had been proposed for upland crops were harvested early and shifted to rice.

Method of establishment and landscape position greatly affected the yields of the second crop. In rainfed fields, transplanted second rice crops had higher average yields (2.2 t/ha) than wet-seeded second rice crop (1.5 t/ha). Transplanted crops were an average of only 3 days earlier than wet-seeded crops, but, depending on age of seedlings when transplanted, escaped late drought because they were harvested 2–4 weeks earlier. Fields in bottomlands outyielded higher fields. As shown in Table 5, the average week of drying varied by landscape position.

As it became apparent toward the end of some first crops that stress conditions were likely to persist because of lateness in season or of field position, farmer-cooperators who doubted the suitability of a second rice crop and were also reluctant to plant an early upland crop were encouraged to try a ratoon rice crop. Six fields with a ratoon crop produced average yields of 0.8 t/ha in 42 days.

Original cropping pattern designs included soybean and sweet potato, but they were replaced with one of the other upland crops — cowpea, mung bean, peanut, or sorghum —

Table 5. Effect of landscape position on 3 rainfed field characteristics governed by water regimes, Iloilo, Philippines, crop year 1977–78.

Landscape position	Av week of first crop establishment (wk no.)	Av no. of flooded days on first rice crop	Av week during which the field last held standing water (wk no.)
Bottomland	25	78	48
Plain	27	78	45
Plateau	27	78	41
Side slope	28	61	41

Table 6. Proposed, actual, upland, and actual second crop of upland cropping patterns by landscape position, Iloilo, Philippines, crop year 1977–78.

Landscape position	Fields* (no.)							
	Proposed		Skipped		Unplanned		Actual	
	Rice	UC	Rice	UC	Rice	UC	Rice	UC
Backyarded	8	—	—	—	—	—	8	—
Plain	16	9	2 UC	4 Rice	2	2	16	5
Plateau	15	14	11 UC	2 Rice	2	3	4	25
Side slope	9	17	9 UC	1 Rice	—	4	1	21
Total	48	40	22	7	4	9	29	46

*UC = upland crops.

because soybean yields had not been promising the 2 previous years and there was a lack of market for a large volume of sweet potatoes. Mean yields of mung bean, cowpea, and sorghum planted after a single rice crop are shown by landscape position in Table 7. About 30% of the plantings produced no yield because of drought. As shown in Table 6, most upland crops following one rice crop were on side slopes and plateaus. Original pattern designs had assumed an upland crop would follow two rice crops in the wetter landscape positions, but because of drought, no third crops were attempted.

Rainfall between late October and mid-January in Iloilo province is generally erratic. During this period even partially irrigated areas are strongly dependent on rainfall to supplement reduced irrigation flow. To gauge the risk of low rainfall over the second crop period, a wet and dry pentad (5-day period) diagram was constructed. When a group of 3 consecutive pentads have a total rainfall that exceeds 53 mm, or when any 2 of the 3 have individual rainfall totals that exceed 9 mm, the middle is considered a wet pentad. Figure 6 shows that year-to-year conditions over 23 years of observations differed in the November-January period.

Based on these data and other analyses presented earlier (*see* Environmental description), rice as a second crop is risky in rainfed Iloilo areas, except in lower positions, which received water from higher elevations. Even grain legumes as a second crop appear vulnerable in many years.

A simple schematic diagram, which assumes a starting point of sufficient water accumulation for puddling a rainfed field, is shown in Figure 7. It indicates decisions a farmer must make over a growing season in any of the four landscape positions. Either a WSR or a TPR crop is grown as the first crop, but subsequent crops may be full rice, ratooned rice, or an upland crop.

Although four water source classes occur within the Iloilo test site, test patterns were concentrated in rainfed fields in CY 1977–78. Only 8 partially irrigated test fields — with supplemental water for about 1 month beyond the end

Table 7. Yields of upland crops planted after 1 rice crop, by landscape position. Iloilo, Philippines, crop year 1977–78.

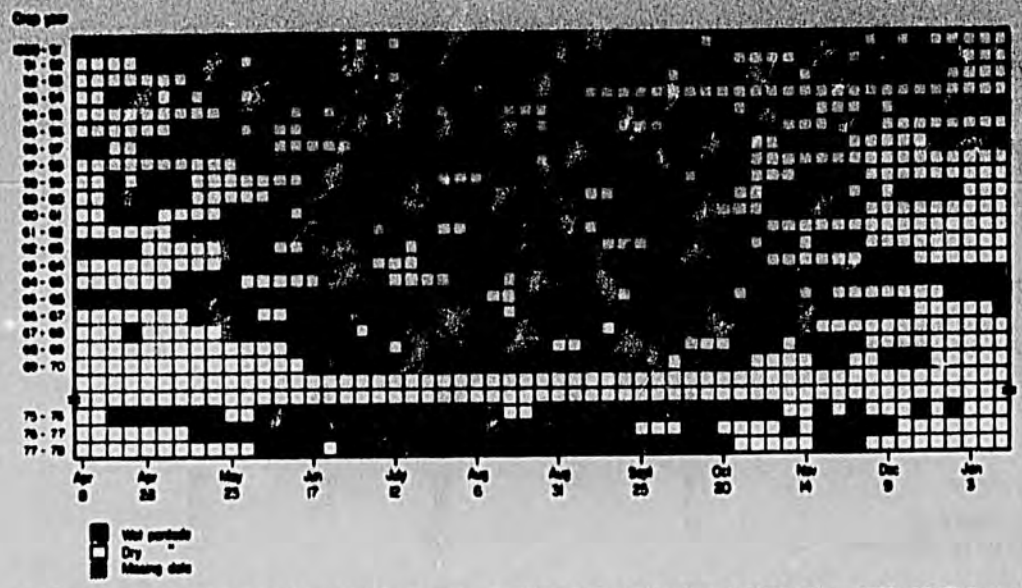
Crop	Landscape position	Fields (no.)	Yield* (t/ha)
Mung bean	Side slope	7	0.7 (2)
	Plateau	7	0.8 (2)
	Plain	2	0.9 (0)
Cowpea	Side slope	7	1.1 (2)
	Plateau	7	0.2 (4)
	Plain	3	0.6 (1)
Sorghum	Side slope	5	2.7 (0)
	Plateau	4	2.2 (1)
	Plain	1	2.8 (0)
Peanut	Side slope	2	0.5 (1)
	Plateau	2	0.9 (1)
	Plain	—	—

*Each value in parentheses indicates number of failures. The failures were included as zero yield in the computation of yields.

Table 8. Yields of the first and second rice crops across pattern groups by water source class. Iloilo, Philippines, crop year 1977–78.

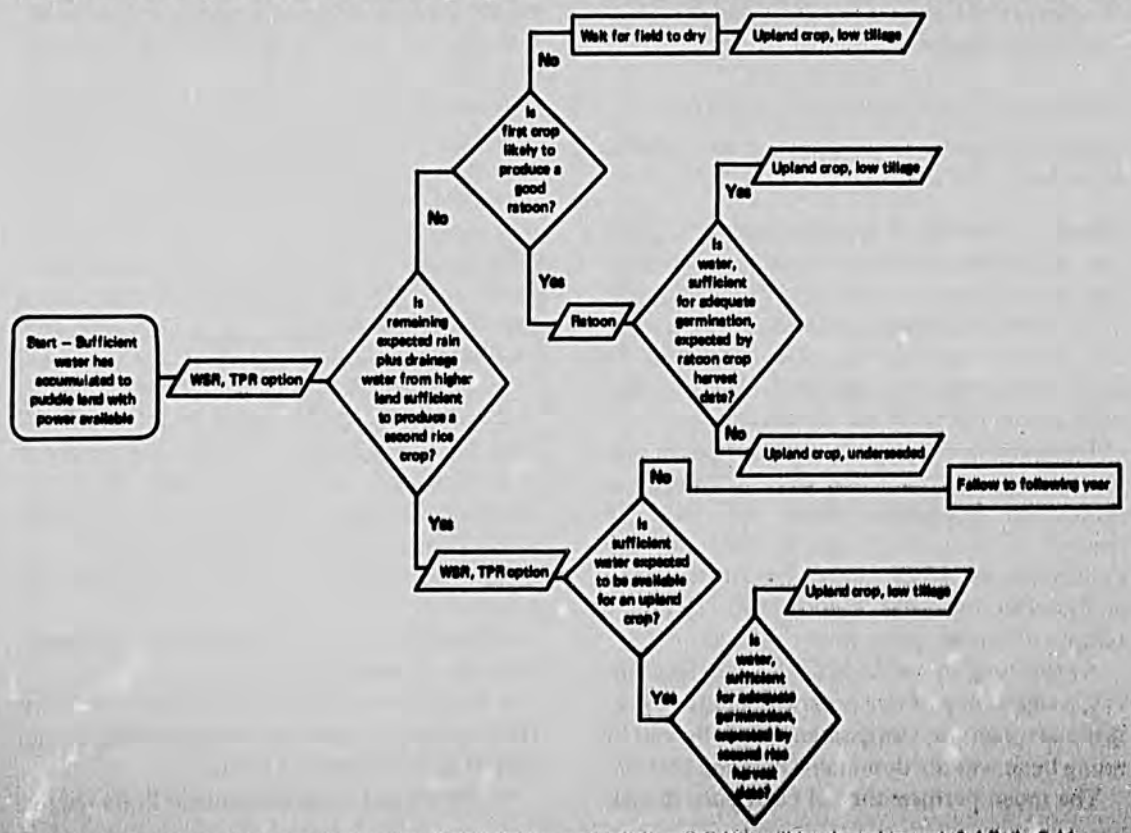
Water source class	Yield* (t/ha)		Failures (no.)	
	Crop 1	Crop 2	Crop 1	Crop 2
Entirely rainfed	0.2 (29)	1.6 (29)	0	0
Partially irrigated	0.6 (8)	2.4 (7)	0	1

*Each value in parentheses indicates number of observations.



6. Wet and dry 5-day periods (pentads) for crop years 1950–51 to 1969–70 and 1975–76 to 1977–78, Tigbauan, Iloilo, Philippines.

of the dry season — were used. To examine the impact of partial irrigation on the yields of first and second rice crops, mean yields of these two crops were compared across landscape positions (Table 8). Average yields in partially irrigated fields were about 1.5 t/ha higher and the period of flooding was 13 days longer than in rainfed fields. Similar flooding differences and



7. A schematic to determine which pattern (R-UC, R-Ratoon-UC, R-R or R-R-UC) will be planted in a rainfed Iloilo field.

Table 9. [illegible]

Cropping pattern	CY [illegible]		CY [illegible]		CY [illegible]	
	E	F	E	F	E	F
Iloilo						
Rice	10	20	8	20	13	18
Rice-upland crop	47	38	14	30	47	28
Rice-rice	15	11	22	78	34	28
Rice-rice-upland crop	13		58	10	2	10
Upland crop-rice-upland crop	6					
Rice-rice-rice			16	7	7	
Total	89	74	110	145	103	289
Pangasinan						
Rice				13		29
Rice-upland crop	76	54	31	108	32	152
Rice-rice	3		10	22	22	11
Rice-rice-upland crop	18		10	2	18	3
Upland crop-rice-upland crop			23	12	15	7
Rice-rice-rice			6			
Total	97	54	80	152	89	204

yield performance had been reported previously. A higher percentage of second rice crops was attempted on partially irrigated fields, but about one-third of the second rice crops failed in both rainfed and partially irrigated fields.

ECONOMICS OF CROPPING PATTERNS

Cropping Systems Component of Agricultural Economics Department

Economic viability of cropping patterns. Each year at the Iloilo and Pangasinan research sites, data are obtained for estimating the profitability of new multiple cropping technology. As a separate activity, all crop activities on about 50 farms at each site are also monitored through daily records kept by the farmers.

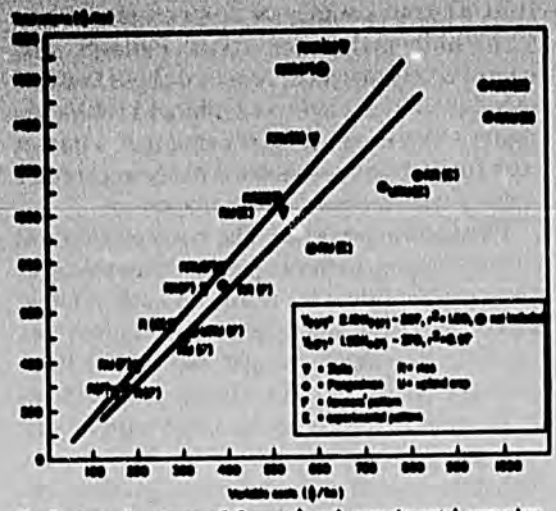
The numbers of experimental cropping patterns of various types that were monitored in Iloilo and Pangasinan from CY 1975–76 through CY 1977–78 are in Table 9. All experimental plots were monitored and analyzed in each year; before 1977–78 only a sample of farmer plots were analyzed.

At the time of a CY 1974–75 baseline survey, a single crop of rice occupied about 80% of Iloilo cropland. In Pangasinan, rice followed by mung bean was the dominant cropping pattern.

The mean performance of each pattern type over the 3 crop years is shown in Figure 8. It was estimated by computing the annual mean performance of each pattern across farms, then taking the 3-year average. Land types by landscape position and water availability are combined. Therefore, different pattern types may imply different fixed costs (in terms of land value) as well as different current input costs. However, only the current input costs are shown on the horizontal scale. Differences in yields and current inputs between farmers' and experimenter's patterns should not be attributed to differences in land types because farmers' and experimental patterns of a given type are grown on similar land types.

The linear relationships between gross returns and variable costs in Figure 8 are estimated from farmers' patterns for which there were at least 2 years of observations. The lower line represents the ratio of returns to variable costs in Pangasinan, and the upper line represents the same ratio in Iloilo. The general conclusions are:

- farmers' rates of variable inputs are lower than the experimenters';
- Pangasinan farmers' rate of return on variable inputs is higher than experimenters', but that of Iloilo farmers is lower;
- farmers and experimenters in Iloilo receive



8. Costs and returns of farmers' and experimental cropping patterns, Iloilo and Pangasinan, Philippines, 1975–78.

higher returns on current inputs than those in Pangasinan; and

- new multiple cropping technology increased net returns through higher levels of inputs, and not by increased efficiency of current inputs.

The cost data in Figure 8 do not reflect land costs. Most of the Iloilo and Pangasinan farmers, however, are tenants who pay landlords in proportion to their production. Therefore, if land costs were included in the analysis, the curves in Figure 8 would be about the same. It appears that multiple cropping provides neither more efficient use of variable inputs nor, in the case of tenants, land. However, this conclusion may relate primarily to the sequential rice-based cropping patterns; other types of patterns, such as intercropping, may offer higher resource efficiencies. The sequential pattern of rice followed by rice ratoon may also more efficiently use current inputs. Such patterns would be represented by points to the left of those shown in Figure 8.

Rates of return on current inputs are lower in Pangasinan than in Iloilo. Similar cropping patterns, particularly with improved management, produce similarly at the two sites but are more costly in Pangasinan (Fig. 8). Farmers and experimenters in Iloilo spent less time hand weeding and preparing land. The higher adoption of improved patterns in Iloilo indicates that the differences are more pronounced at higher management levels, as shown in Figure 8, and that farmers recognize these differences and respond accordingly.

Levels of inputs on cropping pattern trials and farmers' pattern from CY 1975–76 to CY 1977–78 were examined in detail. On four patterns grown by Iloilo farmers, and also grown as trials under research supervision, the farmers

Table 10. Costs and returns of experimental cropping patterns in Pangasinan, Philippines, crop year 1977–78.

Cropping pattern by land type	Plots (no.)	Cost ($/ha)			Returns ($/ha)	
		Labor	Material	Total variable	Gross	Net above TVC[a]
Shallow water table, irrigated						
Rice-rice	6	506	363	869	1268	399
Rice-rice-upland crop	10	586	425	980	1442	462
Shallow water table, rainfed						
Rice-mung bean	5	421	284	705	1110	405
Rice-cowpea	5	415	353	768	1094	326
Rice-sorghum	3	457	288	745	975	230
Rice-rice	7	481	303	784	926	142
Rice-rice-upland crop	5	461	441	902	1301	400
Deep water table, irrigated						
Rice-rice	5	348	293	641	943	302
Corn-rice-mung bean	5	429	396	825	1593	768
Corn-rice-cowpea	5	390	454	844	1391	547
Corn-rice-sorghum	5	290	340	630	912	282
Deep water table, rainfed						
Rice-mung bean	9	282	282	564	927	363
Rice-sorghum	4	245	228	473	782	309
Rice-rice	4	416	315	731	1656	925
Rice-rice-upland crop	3	427	467	[illegible]	1481	[illegible]

[a]Total variable costs.

used about 57% of the variable inputs used by researchers. On three patterns grown by both farmers and researchers in Pangasinan, farmers used 47% of researchers' inputs. Tables 10 and 11 show costs and return for CY 1977–78. The levels of management applied to cropping pattern trials are approximate optimum levels as determined in component technology trials. The experimental patterns generally offer higher profits than farmers' technology.

Table 12 compares the rates of return on total variable costs that farmers receive on their present patterns with the rate of return they could receive on the additional investment required for switching to various other patterns, with farmers' management or with improved (experimental) management. The rates of increased investment in variable costs that would be required are also shown.

On the shallow water table with irrigation, for example, farmers presently grow a single rice crop, rice followed by mung bean, or two rice crops.

A single rice crop returns $1.70/dollar invested. A farmer has four alternatives for increasing profits: rice-mung bean or rice-rice with farmer-level management, or rice-rice or rice-rice-upland crop with improved management. For adoption of rice-mung bean (farmers' management), a 40% greater investment is required. A farmer would earn $1.60/additional dollar spent. By increasing his investment to 120% of the present level spent on one rice crop, a farmer could grow 2 rice crops and earn $2.10/additional dollar spent. Patterns with improved management required about fourfold increase in investment and offered $1.40/additional dollar spent. In such a situation, a farmer with limited cash resources is likely to choose a pattern with farmer-level management.

Whole-farm analysis. The costs and returns of the cropping patterns presented assume constant market prices for resources such as labor, power, and cash. But farm resources often cannot be conveniently bought and sold at those assumed prices. In 1978 a linear programming (LP) method for economic evaluation of new cropping patterns was used. With this computational method farm resources are, in effect, valued at their *opportunity* costs.

The specific operations and resources of a sample of 10 farms, 5 each from the cropping systems research sites in Pangasinan and Iloilo, were studied. The sample farmers had participated in a daily recordkeeping project since CY 1975–76. They were chosen to represent a range of resource endowments and other economic and demographic features (Table 13).

The models developed represented resource allocation over a single crop year comprising 52 (weekly) periods in the Iloilo models and 26 (biweekly) periods in the Pangasinan. Methods of crop production that differed in crop, variety, level of input use, planting date (or dates of other operations), or land type were specified as

Table 11. Costs and returns of farmers' cropping patterns in Pangasinan, Philippines, crop year 1977–78.

Cropping pattern by land type	Plots (no.)	Cost ($/ha)			Returns ($/ha)	
		Labor	Material	Total variable	Gross	Net above TVC*
Shallow water table, irrigated						
Rice	15	140	44	184	305	121
Rice-mung bean	51	164	91	255	417	162
Rice-rice	9	309	90	399	761	362
Shallow water table, rainfed						
Rice-mung bean	8	342	71	413	703	290
Deep water table, irrigated						
Rice	9	140	22	162	379	217
Rice-mung bean	18	214	95	309	704	[illegible]
Deep water table, rainfed						
Rice-mung bean	20	164	68	232	433	201

*Total variable costs.

[illegible]

Land type	Farmers' cropping pattern to be replaced	Rate of return on TVC[a]	Replacement pattern[b]	Increase in TVC (₱)	Increase in rate of return
Shallow water table, irrigated	Rice-fallow	1.7	Rice-mung bean (F)	40	1.6
			Rice-rice (F)	120	2.1
			Rice-rice (E)	370	1.4
			Rice-rice-upland crop (E)	430	1.4
	Rice-mung bean	1.6	Rice-rice (F)	160	2.3
			Rice-rice (E)	340	1.4
			Rice-rice-upland crop (E)	260	1.4
	Rice-rice	1.9	Rice-rice (E)	120	1.1
			Rice-rice-upland crop (E)	180	1.2
Shallow water table, rainfed	Rice-mung bean	1.7	Rice-mung (E)	70	1.4
			Rice-rice (E)	80	0.8
			Rice-rice-upland crop (E)	120	1.2
Deep water table, irrigated	Rice-fallow	2.3	Rice-mung (F)	80	2.2
			Rice-rice (E)	300	1.2
			Corn-rice-upland crop (E)	410	1.8
	Rice-mung bean	2.3	Rice-rice (E)	110	0.7
			Corn-rice-upland crop (E)	170	1.7
Deep water table, rainfed	Rice-mung bean	1.9	Rice-mung bean (E)	140	1.5
			Rice-rice (E)	220	1.2
			Rice-rice-upland crop (E)	260	1.6

[a]TVC = total variable costs (labor and materials). [b]F = farmers' management, E = improved management, as in experimental trials. [c]Indicates the number of dollars returned per dollar spent on additional variable inputs required in switching to new pattern.

different *activity vectors*. Land was classified by water regime and ownership status, and, sometimes, by landscape position.

Impact of introduction of new technologies. A general assessment of the impact of the introduction of new technology (NT) compared:

1. the historical or pre-NT situation, in which only historical technology (HT) vectors were used, and,
2. the new situation where all the appropriate NT available in each site were treated as a package of NT, and included in the farmers' options.

The NT includes methods of crop establishment and new varieties as well as improved upland crop varieties. As seen in Tables 14 and 15, the introduction of NT resulted in higher cash surpluses being generated in all models. However, the uniform improvement in the surplus reflected the differential impact of NT on different types of farms (Tables 16 and 17).

Most models show that, after the introduction of NT, a mix of rice crop establishment methods is specified in the optimum solution. This shows an aspect of NT evaluation — the complementarities that exist between different technologies — that is particularly important because comparison and evaluation of technologies often tend to stress the superiority of a particular technology, and thus suggest that one should be exclusively adopted.

Transplanted IR36 commonly appears in the optimum farm plan but other crops also enter, or are close to entering, because of the new returns from alternate opportunities for using farm resources. Other crops use labor at different times, thus reducing total [illegible] to the farmer. A study of [illegible]

[illegible]

Farm no.	Land: Farm size (ha)	Land: Lowland (%)	Land: Irrigated* (%)	Land: Owned (%)	Family labor (h/ha)	Hired labor (h/ha)	Other expenses ($/ha)	Rice seed expenses ($/ha)	Total fertilizer ($/ha)	Total pesticide ($/ha)
					Pangasinan					
1	2.4	81	81	38	48	1264	1771	[illegible]	0	1
2	2.7	78	44	25	112	252	489	2169	257	1
3	2.7	74	44	11	55	456	210	[illegible]	285	1
4	2.9	58	16	15	55	255	255	1439	0	1
5	1.6	78	48	48	48	228	148	2660	41	1
					Iloilo					
1	2.7	58	100	58	54	578	327	1916	384	1
2	2.5	100	100	0	54	550	268	2550	255	1
3	2.5	58	36	14	191	467	184	2519	313	1
4	2.4	100	0	0	191	364	172	2550	169	3
5	1.6	36	0	72	191	358	94	1149	169	1

*Percentage of lowland that is irrigated.

Table 14. Projected impact of new technologies (NT) on Pangasinan case study farmers, based on linear programming data. Crop year 1977–78.*

Farmer	Technology	Total surplus: $/farm	Total surplus: $/ha	Total rice area (ha)	Total area in upland crops (ha)	MCI	Total family labor (h)	Area (%) with NT
1	HT	403	202	1.24	4.23	228	1154	0
	HT + NT	1047	429	2.62	3.12	239	1656	78
2	HT	801	189	2.10	3.18	198	2624	0
	HT + NT	913	342	3.02	2.63	212	3672	36
3	HT	447	131	2.80	3.65	194	3216	0
	HT + NT	657	196	2.80	3.50	194	2429[b]	43
4	HT	611	161	3.58	2.89	171	3268	0
	HT + NT	1220	323	4.36	2.79	190	3223	61
5	HT	76	48	1.64	1.28	194	1867	0
	HT + NT	163	104	1.96	1.25	205	2042	64[c]

*HT = historical technology, NT = new technology, MCI = multiple cropping index. [b]Labor in the NT situation was reduced because farmer 3 had access to a hand tractor owned by a relative. [c]Farmer 5 adopted the new technology in the form of a new variety (IR36) but used very low levels of fertilizer, etc.; hence the increase in surplus is low.

Table 15. Projected impact of new technologies on Iloilo case study farmers, based on linear programming data. Crop year 1977–78.*

Farmer	Technology	Total surplus: $/farm	Total surplus: $/ha	Total cropped area (ha)	Area (%) with NT	Total FL and HL use[b] (h)
1	HT	1148	314	7.322	0	[illegible]
	HT + NT	2088	570	7.288	100	[illegible]
2	HT	498	133	6.284	0	[illegible]
	HT + NT	717	258	1.888	35	[illegible]
3	HT	951	237	4.001	0	[illegible]
	HT + NT	1574	541	4.888	71	[illegible]
4	HT	388	88	7.273	0	[illegible]
	HT + NT	836	158	6.948	[illegible]	[illegible]
5	HT	219	139	2.288	0	[illegible]
	HT + NT	407	254	2.888	[illegible]	[illegible]

*HT = historical technology, NT = new technology, FL = full-time labor, HL = hired labor. [b]Excluding share labor.

Table 18. Total area of various rice crops on Pangasinan case study farms, crop year 1977–78.*

Farm no.	Technology	Area (ha)			
		DSR	WSR	TPR	All rice
1	HT	0.58	0	.58	1.16
	HT + NT	0.57	0	1.46	2.03
2	HT	0	0	2.10	2.10
	HT + NT	0.92	0	2.10	3.02
3	HT	0	0	2.8	2.8
	HT + NT	0.22	0	2.58	2.8
4	HT	0.88	0	2.70	3.58
	HT + NT	1.18	0	2.84	4.02
5	HT	0	0	1.04	1.04
	HT + NT	.32	0	1.04	1.36

*HT = historical technology, NT = new technology, DSR = direct-seeded rice, TPR = transplanted rice.

opportunity cost of 0 in Table 18 (meaning no alternate use of resources that would pay a higher return) indicates that crops should be staggered so that their labor requirements complement one another. The periods of harvesting different crops are, for example, such that there is no large labor requirement in any week. The time of heavy labor requirement for transplanting TPR is different from the time for weeding WSR. DSR is not among the solutions of the model because it conflicts with land preparation for the corn crop. The observations indicate that the relative size of areas and the crop performances in upland and lowland areas within a farm crucially affect choice of technology in a part of the farm.

Marginal value products of cash. The *value* of cash varies with the supply of and demand for it and is affected by the productive opportunities for its use. In general cash tends to be scarce until the first crops are sold; furthermore, the cash expenditures during the first-crop period may be substantial because of land preparation, and crop establishment and cultivation costs.

In the HT situation the system has generally reached a relative equilibrium through an evolutionary process. The nature of technology is adapted to the resource levels of the farms and additional availability of cash, without a change in technology, can do little to improve the productive capacity of a farm. This is reflected in low marginal value products (MVP) of cash in the HT situation in the models. In that situation the MVP of cash frequently is $1.14/hour, or slightly higher, throughout the year. The introduction of NT makes the MVP of cash rise, particularly in farms low in cash. In general, highly cash-intensive activities are less likely to be attractive to the farmers in the early part of the crop year.

The MVP of cash also indicates the possible effects of changes in the type and level of credit availability or other forms of cash inflow into the farm. An examination of such effects through parametric programming procedures

Table 17. Total area of various upland and rice crops. Iloilo case study farmers, crop year 1977–78.*

Farmer	Technology	Total area (ha)				
		Upland	DSR	WSR	TPR	All rice
1	HT	3.094	0	1.869	2.029	3.898
	HT + NT	4.713	0	1.318	1.338	2.656
2	NT	0.539	0	2.679	3.177	5.856
	HT + NT	0.539	1.487	1.710	3.177	6.374
3	HT	0.882	0.348	0.943	2.110	3.401
	HT + NT	0.882	0	4.149	0	4.149
4	HT	2.899	1.020	0.882	2.141	4.043
	HT + NT	3.268	0	2.576	0.776	3.352
5	HT	2.582	0	0	0.898	0.898
	HT + NT	2.277	0	0.148	0.563	0.711

*HT = historical technology, NT = new technology, DSR = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice.

Table 18. Marginal opportunity cost (MOC) of various new technologies on related land, farmer 1, Iloilo, Philippines, 1976.*

DSR, 1st crop		WSR, 1st crop		TPR, 1st crop		WSR, 1st crop/cowpea		TPR, 1st crop/cowpea		TPR, 1st crop/relayed		Mung 2d crop	
Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)	Wk no.	MOC ($/ha)
19–38	14	20–37	8	22–37	18	20–49	17	22–46	86	22–47	0	44–08	0
20–38	0	21–38	65	23–38	86	21–49	70	23–47	117	23–48	9	46–07	0
21–37	69	22–39	68	24–39	28	22–50	23	24–48	53	24–49	214	46–08	0
22–38	106	23–40	30	25–40	8	23–51	18	25–49	43	25–50	186	47–09	0
23–39	97	24–41	30	26–41	0	24–52	0	26–50	27	26–51	164	48–10	0
		25–42	27	27–42	0	25–01	0	27–51	32	27–52	173	49–11	0
		26–43	24	28–43	0	26–02	84	28–52	104	28–01	169		
		27–44	10	29–44	0	27–03	12	29–01	57	29–02	209		
		28–45	8	30–45	1	28–04	157	30–02	180	30–03	215		
		29–46	0	31–46	0	29–05	60	31–03	111	31–04	227		
		30–47	46	32–47	43	30–06	0	32–04	60	32–05	230		
		31–48	29	33–48	17	31–07	36	33–05	77	33–06	186		
		32–49	260	34–49	103	32–08	33						
		33–50	262	35–50	184	33–09	60						

*All rices are IR36. DSR = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice. Wk no. = time crops occupy the land.

for a particular farm model (Table 19) shows that increasing the cash supply lowers the MVP of cash and increases the overall cash surplus by more than the added supply. The MVP of cash falls to its marginal value after first crops are sold, indicating that credit is no longer needed.

Labor use. In a similar fashion, introduction of NT also tends to raise the MVP of labor in certain periods. That is brought about primarily by the importance of early crop establishment and a quicker turnaround time to facilitate multiple cropping (in addition, of course, to the higher yields associated with NT).

The impact of NT on labor use and the MVP of labor depends not only on the farmers' own endowment of family labor but also on the labor market conditions prevailing in the community. Both supply conditions and market imperfections affect the way in which NT influence labor use and resource allocation on the farms. Tradition and custom have established the types of labor used in certain operations in the historical situation. Thus, harvesting and threshing are done by share labor (payment being in the form of a fixed share of the harvest); hired labor or cash payment is not used in this case. Some farmers tend to do certain operations with family labor only. Some operations may be done using a combination of different types of labor.

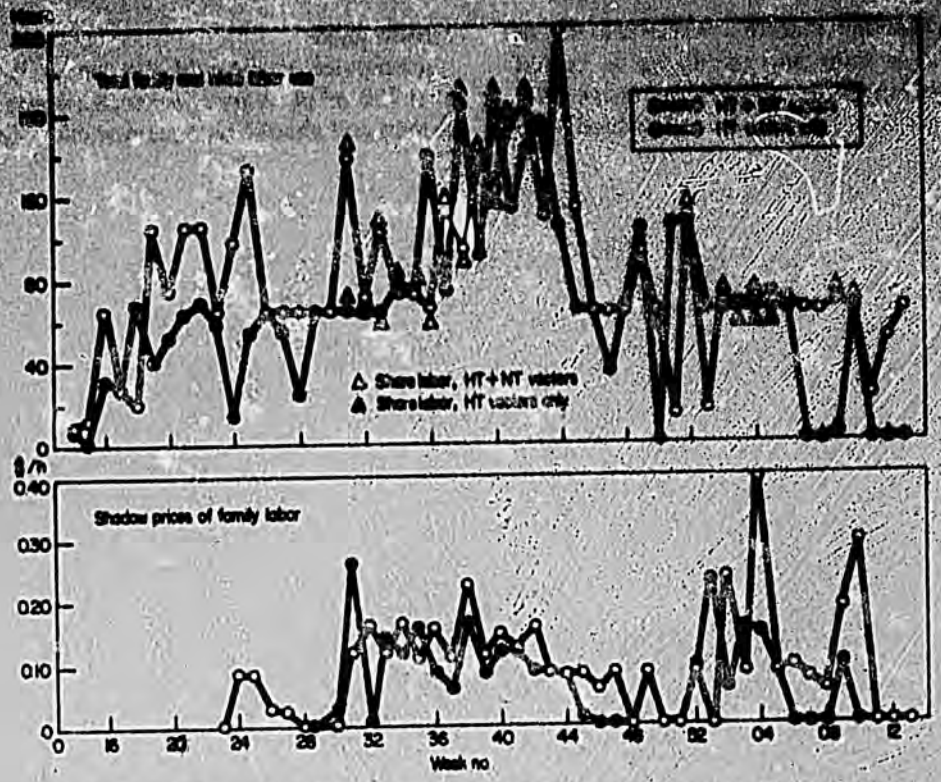
Figure 9 shows seasonal labor use and shadow prices of family labor on an Iloilo farm. The MVP of labor at certain periods, particularly near the end of the cropping season, were raised by the introduction of NT — the result of the slightly delayed harvesting and higher yields of second crops of IR36 compared with the single crops of BE3 that farmers traditionally planted.

The seasonal pattern of shadow wages conforms to the pattern of wages actually observed when payments in kind are considered. Observations made in 1977 at Cale, Batangas, showed that the real wages paid (as harvester's share) to harvesting labor can be high — nearly

Table 19. Shadow prices of cash at 4 levels of available credit in a linear programming model for 3.5 ha. Iloilo (Philippines) farm, 1977–78.*

Credit level ($)	MVP of cash, early season ($/$)	MVP of cash, late season ($/$)	Financed surplus ($)	Rice area (ha)	Rice output (t)
191	4.2	1.1	152	4.8	12.8
381	3.7	1.1	717	6.4	18.3
572	2.9	1.1	1172	6.4	23.2
760	1.1	1.1	1369	7.1	25.2

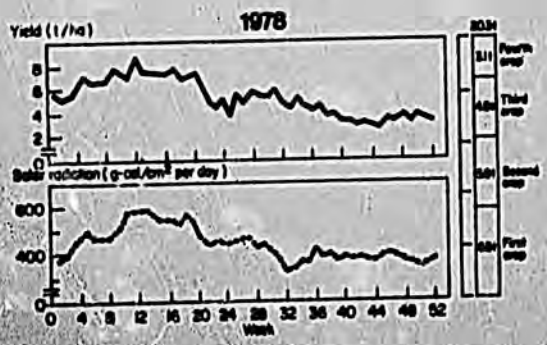
*MVP = marginal value products.



9. Labor use and shadow prices of family labor for farmer 1, Iloilo, Philippines, 1977–78. HT = historical technology, NT = new technology.

$0.50/hour (1977 Annual Report). That implies that the cash surplus can be increased if labor can be hired at wage rates below these MVP.

The detailed study of the solutions of the actual farm models provides insight into the manner in which choice of technologies interacts with the resource base. The present models can provide an assessment of new technologies. Once these models have been fully exploited, simpler, typical farm models for the two sites can be specified and developed.



10. Yields and solar radiation for the continuous rice production model.

CONTINUOUS RICE PRODUCTION MODEL

Cropping Systems Components of the Office of Rice Production Training and Research and Agricultural Economics Department

In 1977, 23.7 t/ha of rice was produced from 4 rice crops grown in 1 ha and harvested 3 times a week from 250-m² plots. Three men worked about 5 hours a day, 6 days a week. There were indications that the labor requirement was tedious and that the laborers preferred only one harvest a week.

In 1978, a 1.3-ha field was established using 1,000 m² plots. IR36 was grown as the first 3 crops but the new short-duration (91-day) line IR9129-169-3 was used as the fourth crop. Four men provided the labor in a 5-day work week. Yields during the year are shown in Figure 10.

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SOIL AND CROP MANAGEMENT

Multiple Cropping Department

Many elements of component technology affect the performance of the crop to which they are applied, and that of other crops in the pattern. Some elements increase yields, others reduce costs. A major interest of the cropping systems research has been an adoptable component technology that makes efficient use of inputs and leads to increased productivity and stability.

Figures 1 and 2 schematically represent the decision-making processes that Philippine farmers in Iloilo and Pangasinan provinces may follow. The diagrams suggest the component technology that should be changed to improve pattern performance within its present domain of adaptation or to expand that domain to a larger area. For rice-rice-upland crop patterns, the most intense patterns possible in the diagrams, the critical point is the planting date of the first crop. Practicable tillage techniques and planting methods that advance planting dates and are compatible with the physical factors governing water regimes in a field (*see* Environmental description in this and previous reports) are critically needed. For the second rice crop, intensity of tillage and factors that affect field duration are important. The second rice crop forces a following upland crop into a period with drier soils, and stand establishment of the upland crop becomes a major concern. But because upland crops grown after two rice crops have only moderate yield potentials, they are seldom objects of tillage and planting methods that require high labor, energy, and machine inputs.

Effect of previous crop and tillage on land preparation for dry-seeded rice. The effect of a previous crop on tillage inputs for dry-seeded rice (DSR) land preparation was studied in 16 Pangasinan fields from which mung bean had just been harvested or which had been left fallow after a second rice crop. At the time the preceding crop was harvested, all fields were extremely dry.

Twelve fields on which mung bean had grown were divided into high and low tillage groups. The low-tillage group received two or less primary and secondary tillage operations before planting, the high-tillage group received four or more. Fuel consumption and rate of land preparation are given in Table 1.

Mung bean fields had received high tillage required less energy and were worked at a faster rate both before and after tillage than fields on which mung bean had not been grown. Clods more than 5 cm in diameter occupied 10% of the surface 15-cm soil volume when the preceding crop was high-tillage mung bean. After fallowing, clods more than 5 cm in diameter occupied 16% of the surface 15-cm volume.

Effect of dry-season land preparation on wet-season crop planting date and performance. To determine if primary tillage at the end of the preceding year would advance the planting date and improve the performance of the following wet-season crop, about one-third of the 96 cropping pattern test fields in Iloilo were plowed after the last crop of the preceding pattern. Labor input for tillage operations and time of rice establishment were compared for fields prepared with and without tillage in the previous patterns (Table 2).

Plowing in the dry season increased the total labor requirement and labor cost for land preparation, but first-crop establishment dates were not influenced by dry-season tillage.

Yield and emergence of dry-seeded rice in relation to early rainfall. The influence of early rainfall patterns on the emergence and yield of dry-seeded rice was studied in experiments planted in Pangasinan and Iloilo at the start of the 1978 wet season. Eight seeding dates were

Table 1. Comparison of average fuel consumption and penetration depths before and after tillage by 8 to 8-hp power tiller rotovator until field appeared suitable for planting, Pangasinan, Philippines, 1978.

Tillage group	Fuel consumption[a] (liters/ha)	Depth (cm) of penetration[b] at 18 kg/cm²	
		Before tillage	After tillage
Fallow	44 (4)	<1	4.8
Mung bean, planted after low tillage	38 (6)	3.7	6.8
Mung bean, planted after high tillage	28 (6)	7.8	8.4

[a]Each figure within parentheses represents number of fields.
[b]Each field (about 300 m²) was divided into 3 sections, and 5 penetrometer readings were taken in each section.

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

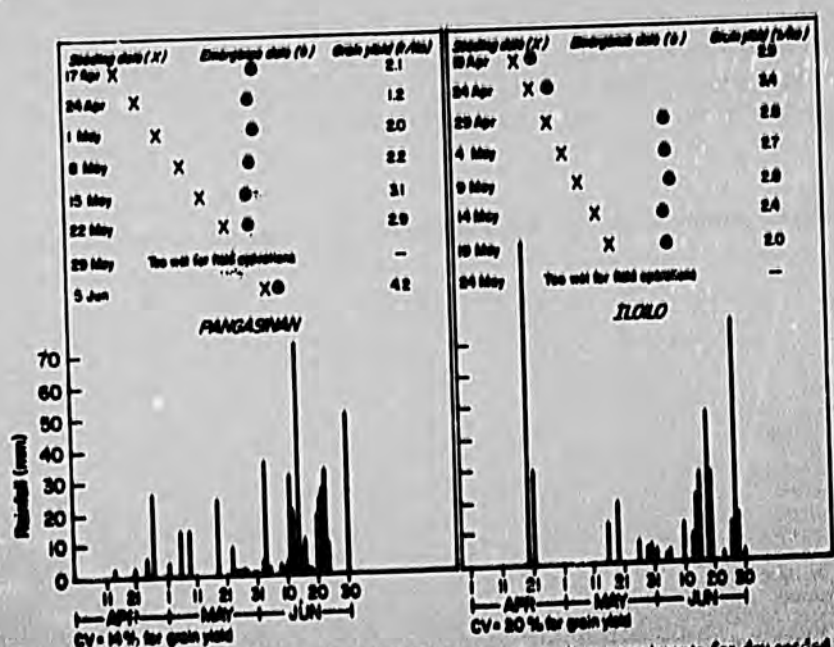
[illegible]

spaced at 5-day intervals in Iloilo, and at 7-day intervals in Pangasinan. The first planting date was so scheduled that the last planting date would take place after the rains normally start and late plantings would be in wet but unpuddled soil. Insecticide treatments were applied to subplots of the planting-date treatments. Because the planting date-insecticide interactions at either location were not significant, mean yields across insecticide treatments are discussed here.

[illegible]

The Pangasinan experiment was on a partially irrigated silty clay loam soil, but irrigation water was not available until early July.

Grain yields were significantly affected by planting dates. The planting on 29 May was forgone because the plots were too wet. The emergence of seedlings continued over a protracted period, especially in the early plantings. Many seedlings that emerged early in the first three plantings died. The emergence count for the last planting showed that stand reduction in the first 3 plantings was 62%; that in the second 3 plantings, 25%. Low initial stands and poor early growth in the early plantings reduced yields.



[illegible] dates, emergence dates, grain yields, and rainfall distribution in seeding experiments for dry-seeded rice at Pangasinan and Iloilo, 1978 wet season. Emergence date is when 50% of the final population had emerged.

In the field experiment, seedings from the 2 earliest plantings emerged and were established by rains totaling 134 mm over 2 days. The plots were under water during the last half of May; their field duration was 123 days. Plantings on subsequent dates emerged over a long period in response to several rains between 15 May and 5 June. The scheduled last planting was forgone because plots were too wet. Uneven emergence in the 29 April–19 May plantings caused uneven grain ripening in the five treatments. Although the 5 treatments were harvested only 95 days after 90% emergence, most grains were ripe because many plants in the plots were 105 days old or older. Grain yield differences arising from planting dates were not significant.

Data from these experiments and from similar experiments in 1977 indicate that although a dry-seeded rice crop gives high yields and can be harvested much earlier than a crop planted on puddled soil, uneven emergence and stand losses may affect farmer's acceptance of the practice.

Tillage techniques for transplanted and wet-seeded second rice crops. An experiment at IRRI compared five land preparation techniques in a factorial arrangement with transplanting and wet seeding as crop establishment methods.

The experiment sought the effects of different land preparation techniques — different tillage intensities, periods between first-crop harvesting and second-crop planting — and establishment methods on the performance of the rice and the crop and its total labor required for land preparation.

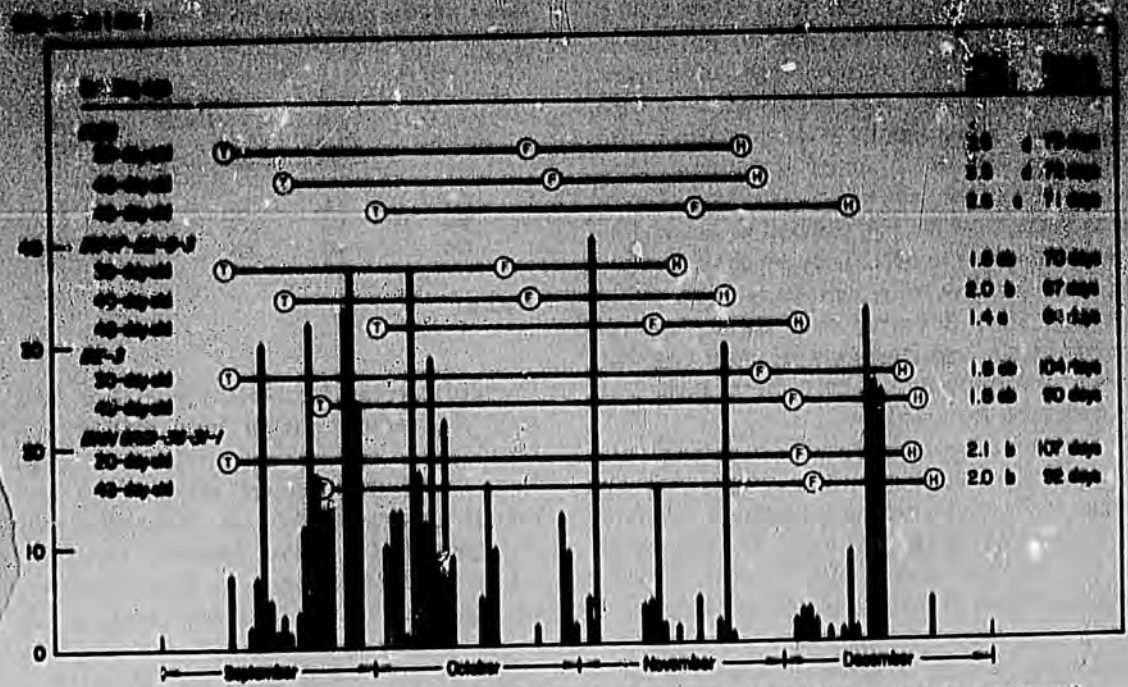
Land preparation was started the day after the preceding crop, a wet-seeded rice, was harvested. Because yield differences arising directly from the treatments were of major interest, the experiment was irrigated to eliminate possible drought effects. The land preparation treatments were fixed at the levels shown in Table 3 and used in main plots of 100 m². For the transplanted treatment (TPR), 2 or 3 IR36 seedlings were placed in 25- × 25-cm hills; for the wet-seeded treatment (WSR), IR36 seed was broadcast at 90 kg/ha. Blanket applications of N, P_2O_5, and K_2O, each at 30 kg/ha, were a basal treatment, and two 30-kg N/ha were top-dressed during vegetative development.

There were no significant differences among yields or weed weights (Table 3). Statistical sensitivity was not high partly because of rat damage, which caused uneven yield losses. But a more sensitive statistical test on tiller counts, which were less affected by rat damage, also indicated no significant treatment effects and interactions. Comparisons indicated significant differences in the labor hour inputs required by the land preparation techniques. The results suggest that the interval between successive rice crops can be shortened and that the level of tillage can be reduced without greatly affecting yields.

Table 3. Effects of land preparation technique and establishment method on grain yield, weed weight, and labor.[a] IRRI, 1977–78 dry season.

Land preparation technique	Grain yield[b] (t/ha)			Weed wt[c] (g/m²)			Labor[d] (h/ha)
	WSR	TPR	Mean	WSR	TPR	Mean	
Traditional 1 plowing plus 2 harrowings, during an 11-day period	3.7	5.0	4.4	7.9	9.1	8.5	146 a
Two vened-roller passings, during a 3-day period	3.7	5.5	4.6	15.4	14.1	[illegible]	86 b
Two vened-roller passings, during a 5-day period	4.1	4.3	4.3	8.2	13.8	11.0	108 b
Two rotavator passings, during a 3-day period	4.7	5.3	5.0	4.5	9.4	7.0	88 b
Stubble cutting by hand plus 6.4 kg a.i. paraquat/ha during a 1-day period	4.6	3.9	4.3	9.2	10.0	9.6	86 b
Mean	4.2	4.8	4.5	9.[illegible]	11.2	10.2	

[a]WSR = wet-seeded rice, TPR = transplanted rice. [b]CV_a = 27%, CV_b = 16%. Means for treatment combinations are in the over 4 replications of IR36. [c]At 30 days after transplanting or emergence. CV_a = 30%, CV_b = 19%. Includes broadleaf, sedge or sedge species. Any two means followed by a common letter are not statistically different at the 5% level. CV = 37%.



2. The effect of transplanting date and seedling age (left) on the field duration (days), flowering date, harvest date and yield (right) of 4 rices. Iloilo, Philippines, 1978.

Effects of photoperiod-sensitive varieties, seedling age, and date of planting on rainfed second-rice crop yields. Two strategies that exploit varietal characteristics were examined as possible means of increasing the level and stability of yields of second rice crops at the Iloilo research site:

- Planting photoperiod-sensitive cultivars with intermediate plant stature and high potential.
- Planting old seedlings of short-statured, short-duration, high yielding cultivars.

The experiment to test the strategies is summarized in Figure 2. The experiment was on a medium-textured soil in a rainfed field that received limited runoff from surrounding fields. The field had a somewhat drier water regime than most fields in the research site.

A seedbed for IR36, BE-3, IR747-B2-6-3, and BKN6819-36-31-1 was planted on 8 August 1978. A second seedbed for only IR36 and IR747-B2-6-3 was planted on 15 August. IR36 is the most common variety grown by farmers near the site, BE-3 is a photoperiod-sensitive local variety, IR747-B2-6-3 is a short-duration high yielding line, and BKN6819-36-31-1 is a high yielding photoperiod-sensitive line. All seedbeds were fertilized with N, P_2O_5 and K_2O, each at the rate of 20 kg/ha. The plots received P_2O_5 and K_2O, each at 30 kg/ha, and 25 kg N/ha as basal application at 30 days after emergence, and at panicle initiation. In all treatments 30-day-old seedlings were transplanted 3–4/hill, and 40- and 45-day-old seedlings were 7–8/hill. Hills were spaced 25 cm apart.

In any combination tested, IR36 was the highest yielder and its average growth duration was only 1 week longer than that of IR747-B2-6-3. The yields of the 30- and 40-day-old IR36 seedlings from the same nursery were not significantly different. But the yields of the 40-day-old seedlings taken from a later nursery were significantly lower, apparently because of severe drought stress during and after flowering. IR747-B2-6-3 followed a yield pattern parallel to but significantly lower than that of IR36.

BKN6819-36-31-1 and BE-3 were similar with respect to flowering date in relation to planting date and seedling age differences. BKN6819-36-31-1 was harvested 2–3 days later but yielded slightly more than BE-3. The BKN line was only 80 cm tall at maturity; BE-3 was 124 cm. The daily rainfall plotted on Figure 2 indicates that the photoperiod-sensitive rices were subjected to a relatively dry 2-week interval at the flowering and early grain-filling period. Until flowering both BKN plantings made ample vegetative growth, suggesting that yield potential would have been high had water been sustained.

Because of its comparatively high yield performance and flexible seedling age and planting date, IR36 can be used as a second crop where water scarcity is likely to occur. Because of its short stature and ample early growth, BKN6819-36-31-1 could be tested as a second crop with higher nitrogen fertilizer rates for rainfed or partially irrigated areas likely to have sufficient water through late December.

Effect of age and number of seedlings on yield and field duration. To examine the effects of planting older seedlings on yield and field duration, an experiment with a factorial combination of seedling age (15, 20, and 40 days) and number of seedlings per hill (3–4, 5–6, and 7–8) was planted 2 September 1978 in a farmer's field in Pangasinan. Before planting, the field was tilled by conventional methods, and a basal application of 21 kg N/ha was made before final harrowing. Seedlings from a nursery that had not been fertilized were transplanted at 25- × 25-cm spacing. Fertilizer was applied as a topdressing of 28 kg N/ha at 30 days after emergence and 21 kg N/ha at panicle initiation. Yields are shown in Table 4. The main effect of seedling age and the interaction between age and number of plants per hill were statistically significant. Within age treatments, the influence of number of plants per hill was not significant. Furthermore, neither productive tillers per plant nor total tillers per plant were significantly affected by treatments.

The 40-day-old-seedling plots were harvested 10 November and the 15- and 20-day-old-seedling plots 29 November. No rain fell between the harvest dates, but the plots

Table 4. Effect of seedling age (15, 20, 40 days) and number of seedlings per hill on yield of IR36 (Pangasinan, September–November 1978).*

Plants (no./hill)	Yield (t/ha)			
	15-day seedlings	20-day seedlings	40-day seedlings	Mean
3–4	2.4	2.9	2.8	2.1
5–6	2.2	2.8	2.9	2.6
7–8	2.8	3.4	3.1	3.2
Mean	2.2	3.1	3.0	3.1

*CV = 8%.

received irrigation for a short period. A 5–10% yield depression resulted from planting old seedlings. To cover the expected lower yield from 40-day-old seedlings and the extra seed required, a farmer should use old seedlings only if he anticipates a loss greater than about 10–15% from late-season drought stress on a crop planted with optimal-age seedlings. To allow for nursery preparation time and land preparation between crops, the decision to plant 40-day-old seedlings should be made about 5–6 weeks before the preceding crop is harvested. Such a decision must be based on the farmer's perception of water availability from rain or irrigation, or both, 10–11 weeks in the future.

Use of old seedlings for rainfed rice. Use of old seedlings to shorten the growing season may provide a means of escaping drought, particularly for a second rainfed rice crop.

Two IRRI experiments in March 1978 evaluated the reduction in yield and growth duration for old seedlings and the extent to which an increased number of seedlings per hill compensated for yield loss. The first trial used IR36 in a split-plot design with age of seedlings (18, 28, 34, and 48 days) as main plots and number of seedlings per hill (3, 6, 9, and 12) as subplots. The second study evaluated the varietal differences of IR36 (maturing 110 days after seeding [DS]), IR38 (125 DS), and IR32 (140 DS) when transplanted at 18 and 40 DS at 3 and 9 seedlings/hill.

Wet seedbeds were planted at different times to obtain seedlings of the desired ages for transplanting. The seedbeds were fertilized with N, P_2O_5, and K_2O, each at the rate of 30 kg/ha at sowing time and 10 kg N/ha every 7 days in the

Table 5. Effect of seedling age on grain yield and field duration of TN1,[a] IRRI, 1978.

Seedling age (days)	Grain yield (t/ha)	Field duration (days)	Yield (kg/day)
18	5.52 a	84.0 a	65.9 a
28	5.52 a	82.0 b	70.0 a
34	5.57 a	81.1 c	68.5 a
40	4.89 b	76.1 d	61.8 b

[a]With varietal mixture; av of 4 replications and 4 numbers of seedlings per hill. In a column, means followed by the same letter are not significantly different at the 5% level.

seedbeds, starting at 14 DS. The seedlings were transplanted at 23- x 25-cm spacing after a basal fertilization of 60 kg N/ha and 30 kg each of P_2O_5 and K_2O/ha. Each treatment received 30 kg N/ha at the panicle initiation stage. Weeds and insect pests were adequately controlled. Because the older seedlings matured unevenly, each plot was harvested when grains had 25% moisture content.

In the first trial, yield and field duration (days from transplanting to harvest) were affected only by seedling age but not by number of seedlings per hill. The average grain yield was significantly reduced only when 48-day-old seedlings were used (Table 5), but the yield at that seedling age was still good. Seedlings of different ages differed significantly in field duration although there was only a 9-day difference between the oldest and youngest seedlings.

In the second trial, increasing the number of 18-day-old seedlings, regardless of the variety, from 3 to 9/hill had no significant effect on grain yields (Table 6). That was true also for the 40-day-old seedlings, except those of IR32, whose yield seemed to decrease when seedling number was increased to 9/hill. At 3 seedlings/hill, the early maturing IR36 appeared to be more sensitive to the use of old seedlings than IR38 and IR32. Averaged over age and number of seedlings per hill, the yields of IR38 appeared the highest (5.86 t/ha) followed by those of IR36 (5.50 t/ha) and IR32 (5.02 t/ha).

The varieties differed slightly in the relative time gain from transplanting to maturity (Table 7). The time gained by using old seedlings varied from 5 to 9 days and appeared to be limited by the long (about 2 wk) seedling recovery period after transplanting, particularly for IR38. Increasing the number of seedlings per hill did not substantially reduce field duration.

IR36 was superior in yield per day to IR38 and IR32 (Table 8). There was no advantage in increasing the number of young seedlings per hill. The advantage of increasing the number of seedlings per hill was apparent only with the 40-day-old seedlings of IR36. The use of 40-day-old seedlings did not, however, significantly reduce yield per day for any of the varieties studied.

Ratoon cropping of transplanted rice. In preliminary trials on ratoon cropping of transplanted rice, IR32 produced nearly 2.3 t/ha when the main crop was planted with 9 seedlings (18-day-old)/hill and cut low. IR36, consistently a poor ratooner, yielded between 0.4 and 1.1 t/ha. Ratooned IR36 had small panicles and 30% of the hills did not ratoon. IR38 and

Table 6. Effect of seedling age and number per hill on the grain yields of 3 varieties.[a] IRRI, 1978.

Seedling age (days)	Yield[b] (t/ha)		
	3 seedlings/hill	9 seedlings/hill	Difference
	IR36[c]		
18	5.82 a	5.87 a	0.06
40	4.87 b	5.31 abc	−0.44
	IR38		
18	5.80 a	5.84 a	0.04
40	5.93 a	5.48 ab	0.45
	IR32		
18	5.34 ab	4.93 bc	0.41
40	5.46 ab	4.92 c	0.99**

[a]Av of 4 replications. [b]In a column, means followed by the same letter are not significantly different at the 5% level. [c]With varietal mixture.

Table 7. Effect of seedling age and number per hill on field duration of 3 rice varieties.[a] IRRI, 1978.

Seedling age (days)	Field duration		Total growth duration[b] (DS)
	3 seedlings/hill	9 seedlings/hill	
	IR36[c]		
18	87.0	87.0	105.0
40	78.8	78.0	118.4
	IR38		
18	100.0	98.0	118.0
40	92.0	91.0	132.0
	IR32		
18	112.5	115.0	131.0
40	104.5	105.3	144.0

[a]Av of 4 replications. [b]Averaged across seedling number in each seedling age. DS = days after seeding.

[illegible]

Seedling age (DAT)	Yield[a] (kg/ha)		
	3 seedlings/hill	5 seedlings/hill	Difference
	[illegible]		
18	[illegible] a	[illegible] a	[illegible]
40	[illegible] ab	[illegible] a	0.77*
	[illegible]		
18	[illegible] b	[illegible] b	[illegible]
40	[illegible] ab	[illegible] b	[illegible]
	[illegible]		
18	[illegible] a	[illegible] a	[illegible]
40	[illegible] a	[illegible] a	0.7*

[a]Av of 4 replications. [b]Days after seeding. *In a column means followed by the same letter are not significantly different at the 5% level.

IR32 had an average of 12% nonratooning hills.

The effects of cutting height, age of seedlings, and number of seedlings were tested. Because of within-field variation due to leveling and differential typhoon damage (two typhoons occurred during the flowering and grain-filling stages), the flowering dates varied widely and results were not consistent. Low cutting and use of old seedlings for the main crop resulted in longer growth duration. Although average yields were similar, the highest yield potential was generally associated with low cutting height that led, however, to longer growth duration.

NPK responses for transplanted rice in Pangasinan. In the design and testing of cropping patterns, it is necessary to specify the fertilizer levels to be used on each crop, but researchers at cropping systems project sites seldom have enough staff to undertake intensive soil fertility and fertilizer rate studies.

A 1978 study was designed to determine if a combination of a conventional fertilizer experiment replicated within a field and a fertilizer experiment replicated across the fields, but with a subset of treatments from the conventional trial, could generate useful information with a minimum of staff input. Fertilizer-response information for the transplanted rice crop in the Pangasinan green corn-rice-upland crop pattern (GC-R-UC) was obtained in a farmer's field through a conventional experiment containing a factorial set of treatments at 3 nitrogen levels (50, 70, and 90 kg N/ha), 2 phosphorus levels (0 and 30 kg P_2O_5/ha), and 2 potassium levels (0 and 30 kg K_2O/ha) replicated in 4 replications. The 70 kg N/ha treatment was the current recommendation for the cropping pattern. Twenty-six-day-old IR36 seedlings (transplanting delayed by a typhoon) were the test crop. One-third of the nitrogen and all of the phosphorus and potassium fertilizers were incorporated at the last harrowing. Six treatment combinations, which were a subset of the full factorial set in the conventional experiment, were placed in plots in farmer-cooperators' fields in which the GC-R-UC was being tested. Except for fertilizer levels and applications, the seedlings and other practices used by the farmer on the six plots and on the remainder of the test field were the same. The six treatments were replicated over six test fields.

The conventional factorial experiment on a full factorial set of treatments in a single field, and a subset of factorial treatments in an experiment replicated over several fields determined the mean fertilizer response and variability in fertilizer responses over fields. The precision of the tests for those treatments common to both experiments were comparable. The analyses of variance and selected treatment means are shown in Table 9. *F*-tests on nitrogen effects were significant at the 5% level for the experiment replicated across fields and at the 1% level for the conventional experiment, but the effects of phosphorus and potassium and the interactions involving the two elements were not significant in either experiment. A regression of the yield for each treatment within a field on the mean yield over all treatments indicated no major field-treatment interactions.

The results indicated that the phosphorus and potassium fertilizers should not be expected to increase rice yields in the GC-R-UC in Pangasinan. However, nitrogen rates above 50 kg N/ha appeared to increase rice yield at an average rate of 13 kg grain/kg N applied.

Nitrogen fertilizer management for dry-seeded rice. To determine optimum dry-seeded rice (DSR) cultivation methods for cropping patterns with two rice crops, two experiments on nitrogen fertilizer management were conducted in farmers' fields. One (in Pangasinan) was on the number and timing of split applica-

[illegible]

Analysis of variance

Wheat field			Aman field		
Source	df	Mean square	Source	df	Mean square
Blocks	3	[illegible]	Blocks	3	[illegible]
Treatments	11	[illegible]	Treatments	8	[illegible]
Error	33	[illegible]	Error	24	[illegible]
CV =	7%		CV =	5%	

N rate (kg N/ha)	Grain yield[a] (t/ha)	N rate (kg N/ha)	Grain yield[b] (t/ha)
30	3.8	30	4.0
70	3.9	70	4.2
90	4.2	90	4.5

K rate (kg K_2O/ha)	Grain yield[c] (t/ha)	K rate (kg K_2O/ha)	Grain yield[d] (t/ha)
0	4.0	0	4.2
30	4.0	30	4.1

P rate (kg P_2O_5/ha)	Grain yield[e] (t/ha)	P rate (kg P_2O_5/ha)	Grain yield[f] (t/ha)
0	4.0	0	4.2
30	4.0	30	4.1

[a]The error df was reduced by 1 because 1 missing plot value was estimated. [b]Mean yields over 4 replications and phosphorus and potassium treatments. [c]Mean yields over 8 replications for nitrogen = 30 and 90, and over 8 replications and 4 phosphorus and potassium treatment combinations for nitrogen = 70. [d]Mean yields over 4 replications and other factor levels. [e]Mean yields over 8 replications for nitrogen = 70 kg N/ha and other factor levels.

tions of nitrogen fertilizer, and the other (in Iloilo) was on nitrogen fertilizer and seeding rates. Yields from the experiments are shown in Tables 10 and 11. Seeds were row-sown in furrows 25 cm apart in May before heavy rains and were covered with the use of a peg-toothed harrow.

The nine treatments in the Pangasinan experiment (Table 10) were applied to four replications of a randomized complete block design. No phosphorus or potassium fertilizer was used. Single degree-of-freedom comparisons among the 7 treatments that received only 2 applications indicated that treatments with a basal application and a topdressing at 30 or 40 days after emergence (DE) (treatments 2, 4, 6, 7, and 8) yielded significantly higher than treatments that received an application at panicle initiation and either a topdressing at 30 DE or a basal application (treatments 1 and 5). Of the treatments receiving basal application and a topdressing at either 30 or 40 DE, those with a topdressing at 30 DE yielded significantly higher than those with topdressings at 40 DE. A comparison of treatments 2 and 6 with treatments 3 and 9 indicated that plots receiving basal and 30 DE applications significantly outyielded plots receiving basal, 30 DE, and panicle initiation applications. The results suggest that for total applications of about 70 kg N/ha on dry-seeded IR36, between 40 and 60% should be applied at planting and the remainder at 30 DE.

The 20 treatment combinations in the Iloilo experiment (Table 11) were applied to 4 replications of a split-plot design. Nitrogen rates in the main plot treatments followed a local management recommendation that one half be applied 20 DE and half at panicle initiation. All treatments received a basal application of 30 kg P_2O_5/ha.

Table 10. Mean grain yield of dry-seeded IR36 as affected by number and time of applications of urea at 70 kg N/ha. Pangasinan, Philippines, 1978 wet season.

Treatment	Amount of N[a] (kg/ha)			Yield	Grain yield (t/ha)
	Basal	30 DE	40 DE	PI	
1	0	35	0	35	3.0
2	35	35	0	0	3.5
3	35	21	0	21	3.5
4	35	0	35	0	3.5
5	35	0	0	35	3.5
6	42	28	0	0	3.5
7	35	0	42	0	3.5
8	42	0	35	0	3.5
9	35	35	0	35	3.1

[a]Basal = applied in furrow with seed, 30 DE = days after emergence, PI = panicle initiation [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

CV(a) on N rate = 9%, CV(b) on seeding rate = 9%.

Interactions were not significant, but the main effects of seeding rate and nitrogen rate were significant. Among yields averaged across seeding rates, the maximum occurred at 120 kg N/ha; among yields averaged across nitrogen rates, the maximum occurred at 150 kg seed/ha. The rates of 120 kg N/ha and 150 kg seed/ha corresponded to 6.0 t/ha yield, the highest mean yield of any treatment combination.

The results of this experiment suggest that high seeding and nitrogen rates are required for maximum yields of DSR as a first crop in Iloilo patterns. Results of the Pangasinan experiment suggest, however, that a basal application in the seed furrow and a topdressing 30 DE instead of the application method used in this experiment could improve the efficiency of nitrogen fertilizer and maximize yields with a lower level of nitrogen.

Water damage to upland crops. Upland crops planted in sequence with wetland rice are often subjected to waterlogging during late monsoon rains. Earlier IRRI trials (1977 Annual Report) showed that crop response and susceptibility to flooding vary.

In May 1978, two field experiments evaluated the effect of flooding on soybean (Multivar 80) and corn (DMR-2), which represent the major upland crops commonly grown in rotation with rice. Flooding treatments were imposed on each crop with growth stage (15 DS and grain-filling stage) in the main plot and flooding duration (no flooding, and 4, 8, and 12 days of continuous flooding) in the subplot. Flooding to soil saturation was by surface irrigation, and plots were separated by canals and bunds to reduce lateral seepage to adjacent untreated plots.

The effects of flooding on various characters of soybean and corn are summarized in Table 12. Flooding at two growth stages had significantly different effects on grain yield and plant height of corn. Flooding duration significantly affected grain yield and number of pods of soybean, and corn grain yield, number of plants and ears, and plant height at 30 DS. Generally flooding at the early stage had a greater depressive effect on most characters of both crops than flooding at the later stage. The change in yield per day brought about by flooding at the vegetative stage was linear (−0.03* t/ha for soybean and −0.23** t/ha for corn).

Table 12. Effect of 4 flooding durations and flooding at 2 growth stages on yields of corn and soybean. IRRI, 1978.

Flooding duration (days)	Yield[a] (t/ha)			
	Corn flooded at		Soybean[b] flooded at	
	15 DS	Grain filling	15 DS	Pod filling
0	4.68 a	4.32 a	1.15 a	1.28 a
4	3.91 ab	3.08 a	1.06 ab	1.27 a
8	3.04 b	3.44 a	0.91 b	1.07 ab
12	1.98 b	3.84 a	0.84 b	0.90 b

[a] In a column means followed by a common letter are not significantly different at the 5% level. DS = days after seeding. [b] Plants were affected by Fusarium root rot.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			Sampling depth 0–5 cm		
None	40 a	41 a	45 a	[illegible]	[illegible]
Row	35 b	37 b	38 b	[illegible]	[illegible]
Complete	30 c	31 c	30 c	[illegible]	[illegible]
			Sampling depth 5–15 cm		
None	45 a	50 a	51 a	[illegible]	[illegible]
Row	44 b	46 b	48 b	[illegible]	[illegible]
Complete	41 c	42 c	48 c	[illegible]	[illegible]
			Sampling depth 15–30 cm		
None	52 a	52 a	55 a	[illegible]	[illegible]
Row	50 ab	50 ab	54 ab	[illegible]	[illegible]
Complete	48 b	49 b	53 b	[illegible]	[illegible]

*In a column of a sampling depth, means followed by a common letter are not significantly different at the 5% level.

In both crops stunting and reduced plant stands resulted only when flooding was imposed at the early stage. Flooding also seemed to delay crop maturity more when it occurred at the vegetative stages than at filling stage. Ear length, total dry matter, and number of pods and seeds were little affected by flooding. The seed weights of both crops tended to be more slightly affected by flooding at the filling stage.

Effect of tillage and fertilizer on corn grown after rice in three growing systems. Dry-seeded rice was grown in three different systems during the 1977 rainy season — unpuddled nonflooded (S_1), unpuddled flooded (S_2), and puddled flooded (S_3). Rainfed corn (Penjalinan) was planted after the rice without fertilizer (F_1) and with fertilizer (F_2) (60-26-50 for NPK) after no tillage (T1), row tillage (T2), and complete tillage (T3). T2 consisted of 2 rototillings in 20-cm-wide swaths 100 cm apart; T3 was 2 complete rototillings.

Corn was dibbled 3 seeds/hill at a 100- × 20-cm spacing and thinned to 1 plant/hill 30 DS. Fertilized plots received 30 kg N, 26 kg P, and 50 kg K/ha at planting, and another 30 kg N/ha dibbled about 7 cm from the corn hills at 5-cm depth 30 DS.

The experiment was on a Lipa clay loam at IRRI that had been used for puddled flooded rice for more than 50 years.

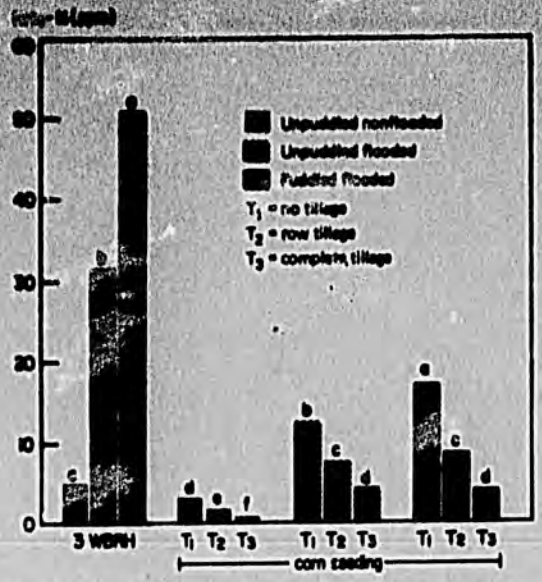
Soil moisture. The soil moisture content at corn planting is shown in Table 13. Soil moisture contents decreased as tillage intensity increased.

At 50 DS, soil moisture content was the same in all plots except those fertilized. In those the soil moisture content of the 0–5 cm layer was slightly higher in the unpuddled nonflooded treatment than in the puddled flooded. More intensive tillage resulted in significantly lower soil moisture content only in the 5–15 cm layer.

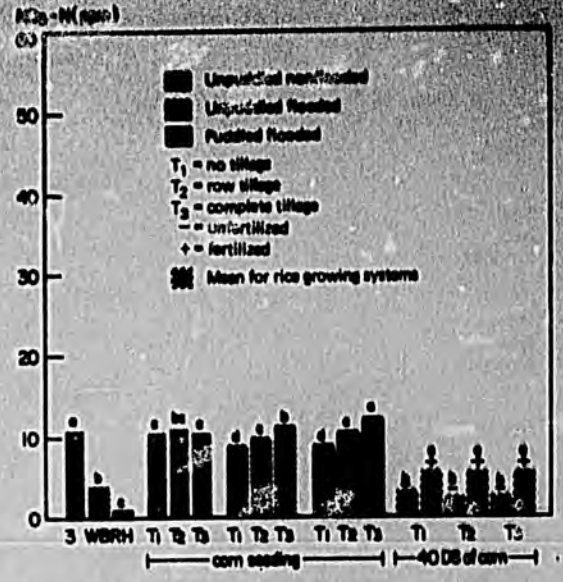
The soil moisture content of the 0–5 cm layer of the fertilized plots was 4–5% higher than in the unfertilized plots; the 15–30 cm layer showed the reverse. The soil moisture differences due to treatments decreased with depth of sampling and time.

Soil chemical analyses. All soil analyses were done immediately after sampling. The levels of nitrogen, phosphorus, potassium, iron, manganese, and zinc before rice harvest, at corn seeding, or after corn seeding, as affected by rice-growing system, tillage, and fertilizer, are summarized in Figures 3–10.

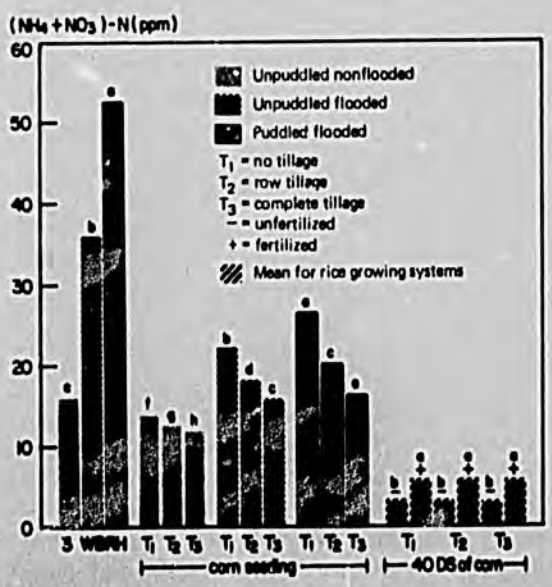
Soil resistance to cone penetrometer. At 5 DS, resistance to the cone penetrometer was 2 kg/cm² at the same depth in puddled flooded as well as in unpuddled flooded plots. The depth at which the same resistance was obtained was significantly greater in the nonflooded plots than in the flooded (Table 14), and the differences were greater for the more intensive tillage treatments. At 50 DS, the trend changed. The more intensive the tillage the deeper was the



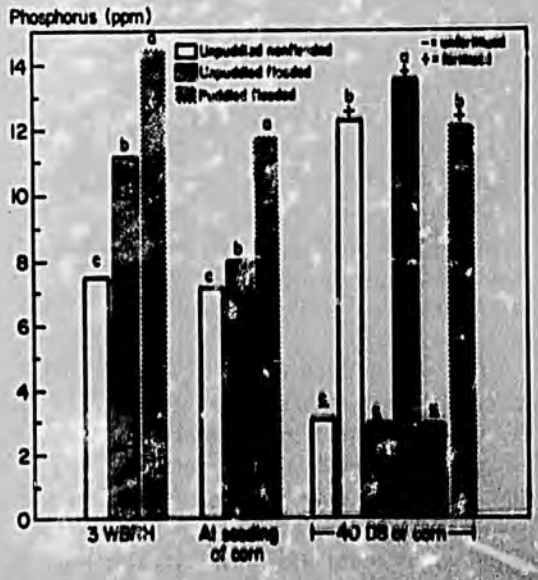
3. Available soil ammonium nitrogen (NH_4-N) 3 weeks before rice harvest (WBRH) and at corn seeding time as influenced by rice-growing systems and tillage treatments. For each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



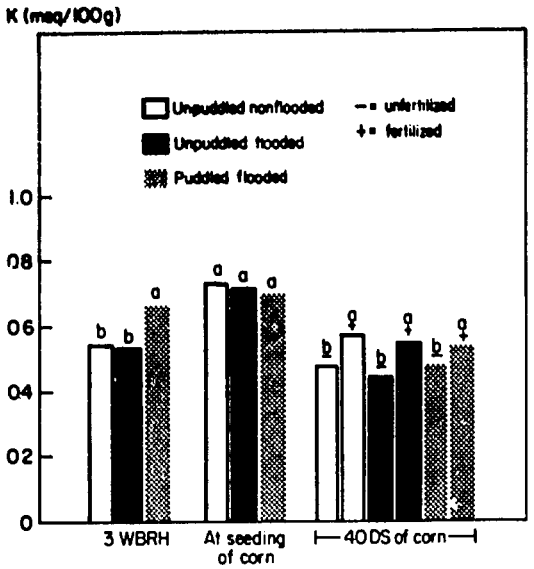
4. Available soil nitrate-nitrogen (NO_3-N) 3 weeks before rice harvest (WBRH), at corn seeding time, and 40 days after seeding (DS) as influenced by rice-growing systems, tillage, and fertilizer treatments. For each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



5. Total available soil nitrogen 3 weeks before rice harvest (WBRH), at corn seeding time, and 40 days after seeding (DS) as influenced by rice-growing methods, tillage, and fertilizer treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



6. Available soil phosphorus 3 weeks before rice harvest (WBRH), at corn seeding, and 40 days after seeding (DS) as influenced by rice-growing systems and fertilizer treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



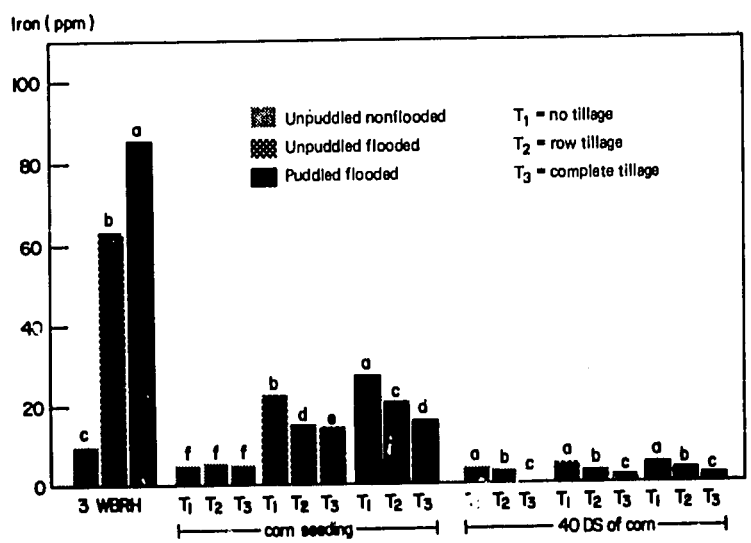
7. Exchangeable potassium 3 weeks before rice harvest (WBRH), at corn seeding, and 40 days after seeding (DS) as influenced by rice-growing systems and fertilizer treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.

point at which a resistance of 4 kg/cm² was obtained (Table 15). To determine the effect of soil moisture on penetrometer resistance, we compared the relation between resistance and moisture content for the no-tillage and twice-rototilled treatments after puddled and unpuddled rice (Fig. 11). Puddled rice soil showed higher resistance in both tillage treatments, particularly at low soil moisture.

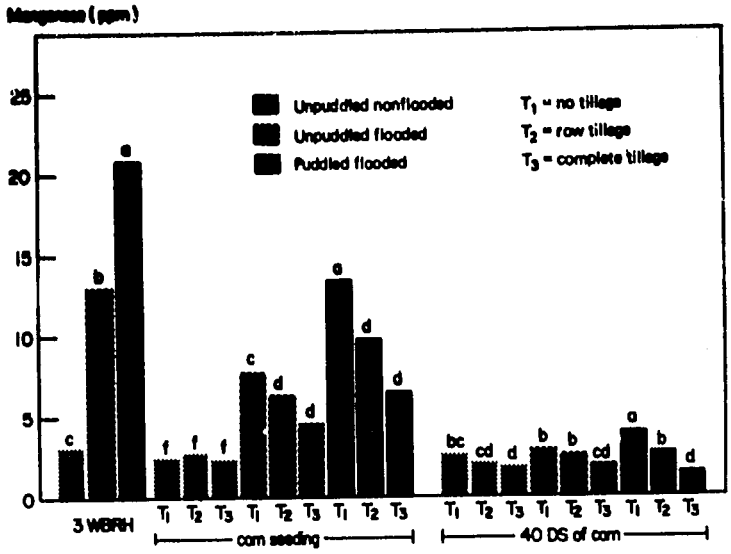
Crop stand. Tillage treatments did not affect corn stand (Table 16). Previous rice-growing systems affected stand only in row-tillage plots in which plant establishment was significantly lower after puddled flooded rice than after unpuddled rice with or without flooding. No-tillage plots had the highest stand regardless of the previous rice-growing system. The more intensive the tillage, the lower the number of established plants. No significant difference occurred in crop stand after it was thinned at 30 DS.

Crop yield. Among the treatments, fertilization had the greatest effect on the dry matter yield of corn, and tillage had the smallest. Tillage and previous rice-growing systems showed their effect primarily on fertilized plots.

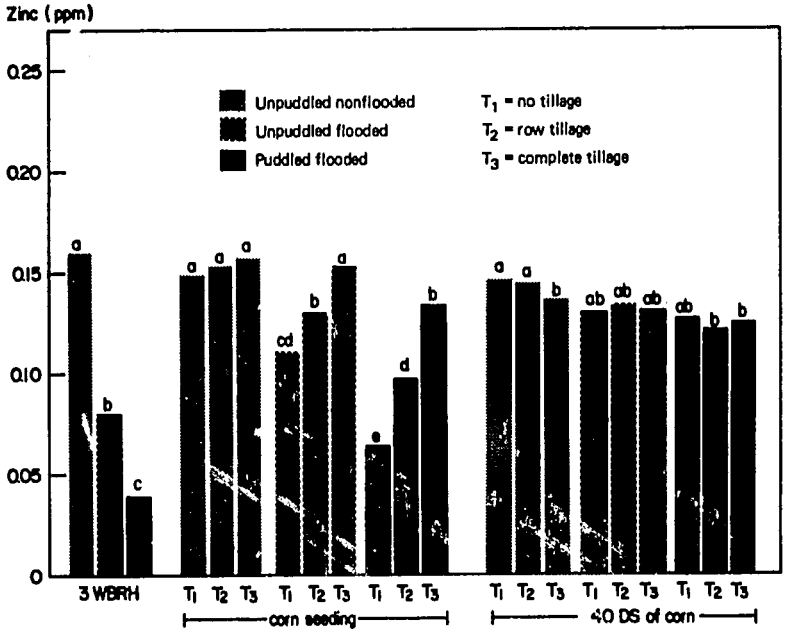
On fertilized plots, except after puddled flooded rice, dry matter production was lowest in the row-tillage plots; it was high in the no-tillage plots and highest in the complete tillage treatments. The fertilized unpuddled flooded rice plots produced the highest dry mat-



8. Water-soluble soil iron 3 weeks before rice harvest (WBRH), at corn seeding, and 40 days after seeding (DS) as influenced by rice-growing systems and tillage treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



9. Water-soluble soil manganese 3 weeks before rice harvest (WBRH), at corn seeding, and 40 days after seeding (DS) as influenced by rice-growing systems and tillage treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.



10. Available soil zinc 3 weeks before rice harvest (WBRH), at corn seeding, and 40 days after seeding (DS), as influenced by rice-growing systems and tillage treatments. In each sampling time, bars with a common letter are not significantly different at the 5% level. IRRI, 1977–78.

Table 14. Depth at which 2 kg/cm² resistance to a cone penetrometer is obtained 5 days after seeding corn. IRRI, 1978.

Tillage for corn	Depth[a] (cm) in rice soils previously			S_1-S_3	S_2-S_3
	Unpuddled nonflooded S_1	Unpuddled flooded S_2	Puddled flooded S_3		
None	22.2 a	21.8 a	20.0 a	2.2*	1.8
Row	20.9 a	17.7 b	17.5 b	3.4**	0.2
Complete	20.6 a	14.0 c	13.7 c	6.9**	0.3

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

Table 15. Depth at which 4 kg/cm² resistance to a cone penetrometer is obtained 50 days after seeding corn. IRRI, 1978.

Tillage for corn	Depth (cm) in rice soils previously			S_1-S_3	S_2-S_3
	Unpuddled nonflooded S_1	Unpuddled flooded S_2	Puddled flooded S_3		
None	8.2 c	8.1 c	1.0 b	7.2**	7.1**
Row	10.1 b	10.0 b	7.9 a	2.2**	2.1**
Complete	12.8 a	12.1 a	8.1 a	4.7**	4.0**

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

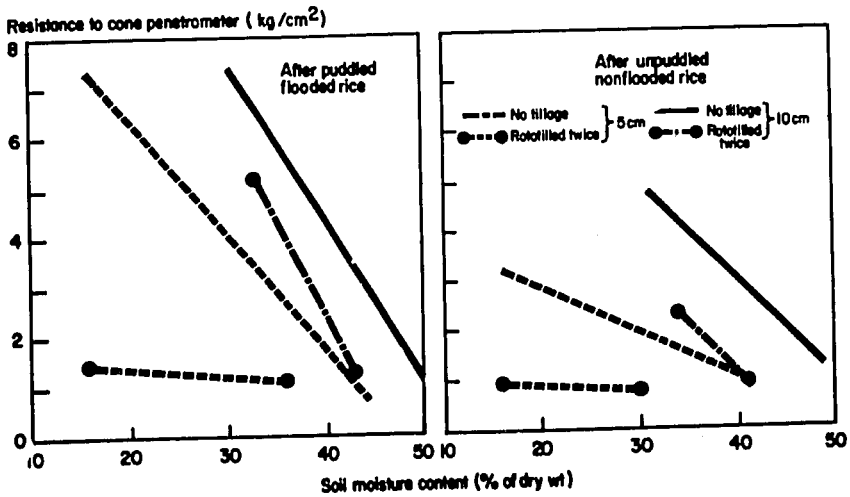
ter of the rice-growing systems, followed by the unpuddled nonflooded and the puddled flooded.

Fertilized plots produced 60% more corn ears with heavier kernels than unfertilized plots. Tillage and the previous rice-growing systems did not affect the number of ears produced.

Fertilizer increased corn yield (Fig. 12). Tillage and rice-growing systems significantly affected corn yield only in unfertilized plots.

Corn nutrient content. Fertilization and intensive tillage increased the nitrogen content of corn plants. Corn on unfertilized plots suffered nitrogen deficiency. Corn had a higher nitrogen content when grown after puddled flooded rice than after unpuddled rice (Table 17).

Phosphorus uptake by corn from fertilized plots was three to four times greater than that



11. Relationship between soil moisture content and penetrometer resistance as influenced by rice-growing systems, tillage treatments, and depths. IRRI, 1978.

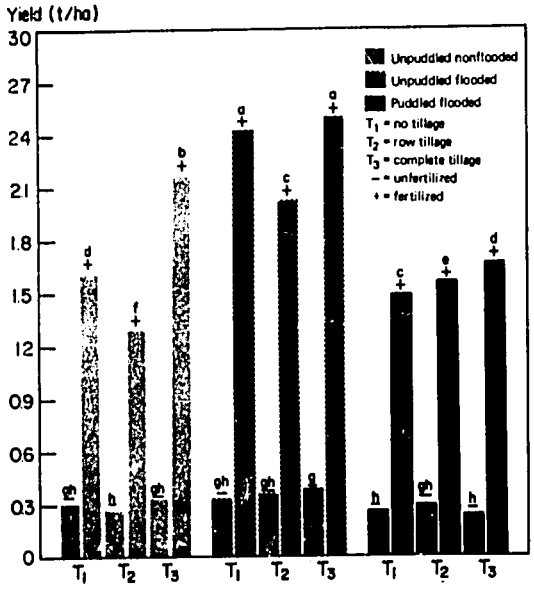
Table 18. Effect of previous rice-growing systems and tillage treatments on number of corn plants at 15 and 30 days after seeding (DS) and 2 days before harvest (DBH). IRRI, 1978.[a]

Tillage for corn	Corn plants (no./m²) grown after rice in previously				
	Unpuddled nonflooded soil S_1	Unpuddled flooded soil S_2	Puddled flooded soil S_3	S_1-S_2	S_1-S_3
		15 DS			
None	14.2 a	14.2 a	14.0 a	0.2	0.2
Row	13.3 b	13.1 b	11.4 b	1.9**	1.7**
Complete	11.6 c	11.7 c	11.3 b	0.3	0.4
		30 DS			
None	5.0 a	5.9 a	4.9 a	0.1	0
Row	5.0 a	4.9 a	4.9 a	0.1	0
Complete	4.9 a	5.0 a	4.8 a	0.1	0.2
		2 DBH			
None	5.0 a	4.9 a	4.9 a	0.1	0
Row	4.9 a	4.9 a	4.9 a	0	0
Complete	4.9 a	4.9 a	4.8 a	0.1	0.1

[a]In a column of respective observation times, means followed by a common letter are not significantly different at the 1% level.

from unfertilized plots (Fig. 13). Corn on unpuddled flooded rice soil had the highest phosphorus uptake for all tillage treatments in both fertilized and unfertilized plots.

In plots with the same tillage treatment, fertilization increased potassium contents of corn.



12. Grain yield of corn as influenced by rice-growing systems, tillage, and fertilizer treatments. Bars with a common letter are not significantly different at the 5% level. The fertilized plots received 60 kg N, 26 kg P, 50 kg K/ha. IRRI, 1978.

Potassium uptake from fertilized plots was four to five times higher than that from unfertilized plots (Fig. 14). Different tillage and rice-growing treatments did not significantly change potassium uptake from unfertilized plots. The potassium uptake by corn grown under row tillage was always the lowest among the tillage treatments.

There were no significant differences in iron content of corn between the different tillage treatments in fertilized, unpuddled flooded, and nonflooded treatments. But the more intensive the tillage on puddled flooded plots, the higher the iron content of corn.

Fertilizer application and increased tillage intensity decreased the manganese content of corn. Corn grown after puddled flooded rice generally had higher manganese content than corn grown after unpuddled rice.

Corn planted on fertilized plots had significantly lower zinc contents than those planted on unfertilized plots. Increased tillage intensity generally decreased the zinc content of corn. Corn grown after unpuddled nonflooded rice had higher zinc content than that grown after unpuddled flooded rice. Zinc content was lowest in corn grown after puddled flooded rice.

Implications. The soil after puddled flooded rice was generally more compact and had a higher moisture content than that after unpud-

Table 17. Nitrogen content of corn grown on soils previously under 3 rice-growing systems, at 70 days after seeding, IRRI, 1978.

Tillage	Nitrogen content[a] (%) of corn on previously				
	Unpuddled nonflooded soil S_1	Unpuddled flooded soil S_2	Puddled flooded soil S_3	S_1–S_2	S_2–S_3
		0-0-0[b]			
None	0.90 c	0.92 e	0.96 e	0.02	0.06
Row	0.96 c	0.96 e	1.13 d	−0.17**	−0.17**
Complete	1.00 c	1.08 d	1.20 cd	−0.08*	−0.12**
		60-26-50[c]			
None	1.23 b	1.19 c	1.27 b	−0.04	−0.08*
Row	1.28 b	1.27 b	1.36 a	−0.08*	−0.09*
Complete	1.36 a	1.38 a	1.43 a	−0.07	−0.05

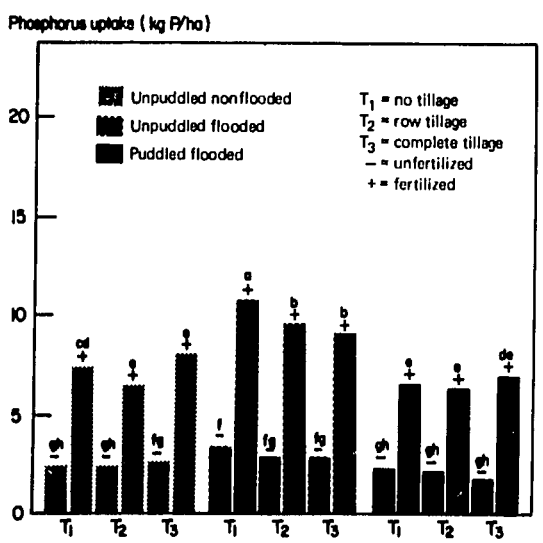
[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]No fertilizer. [c]60 kg N, 26 kg P, 50 kg K.

dled rice. That caused the slightly poorer corn establishment on puddled than on unpuddled soil but the effect was remedied by thinning.

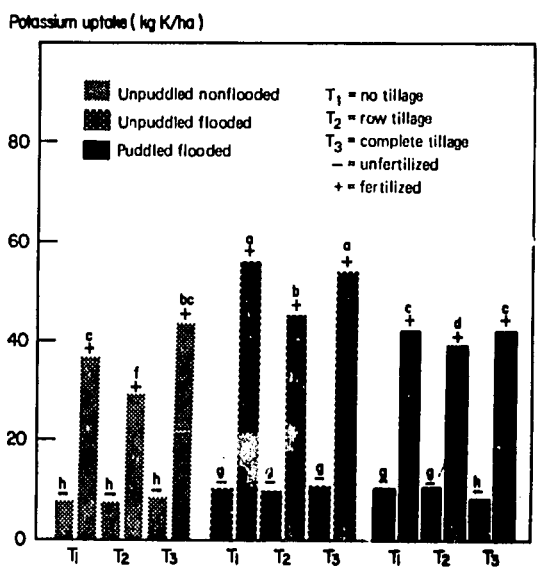
Puddling was more detrimental to corn growth than flooding. Although less nutrient was available in the unpuddled nonflooded rice soil than in the puddled flooded rice soil, corn grew slightly better after unpuddled nonflooded rice.

Tillage improved soil aeration and, consequently, plant growth. Nutrient uptake, and growth and yield of corn on the puddled flooded and unpuddled flooded soils were slightly better with intensive tillage than with no tillage. That was not so with the corn grown after unpuddled nonflooded rice. Tillage reduced weed growth significantly.

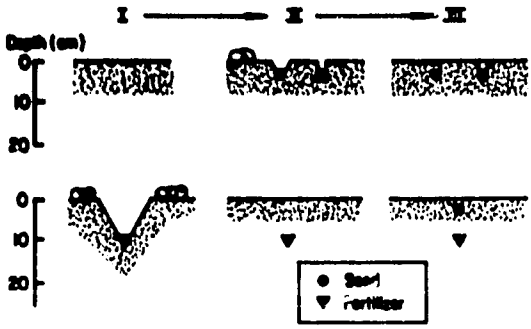
The results indicate that corn after rice in the three systems studied should be established with no tillage and should be fertilized. Interrow



13. Phosphorus uptake of corn at 70 days after seeding as influenced by previous rice-growing systems, tillage, and fertilizer treatments. Bars with a common letter are not significantly different at the 5% level. The fertilized plots received 60 kg N, 26 kg P, 50 kg K/ha. IRRI, 1978.



14. Potassium uptake of corn at 70 days after seeding as influenced by previous rice-growing systems, tillage, and fertilizer treatments. Bars with a common letter are not significantly different at the 5% level. Fertilized plots received 60 kg N, 26 kg P, 50 kg K/ha. IRRI, 1978.



15. Schematic of fertilizer placement. IRRI, 1978.

cultivation, when the topsoil is dry enough, kills weeds and creates a loose dry surface layer that acts as a mulch.

Effect of fertilizer, its depth of placement, and mulching on rainfed corn after puddled flooded rice. The effectiveness of mulch in reducing moisture loss in a rainfed corn crop after puddled flooded rice and the response of the corn to different fertilizer rates and depths of placement were evaluated.

IR26 was grown as a transplanted puddled flooded crop preceding corn on Lipa clay loam at IRRI during the 1977 wet season. After rice harvest, the soil was dried for good land preparation and tilled to about 20-cm depth by 2 carabao plowings and 3 rototillings with a 7-hp tiller. Penjalinan, an 80-day corn variety, was grown in the dry season (January-March). Rainfall was 21.5 mm in January, 8.9 mm in February, and 6.4 mm in March. The corn was fertilized at four different rates, with fertilizer placed shallow or deep (Fig. 15). The corn plots were either unmulched or mulched with 8 t rice straw/ha immediately after seeding. Corn was planted 3 seeds/hill at 100- × 20-cm spacing, and thinned to 1 plant/hill at 30 DS to obtain 50,000 plants/ha.

Soil moisture. By 10 DS, soil moisture in the 0–5 and 5–15 cm soil layers was higher in mulched plots than in unmulched plots (Table 18). Soil moisture in the 15–30 cm layer was not affected by treatments until 55 DS. Changes in soil moisture content below 30 cm were slight because the water table was about 60 cm deep.

Crop stand. The treatments did not affect corn establishment. However, 2 days before

Table 18. Effects of fertilizer rates, mulching, and depths of fertilizer placement on soil moisture content at different depths 10 and 55 days after seeding (DS) of corn grown after puddled flooded rice. IRRI, 1978.

Mulching treatment	Fertilizer placement depth (cm)	Soil moisture[a] (% of dry weight)					
		10 DS at depth of			55 DS at depth of		
		0–5 cm	5–15 cm	15–30 cm	0–5 cm	5–15 cm	15–30 cm
		0 kg N, 26 kg P, 50 kg K/ha					
No mulch	5 cm	28.0 b	41.0 cd	51.7 a	17.7 g	24.3 f	43.3 bc
	20 cm	28.3 b	41.3 bcd	51.3 a	21.0 ef	25.3 f	42.7 cde
With mulch	5 cm	33.3 a	42.7 abc	52.3 a	26.0 cd	34.0 a	45.0 a
	20 cm	33.7 a	42.3 abc	52.3 a	28.3 bc	33.7 a	43.3 bc
		60 kg N, 26 kg P, 50 kg K/ha					
No mulch	5 cm	27.3 b	41.0 cd	50.3 a	20.0 f	27.0 e	42.0 def
	20 cm	27.7 b	42.0 abc	51.3 a	21.0 ef	27.3 e	41.7 efg
With mulch	5 cm	33.3 a	43.0 abc	51.7 a	25.3 cd	33.3 a	44.3 ab
	20 cm	34.0 a	43.0 abc	52.7 a	26.3 bc	33.0 ab	42.7 cde
		120 kg N, 0 kg P, 50 kg K/ha					
No mulch	5 cm	27.0 b	40.0 d	50.7 a	21.7 e	29.3 d	41.0 fg
	20 cm	27.0 b	41.7 abcd	50.3 a	21.0 ef	28.7 d	41.0 fg
With mulch	5 cm	33.0 a	43.7 a	51.7 a	26.0 cd	31.7 c	43.3 bc
	20 cm	33.3 a	43.7 a	51.3 a	27.7 ab	31.7 c	40.7 gh
		120 kg N, 26 kg P, 50 kg K/ha					
No mulch	5 cm	27.3 b	41.0 cd	51.0 a	25.0 cd	29.3 d	41.3 fg
	20 cm	27.0 b	41.7 abcd	52.0 a	24.7 d	29.3 d	39.7 h
With mulch	5 cm	33.0 a	41.7 abcd	51.0 a	28.7 a	31.3 c	43.0 cd
	20 cm	33.3 a	43.3 ab	51.3 a	28.7 a	32.0 bc	41.0 fg

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

harvest the corn stand was less in plots that received 0 kg N, 26 kg P, 50 kg K/ha than in those that received other fertilizer rates, particularly in unmulched plots with shallow fertilizer placement.

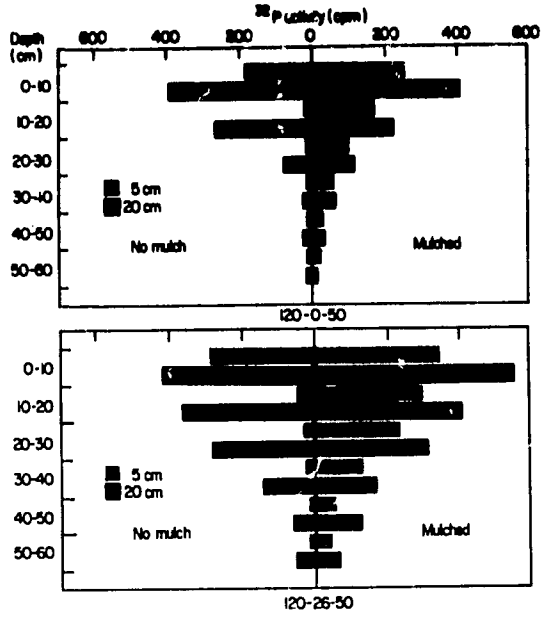
Crop lodging. More corn lodged in plots that received incomplete fertilizer (0-26-50 and 120-0-50) than in plots that received complete fertilizer (60-26-50 and 120-26-50). There was less lodging in mulched and deep-placement plots than in unmulched and shallow-placement plots. The combination complete fertilizer, mulching, and deep placement gave only 3% lodging.

Fertilizer uptake by corn. Fertilizer uptake was less on unmulched and shallow-placement plots than on mulched and deep-placement plots. A combination of complete fertilizer (particularly 120 kg N, 26 kg P, 50 kg K/ha), mulching, and deep placement increased fertilizer uptake significantly. The effects of the treatments on dry matter and grain yields, and seed weight showed the same trend as the effects on fertilizer uptake.

Root distribution over different depths. Corn root distribution was determined manually and by radioisotope (^{32}P). Results from both techniques were closely related, particularly for small roots ($R^2 = 0.99^{**}$). The ^{32}P activity counts at different depths were affected by mulching, depth of fertilizer placement, and phosphorus fertilization (Fig. 16). More roots were obtained in mulched plots than in unmulched plots, in deep-placement plots than in shallow-placement plots, and in plots that received phosphorus fertilizer than in plots that did not. Plots that received phosphorus fertilizer had more roots in the lower layers with deep fertilizer placement than with shallow.

The better root growth on mulched, complete-fertilizer plots resulted in higher nutrient and moisture absorption and better plant growth and yield. The highest yield of 3.1 t/ha — obtained with the combination deep placement of 120-26-50 fertilizer and mulch — was 90% of the potential yield of Penjalinan.

Effect of rice land drainage and soybean tillage treatments on rainfed soybean grown after wetland rice. The effect of tillage and time at which the rice field was drained after harvest on



16. ^{32}P counts at different depths as influenced by fertilizer rate (NPK in kg/ha), mulching, and depth of fertilizer placement. IRRI, 1978.

establishment and performance of rainfed soybean was studied during 1978.

A wetland rice crop (IR26) was grown in the rainy season and the field drained at 21 days, 11 days, and 1 day before rice harvest (DBH). TK-5 soybean was planted as a rainfed dry-season crop after rice with five tillage treatments: no tillage, furrow tillage, bed tillage, one rototilling and three rototillings. The 3 drainage and 5 tillage treatments composed a 3 × 5 split-plot experiment with 3 replications.

Rice straw was cut to ground level and removed after harvest. The soybean seeds were dibbled to about 5-cm depth at 3 seeds/hill at 50- × 8-cm spacing after each tillage treatment was completed. Fertilizer was applied in band as 30 kg N, 26 kg P, 60 kg K/ha.

Soil moisture. The shallow water table (about 60 cm in the dry season) of the experimental area kept the soil moisture content constant at 30 cm and below. However, soil moisture content of the 0–30 cm soil layer varied significantly with different drainage and tillage treatments. The moisture contents of the 5–15

and 15–30 cm layers remained higher in rototilled plots than in nonrototilled plots because the dry top 0–5 cm layer of rototilled plots acted as a mulch.

Plots drained at 1 DBH had consistently higher soil moisture content at planting than those drained at 11 DBH. Plots drained at 21 DBH had significantly lower moisture content than those drained at 11 DBH, except those rototilled. Within each drainage time, furrow-tillage plots always had the highest soil moisture content among the tillage treatments, followed by the treatments with no tillage, bed tillage, one rototilling, and three rototillings. The differences, except those between no tillage and bed tillage, were significant. Soil moisture conditions in the 0–5, 5–15, and 15–30 cm layers were similar.

The differences in soil moisture content among the treatments and layers were less pronounced at the flowering stage (40 DS) than at planting. The soil moisture content of the 0–5 cm layer followed the same trend as that at planting and all were below the permanent wilting point of soybean. The moisture contents of the 5–15 and 15–30 cm layers had different trends and were still higher than the permanent wilting point. In those layers the plots rototilled three times had the highest moisture content followed by the plots with one rototilling, furrow tillage, no tillage, and bed tillage. Time of drainage still had little effect.

The difference in treatments further diminished and the trends in soil moisture content at pod-filling time (60 DS) were similar to those at flowering stage. The moisture contents of the 5–15 cm layer were close to the permanent wilting point.

Bed tillage accelerated moisture loss from the soil. At planting time the bed-tillage and the no-tillage plots had similar moisture contents. Furrow-tillage plots always had higher moisture content than the no-tillage plots because the 0–5, 5–15, and 15–30 cm layers of furrow tillage plots were 10 cm below the original soil surface and were actually the same as the 10–15, 15–25, and 25–40 cm layers of the no-tillage plots.

Crop stand. The no-tillage plots, except those drained 21 DBH, had the best soybean stand, followed by the 1-rototilling, bed-tillage, furrow-tillage, and 3-rototilling plots (Table 19). The trends for the early and late stages of crop growth were similar, except that the stand decreased slightly at the later stage. The higher moisture content in the furrow-tillage plots kept the soil around the seeds reduced. Because the seed zone had high levels of soluble iron and manganese, the stand was reduced.

Nutrient content and uptake. There was no significant difference in nitrogen, potassium, and zinc contents of soybean among the treatments. Neither was there any significant difference in phosphorus content among the no-tillage, one-rototilling, and three-rototilling treatments. But because of low dry matter pro-

Table 19. Effect of drainage and tillage treatments on number of soybean plants at 10 days after seeding (DS) and 2 days before rice harvest (DBH). IRRI, 1978 dry season.[a]

Tillage for soybean	Soybean plants (no./m²) in fields drained		
	21 DBH	11 DBH (control)	1 DBH
		10 DS	
No tillage (control)	53 b	60 a	60 a
Furrow tillage	49 c	48 d	48 c
Bed tillage	53 b	52 c	51 bc
One rototilling	58 a	56 b	52 b
Three rototillings	32 d	33 e	33 d
		2 DBH	
No tillage (control)	46 ab	58 a	58 a
Furrow tillage	42 b	40 b	40 c
Bed tillage	49 a	48 b	49 b
One rototilling	51 a	51 a	51 b
Three rototillings	26 c	28 c	28 d

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

Table 20. Effect of drainage and tillage treatments on total nitrogen, phosphorus, and potassium uptake by soybean plant at 68 days after seeding (DS). IRRI, 1978 dry season.

Tillage for soybean	Total uptake[a] (kg/ha) by soybean in fields drained			2–1	3–2
	21 DBH (1)	11 DBH (control) (2)	1 DBH (3)		
		Nitrogen			
No tillage	40.8 b	49.36 a	59.43 ab	8.53**	9.07*
Furrow tillage	20.58 c	25.86 b	30.99 d	5.28**	5.11**
Bed tillage	22.63 c	27.00 b	34.21 c	4.37**	7.21**
One rototilling	44.64 a	50.31 a	60.12 a	5.67**	9.81**
Three rototillings	42.41 ab	49.57 a	56.67 b	7.16**	7.10**
		Phosphorus			
No tillage	4.84 a	5.91 a	6.38 b	1.08**	0.47**
Furrow tillage	2.87 b	3.42 b	4.10 d	0.55**	0.68**
Bed tillage	3.01 b	3.58 b	4.49 c	0.57**	0.91**
One rototilling	5.03 a	5.70 a	6.72 a	0.87**	1.02**
Three rototillings	4.94 a	5.74 a	6.39 b	0.80**	0.65**
		Potassium			
No tillage	20.56 a	25.21 a	29.03 ab	4.65**	3.82**
Furrow tillage	10.52 b	12.82 b	15.49 d	2.30**	2.67**
Bed tillage	11.20 b	13.57 b	17.03 c	2.37**	3.46**
One rototilling	21.70 a	24.93 a	29.87 a	3.23**	4.94**
Three rototillings	21.14 a	24.69 a	28.30 b	3.55**	3.61**

[a]DBH = days before rice harvest. In a column of respective elements, means followed by a common letter are not significantly different at the 5% level.

duction, the bed- and furrow-tillage treatments had significantly higher phosphorus content than the three other treatments. Furrow-tillage plots had twice the iron and half the manganese of the other tillage plots.

The highest uptake of nitrogen, phosphorus, and potassium was from plots that received one rototilling, followed by that from the plots with three rototillings or no tillage, bed tillage, and furrow tillage (Table 20). The earlier the drainage, the less the nitrogen, phosphorus, and potassium uptake.

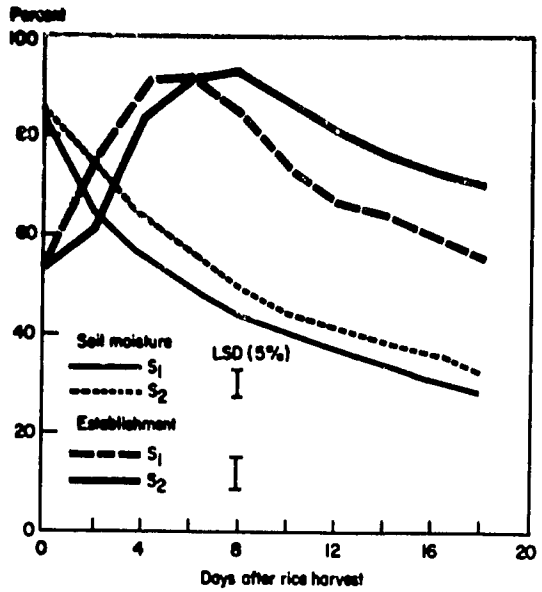
Performance. The earlier the drainage, the less the dry matter produced by the soybean crop. Plots that received a single rototilling produced the highest dry matter weight, followed by plots with either no tillage or three rototillings, no tillage, bed tillage, and furrow tillage. The later the drainage the heavier the seed weight of soybean (Table 21).

Effect of planting time and straw removal on no-tillage rainfed soybean grown after wetland rice. A wetland rice crop was drained 1 day before harvest in February 1978. The rice straw was cut and removed either at harvest (S_1) or at soybean planting time (S_2). Clark 63 soybean was

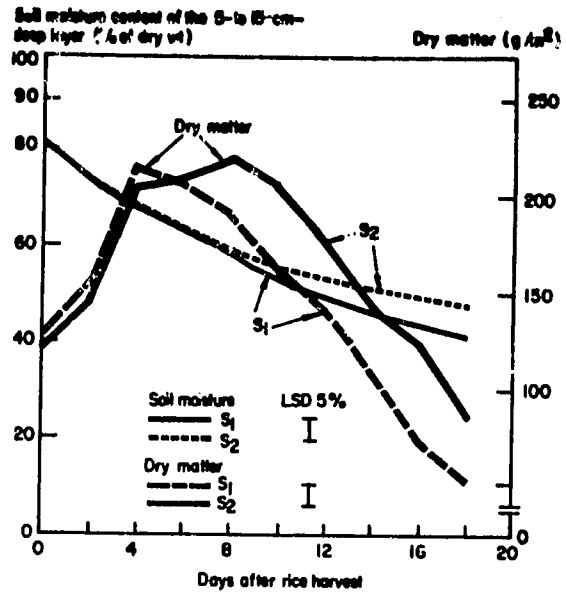
Table 21. Grain yield and grain weight of soybean as influenced by drainage and tillage.[a] IRRI, 1978 dry season.

Tillage for soybean	Soybean yield (kg/ha) in fields drained				Soybean seed wt (g/100 grains) in fields drained		
	21 DBH	11 DBH (control)	1 DBH	Mean	21 DBH	11 DBH	1 DBH
No tillage	100 ab	1157 a	1247 b	1136 b	11.63 c	12.83 c	14.12 c
Furrow tillage	463 c	470 c	559 d	497 e	11.04 c	12.62 c	13.47 c
Bed tillage	530 c	613 c	634 d	593 d	12.33 b	13.66 bc	15.72 b
One rototilling	1099 a	1199 a	1396 a	1231 a	13.50 b	14.76 b	15.98 b
Three rototillings	903 b	866 b	1076 c	955 c	15.11 a	16.09 a	17.45 a
Mean	800	865	982*				

[a]In a column, means followed by a common letter are not significantly different at the 5% level. DBH = days before rice harvest.



17. Relation between moisture content of the 0- to 5-cm-deep soil layer at planting and percentage of established soybean. IRRI, 1978. Straw was removed either at harvest (S_1), or at soybean planting time (S_2).



18. Relation between moisture content of the 5- to 15-cm-deep soil layer at planting and dry matter weight (g/m²) of soybean. IRRI, 1978. Straw was removed either at harvest (S_1), or at soybean planting time (S_2).

planted 10 times at 2-day intervals for 18 days after rice harvest. Soybean seeds were dibbled about 5 cm deep at 3 seeds/hill spaced 50 × 8 cm and band fertilized with 60-26-50 (NPK) at planting. Monthly rainfall was 8.9 mm for February, 6.4 mm for March, and 28.7 mm for April.

Soil moisture. The soil moisture of the 0-5-cm-deep soil layer decreased most sharply from 0 to 8 days after rice harvest, and was lowest in S_1 plots (Fig. 17). The same was true for the layer at the 5- to 15-cm depth, but its rate of moisture loss was significantly lower than that of the 0- to 5-cm-deep layer.

Crop stand. The percentage of established plants (Y) was highly correlated with the moisture content of the 0- to 5-cm-deep soil layer at planting (X), which is expressed as:

$$Y = 163.01 - 1.33X \quad R^2 = 0.96^{**}$$

for X ranging from 90 to 48%, and

$$Y = 10.73 + 1.59X \quad R^2 = 0.92^{**}$$

for X ranging from 56 to 28%.

Maximum establishment was obtained at 50–56% soil moisture (dry weight basis). Stand was maximum 4–6 days after rice harvest when the rice straw was removed at rice harvest, and at 6–8 days after rice harvest when straw was removed at planting (Fig. 17). Thus, if a rice field is drained 1 day before harvest and rice straw left on the field, soybean planting can be delayed until 18 days after rice harvest.

Dry matter production. Dry matter production showed the same trend as percentage of established plants (Fig. 18). The dry matter weight (Y) was highly correlated with soil moisture of the 5- to 15-cm-deep layer at planting (X) expressed as

$$Y = -482.12 + 22.16X - 0.18X^2$$
$$R^2 = 0.74^{**}$$

for X ranging from 37 to 90%.

The maximum dry matter was in plots with about 60% soil moisture of the 5- to 15-cm-deep layer at planting. When rice straw is left on the field, planting can be delayed about 4 days without significantly reducing dry matter production (Fig. 18).

Effects of planting methods and mulching on rainfed soybean after wetland rice. Clark 63 soybean was planted 28 December 1978 after a wetland rice crop. Monthly rainfall was 21.1

mm for January, 21.5 mm for February, 8.9 mm for March, and 6.4 mm for April.

The soybean plots either were left unmulched or were mulched with 8 t rice straw/ha. Four planting methods were used: drill-relay with the seeds drilled in alternate rice interrows 2 days before rice harvest, dibbling seeds 1 day after rice harvest, dibbling seeds into the bottom of a 10-cm-deep furrow, and dibbling seeds into soil rototilled once. The soybean population was 750,000 plants/ha.

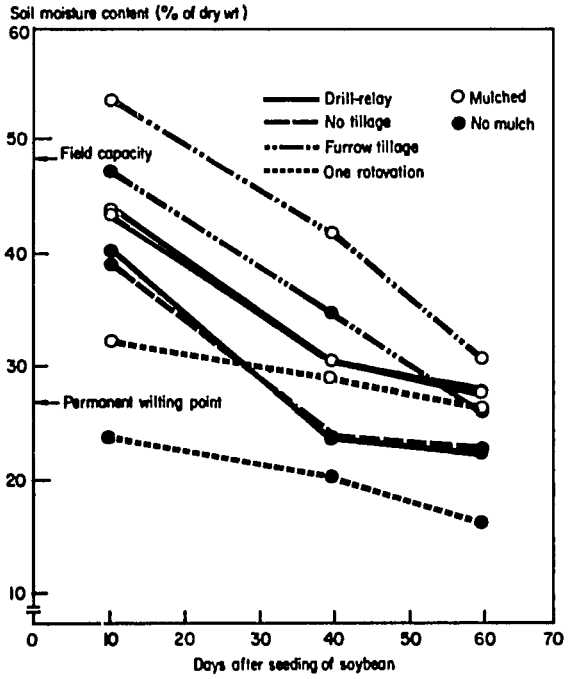
The plots were fertilized with 30-26-50 kg NPK/ha drilled about 7 cm from the soybean rows at planting.

Soil moisture. The soil moisture at the 0- to 5-cm-deep soil layer was higher in mulched than in unmulched plots, and was highest in the furrow-tillage plots (Fig. 19, 20). The same was observed for the 5- to 15-cm layer 10 days after seeding (DS). But at 40 DS the sequence in moisture content of the soil layers, as affected by planting method, changed. Furrow-tillage plots had the highest soil moisture content, no-tillage plots had the lowest. The difference between the no-tillage and the relay plots was not significant.

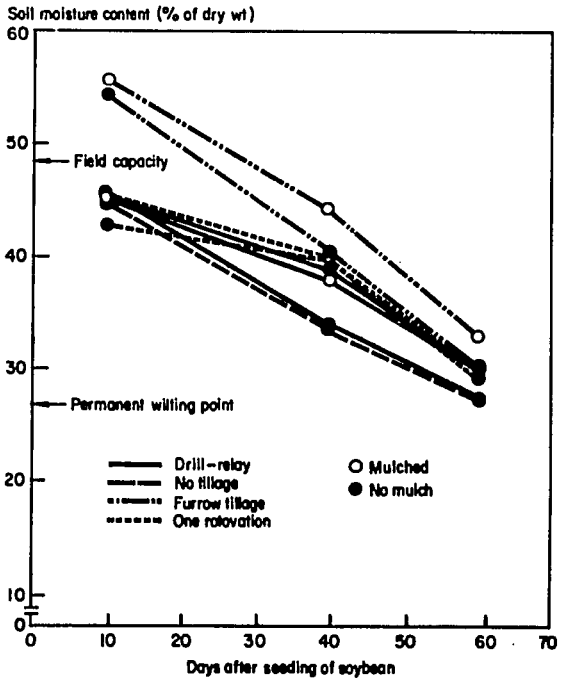
Soil resistance. Mulching significantly reduced soil resistance by conserving soil moisture. The plots with one rototilling and furrow tillage had lower soil resistance than the no-tillage and drill-relay plots.

Soybean performance. Mulching did not significantly affect soybean crop stand (Table 22). It slightly decreased crop stand on furrow-tillage plots, but slightly increased it on plots of the other planting methods. Soybean dry matter production significantly increased in mulched plots, except with furrow tillage. Similarly, grain yield was higher in the mulched plots, except with furrow tillage. In these plots seeds were placed in the reduced soil layer. This led to a reduction of manganese content in plant tops at 63 DS from 106 to 53 ppm and an increase of iron content from 151 for all other plots to 284 ppm for the furrow-tillage plots. Mulch significantly reduced weeds.

Implications. Mulching did not significantly affect crop stand. Mulching and planting were



19. Effect of moisture content of the 0- to 5-cm-deep soil layer at different times in soybean grown after wetland rice. IRRI, 1978.



20. Effect of mulching and planting methods on moisture content of the 5- to 15-cm-deep soil layer at different times in soybean grown after wetland rice. IRRI, 1978.

Table 22. Effect of mulching and planting method on crop stand, dry matter, grain yield, and weed weight of soybean grown after wetland rice.[a] IRRI, 1978.

Planting method and mulching	Crop stand (plants/m²) 10 DS	Crop stand (plants/m²) at harvest	Dry matter (g/m²) 63 DS	Grain yield (kg/ha)	Dry weed wt 29 DS (g/m²)
Drill relay					
No mulch	28.4 c	28.0 c	71.9 e	520 d	119.6 a
Mulch	30.6 c	30.4 c	136.7 d	1069 c	52.8 b
No tillage					
No mulch	55.3 a	55.0 a	166.5 c	1374 b	114.7 a
Mulch	55.9 a	55.9 a	235.8 a	1835 a	52.3 b
Furrow tillage					
No mulch	45.6 b	45.6 b	56.3 f	377 e	34.8 b
Mulch	42.6 b	42.3 b	54.7 f	271 e	6.5 c
One rototilling					
No mulch	49.1 b	48.4 b	208.9 b	1637 ab	3.4 d
Mulch	55.0 a	54.6 a	242.0 a	1968 a	2.1 e

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

completed almost simultaneously. The effect of mulch was not yet visible because the moisture content of unmulched plots was still high. Drill-relay gave low stand because there was less contact between the soil and the seed. The seed was more exposed to the atmosphere than in the dibbled plots.

Except with furrow tillage, mulching greatly improved crop performance because it kept the soil more moist. Because furrow-tillage plots had high moisture content, soil in the seed zone stayed reduced longer than in the other treatments. Plants in furrow-tillage plots suffered from an imbalance of nutrient uptake, as shown by higher iron and lower manganese content.

Table 23. Effect of inoculant and NPK fertilizer on the yield of irrigated soybean planted in 25-cm rows (600,000 plants/ha) in areas previously and not previously planted to soybean. IRRI, 1978.

Treatment[a]	Yield[b] (t/ha) PP[c]	Yield[b] (t/ha) NPP[d]
Control	2.58 a	2.30 b
Inoculant	2.76 a	2.63 ab
Inoculant + N_1	2.88 a	2.72 a
Inoculant + P	2.85 a	2.79 a
Inoculant + K	2.76 a	2.62 ab
Inoculant + PK	2.81 a	2.76 a
Inoculant + N_1PK	2.86 a	2.77 a
N_1PK	2.77 a	2.71 a
N_2PK	2.85 a	2.66 ab

[a]N_1 = 15 kg N/ha, N_2 = 45 kg N/ha, P = 45 kg P_2O_5/ha, K = 45 kg K_2O/ha. [b]Av of 3 replications. Means followed by a common letter are not significantly different at the 5% level. [c]Fields previously planted to soybean. [d]Fields not previously planted to soybean.

Land mulching intensified the imbalance. Because of lower soil moisture, drill-relay plots had poorer growth than no-tillage plots; soybean seeds were placed on the surface of relayed plots, but 5 cm below the surface in the no-tillage plots.

Plots rototilled once gave better crop performance than no-tillage plots; they also had better moisture supply in the lower soil layer and better soil aeration.

Effect of inoculants and plant populations on soybean yield. Indications are that soybean planted at high populations (600,000 plants/ha) in January and February can produce about 3 t/ha. There is also evidence that fields that have previously been planted to soybean benefit from the addition of an inoculant plus low rates of nitrogen (15 kg N/ha). In such fields, an inoculant plus 15 kg N/ha gave the highest (2.883 t) average soybean yield (Table 23).

In areas not previously planted to soybean, the average soybean yields with inoculant plus fertilizer and combinations of inoculant-fertilizer treatments significantly differed from that of the control. The treatment inoculant + phosphorus produced the highest average yield; the treatment inoculant + potassium, the lowest.

The trend was the same for the number of nodules produced. The highest average nodule dry weight of 1.17 g/5 plants (nodule dry weight accumulation after 8 wk) was produced in treatments with inoculant + phosphorus in

areas previously planted to soybean. The lowest (0.92 g/5 plants) was in the treatment with 45 kg each of nitrogen, phosphorus, and potassium per hectare. In areas not previously planted to soybean, the inoculant treatments significantly affected the average nodule dry-weight accumulation. At all growth stages, treatments with either inoculant alone or inoculant plus fertilizer produced higher average nodule dry weight (1.01 g/5 plants) than the uninoculated treatments (0.36 g/5 plants).

In both areas of experimentation, high plant population and narrow spacing produced higher average dry matter accumulation (8.55 t/ha) than low plant population and wide spacing (300,000 plants/ha, 50-cm rows) (6.84 t/ha) 10 weeks after planting.

WEED SCIENCE

Cropping Systems Component of Agronomy Department

Effect of dry-season land preparation on weed growth. Several trials examined the effects of various dry-season weed control practices on weeds in the following wet-season crops.

Method of land preparation. In a trial on an upland field at IRRI, weeds were controlled by different methods during the dry season or the land was left in weedy fallow. At the start of the wet season, rice and corn were seeded separately.

The major weed species in the field were *Amaranthus spinosus, Commelina benghalensis, Rottboellia exaltata, Echinochloa colona, Eleusine indica, Digitaria ciliaris, Dactyloctenium aegyptium,* and *Cyperus rotundus.* Weed counts taken 1 week after crop emergence indicated that method of land preparation had no effect on the number of grasses (Table 24). There tended to be significantly more broadleaf weeds, primarily *A. spinosus,* and less *C. rotundus* in the plowed plots than in the other plots. In the rice plots land preparation methods produced no significant difference in the total number of weeds. But in the corn plots weeds were significantly less in the plots that received two plowings and one harrowing, or were sprayed with paraquat, except in plots left as weedy fallow.

Irrespective of the previous land preparation method, all unweeded corn plots yielded significantly less than plots that were weeded 7 and 28 days after emergence (DE). When the plowed plots and the untreated plot were weeded once 21 DE, they yielded significantly more than those not weeded. Yields did not significantly differ between plots weeded once and those weeded twice. Plots that received paraquat during the dry season yielded significantly more than those that received no paraquat.

Unweeded rice plots gave no yield. Plots weeded once or twice yielded significantly more than those not weeded. Only the plot plowed once yielded significantly more when it was weeded twice than when it was weeded once. In the other land preparation methods, these treatments did not significantly differ.

Average yields from the plot that received two plowings and one harrowing were significantly higher than those from the plots with weeds mowed at the start of the experiment, those plowed once, and those not treated.

Table 24. Effect of various methods of land preparation during the dry season on the number of weeds per 0.5 m² growing in association with upland rice and corn 1 week after crop emergence.[a] IRRI, 1978 wet season.

Previous treatment	Broadleaf weeds		Grasses		Sedges		Total	
	Rice	Corn	Rice	Corn	Rice	Corn	Rice	Corn
None	35 c	32 b	8 a	7 a	64 a	81 ab	107 a	120 bc
Two plowings + one harrowing	103 ab	73 a	13 a	9 a	28 b	12 d	144 a	94 c
Paraquat (0.75 kg a.i./ha) as needed	66 abc	66 a	39 a	5 a	54 a	26 cd	159 a	97 c
Mowing weeds at start of experiment	51 bc	30 b	16 a	7 a	105 a	107 a	172 a	144 ab
Plowing at start of experiment	99 a	69 a	22 a	17 a	70 a	50 bc	191 a	136 ab
Mowing weeds as needed	36 c	31 b	10 a	7 a	117 a	155 a	163 a	193 a

[a]Av of 3 replications and 3 weeding treatments. In a column, means followed by the same letter are not significantly different at the 5% level. a.i. = active ingredient.

Table 25. Effect of different times of land preparation on weed weight in unweeded plots 45 days after crop emergence. IRRI, 1978 wet season.

Weed type	Weed wt[a] (g/0.5 m²) for land preparation in	
	Dry season	Wet season
Broadleaf	5.9 a	3.3 a
Grasses	88.5 a	245.5 b
Total	94.4 a	248.8 a

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

Time of land preparation. In a second trial at IRRI, land preparation for dryland rice was done during the dry season or after the start of the wet season. Land preparation — one plowing followed by two harrowings — was the same for each time. The weight of broadleaf weeds in the unweeded check plots was unaffected by the time of land preparation, but the weight of grasses was significantly higher when the land was prepared after the start of the rains than when it was prepared dry (Table 25). The total weed weight was unaffected by time of land preparation.

Yield from the unweeded plots was not affected by time of land preparation.

Effect of previous land use on weed growth. The effect of previous land use on the weeds growing in association with dry-seeded rice was examined in a farmer's field in Pangasinan province. In all fields the previous land preparation produced no significant difference between the number of grasses, broadleaf weeds, and sedges in the unweeded plots. However, grasses, particularly *E. colona*, were four to six times as many in the field previously maintained as weed-free fallow than in the field previously planted to mung bean or left as weedy fallow. This was reflected in the crop yield (see unweeded check, Table 26). Herbicide performance was also superior in the plots that had less *E. colona*. However, no yield differences were observed for all previous land uses, when a preemergence application of pendimethalin or dinitramine was followed by a hand weeding about 4 weeks later.

When the plots were hand weeded twice, those that were weed-free fallow during the dry season yielded significantly less than those previously planted to mung bean.

Method and degree of land preparation. *Corn.* The stale-seedbed technique was compared with conventional land preparation for weed control in corn. After conventional land preparation, one portion of the land was planted immediately. In the other portion, weeds were allowed to grow for several weeks and then were killed either by glyphosate at 2 kg a.i./ha or by tillage.

Land preparation method produced a dramatic change in the weed flora (Table 27). Where land was prepared conventionally and planted immediately, grasses, primarily *E. colona*, were

Table 26. Effect of weed control practices and land preparation during the dry season on the yield of dry-seeded IR36 rice. Farmer's field, Pangasinan province, Philippines. 1978 wet season.

Weed control method[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha) with previous land utilization		
		Weed-free fallow	Weedy fallow	Planted to mung bean
Dinitramine fb hand weeding 21 DE	1.5	4.7 a	4.6 a	4.4 ab
Pendimethalin fb hand weeding 21 DE	2.0	4.5 a	4.8 a	4.8 a
Butachlor fb hand weeding 21 DE	2.0	3.0 b	4.8 a	4.4 ab
Hand weeded twice, 14 and 35 DE	—	2.9 b	3.8 ab	5.1 a
Pendimethalin	2.0	1.6 c	3.2 bc	3.6 b
Dinitramine	1.5	0.6 cd	3.5 bc	4.2 abc
Butachlor	2.0	0.2 d	4.2 a	3.3 c
Unweeded check	—	0 d	2.5 c	2.0 c

[a]All herbicides were applied at preemergence. fb = followed by, DE = days after emergence. [b]a.i. = active ingredient. [c]In a column, means followed by a common letter are not significantly different at the 5% level.

Table 27. Effect of method of land preparation on number and weight of weeds growing in farmers' fields in association with unweeded rice, Pangasinan province, Philippines, 1978 wet season.[a]

Treatment	Weed count (no./0.5 m²)			Weed wt (g/0.5 m²)		
	Broadleaf weeds	Grasses	Sedges	Broadleaf weeds	Grasses	Sedges
Conventional land preparation	14 a	10 a	306 c	0.9 ab	4.2 a	41.9 c
Stale seedbed — glyphosate (2.0 kg a.i.[b]/ha)	18 a	78 b	9 a	2.0 b	9.2 ab	0.6 a
Stale seedbed — area plowed	14 a	85 b	97 b	0.7 a	14.7 b	14.0 b

[a]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level. [b]Active ingredient.

significantly less than in the other treatments. *C. rotundus* was significantly more abundant in the conventionally prepared plots than in those that were tilled again, and in the tilled plots than in the glyphosate-treated plot. Broadleaf weeds, primarily *Commelina diffusa*, were little affected by land preparation method.

Upland crops planted after rice. In several trials in Pangasinan province upland crops planted after rice did not respond to weeding.

In 1 trial no yield increase was obtained in mung bean by weeding 14 DE, by applying butachlor at 2.0 kg a.i./ha at preemergence (14 DE), or by applying paraquat at 0.5 kg a.i./ha 14 DE. The initial land preparation was 1 plowing plus 1 harrowing or spraying paraquat at 0.75 kg a.i./ha and opening a furrow for seeding.

In another trial with mung bean, cowpea, and soybean the only land preparation was the opening of a furrow for seeding. Yields from plots that were weeded once, weeded twice, or had a direct postemergence application of paraquat were not significantly higher than those from untreated plots.

In a third trial, where a furrow was opened for seeding, paraquat was applied before planting to one-half the plot and no herbicide was applied to the other half. No yield increase of sorghum, soybean, asparagus bean, cowpea, and mung bean resulted from the preplant herbicide, or from 1 hand weeding 21 DE.

At IRRI the effects of degree of land preparation (1 plowing plus 2 rototillings vs spraying of paraquat at 0.75 kg a.i./ha followed by opening of a furrow for seeding), mulching (none, 1.5, 3.0, and 4.5 t/ha), and weed control (no weeding, weeded once, and weeded twice) on weed weight and yield of sorghum, soybean, and mung bean planted after rice were examined in a trial planted in November.

Neither method of land preparation nor amount of mulch had any effect on weed weight. The weed weight decreased as the weeding intensity increased.

Mung bean gave a significantly higher yield in land sprayed with paraquat and prepared by opening a furrow than in land that was plowed once and rototilled twice. No yield difference due to method of land preparation was observed in soybean and sorghum.

All mulched sorghum plots yielded significantly more than the unmulched plot. Mulching had no effect on the yield of soybean and mung bean. For optimum yields sorghum required two weedings, and soybean and mung bean, only one.

In a trial planted at IRRI in October 1977, the effects on weed growth and yield of planting mung bean, soybean, cowpea, and sorghum after rice at different plant spacings were compared. The m[illegible] weed species were *A. spinosus* and *R. ex[illegible]ata*.

In the unweede[illegible] [illegible]ts, plant spacing had no effect on yield. In p[illegible] that were weeded twice, the yield from the crop that was planted at 50 by 5 cm was significantly higher than that at the other plant spacings. When the crop was weeded once, yields generally decreased as intrarow distance between plants increased.

For mung bean (CES 1D-21), plant spacings ranging from 40 by 5 cm to 60 by 20 cm in the

Table 28. Effect of weeding regime on yield of 5 cowpea cultivars. IRRI, 1977–78 dry season.[a]

Cultivar	Weed wt[b] (g/0.25 m²)	Yield[c] (kg/ha)		Weed-caused yield depression (%)
		Plots weeded twice	Unweeded plots	
EG #2	80.0 ab	952 b	878 c	31.0
All Season	96.8 b	958 ab	630 bc	34.2
V59-41	114.2 b	787 a	369 a	53.1
EG #1	39.9 a	1021 b	468 ab	54.2
California Black Eye	83.3 a	915 ab	331 a	63.8

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]From unweeded plots at harvest. [c]Av of 3 replications.

unweeded check plots gave no significant effect on weed weights at crop harvest. Mung bean yields increased significantly as degree of weeding increased. Yields from plots weeded twice (14 and 35 DE) were superior to those from plots weeded once (21 DE), which in turn were superior to those from unweeded plots.

In unweeded sorghum (Cosor 3), weed weights in plots where the row spacing was 25 cm were generally lower at harvest than for the other row spacings. Yields tended to be higher at the 25-cm spacing. Yields from plots weeded once or twice were not significantly higher than those from the unweeded plots. In all row spacings yield tended to decrease as plant spacing within the row increased.

Yields of cowpea (EG#2) and soybean Clark 63) were not affected by plant spacing or weeding regime. In both crops, weed weights in the unweeded plots were unaffected by plant spacing.

Competitiveness of cowpea and soybean cultivars against weeds. In the 1977–78 dry season unweeded plots of five cowpea cultivars differed significantly in weed weight at crop harvest. Significantly less weeds grew in association with EG#1 and California Black Eye than with V59-41 or All Season. For all cultivars, yields from unweeded plots were significantly lower than those from plots that were weeded once or twice (Table 28). Plots that were weeded once or twice did not significantly differ in yield. But the yield depression due to weeds — 31.0% for EG#2 to 63.8% for California Black Eye — indicated differences in the cultivars' competitiveness against weeds. The cultivar that caused the greatest reduction in weed weight suffered most from weed competition.

Neither was there any significant difference in weed weight in the unweeded plots of the five soybean cultivars. But, to obtain optimum yields two weedings (7 and 21 DE) were needed for Clark 63, CES 16–23, and TK#5, and only one (21 DE) for UPL 5Y-2 and Multivar 80. Thus soybean cultivars differed in response to degree of weeding.

Effect of crop rotations on weed growth. *Dry-seeded rice-transplanted rice rotation.* The effect of weed control practices applied to a dry-seeded rice crop on the weeds growing in a subsequent transplanted rice crop was studied in a trial at IRRI. For the dry-seeded rice crop two seeding methods were used and four weed control treatments were superimposed on each field.

Grain yields of dry-seeded rice were significantly higher in all the weeded plots than in the unweeded check plots for both dibbled and row-seeded crops (Table 29). In the dibbled crop, no significant yield differences were observed among the weeded plots. In the row-seeded plots, grain yield from the weed-free plot was significantly higher than that from the plot weeded twice. Yield differences between the methods of seeding were not significant.

No weeding was done in the transplanted rice crop, but no effect of the previous weeding treatments was observed in the crop. The insignificant difference in yield between the various plots was due to the low weed weight in the transplanted crop and the almost complete difference in weed flora between the two rice crops.

Seventeen different weed species grew in association with the dry-seeded rice crop, but only five grew with the transplanted crop. In the

Table 29. Effect of method of seeding and weed control on weed weight and yield of dry-seeded rice and the subsequent unweeded transplanted rice crop.[a] IRRI, 1979 wet season.

Method of seeding and weed control for dry-seeded rice[b]	Weed wt (g/0.25 m²)		Yield (t/ha)	
	Dry-seeded rice	Transplanted rice	Dry-seeded rice	Transplanted rice
Dibbled — no weeding	149.7 b	7.4 a	0.2 c	4.0 a
Dibbled — weeded 14 and 35 DE	6.4 a	8.4 a	4.6 a	4.3 a
Dibbled — weeded 14, 35, and 56 DE	6.4 a	5.8 a	4.4 ab	3.7 a
Dibbled — weed free	—	5.1 a	4.8 a	3.8 a
Row seeded — no weeding	158.6 b	8.4 a	0.3 c	4.4 a
Row seeded — weeded 14 and 35 DE	23.2 a	11.1 a	3.5 b	3.8 a
Row seeded — weeded 14, 35, and 56 DE	1.9 a	7.7 a	4.3 ab	3.9 a
Row seeded — weed free	—	6.5 a	4.9 a	4.1 a

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

dry-seeded rice crop the dominant weed species was *E. colona* (38.7% of the weed flora based on weed weight). *Leptochloa chinensis* was next in importance. Other prominent weed species were *Ludwigia octovalvis* ssp. *sessiliflora*, *Malvastrum coromandelianum*, and *Ricinus communis*.

In transplanted rice, 83.6% of the weed flora was *Monochoria vaginalis*. The only other species that made up more than 10% of the weed flora was *E. colona*.

E. colona and *L. chinensis* were the only species common to both crops. The coefficient of similarity between the weed communities growing in association with the two rice crops, based on the importance value of species common to each crop, was only 14.6%.

Rotation of upland crops. In the unweeded plots of the first crop of a rotation the major weed species associated with the crops were *A. spinosus*, *E. indica*, and *C. rotundus*. The minor species were *Digitaria* sp., *E. colona*, *Trianthema portulacastrum*, and *Phyllanthus niruri*. Based on weed weight at 35 DE *A. spinosus* dominated the weed flora in all plots. There tended to be more *A. spinosus* and *E. indica* in mung bean and rice plots than in corn and sorghum plots (Table 30), and less *C. rotundus* in the mung bean plots than in the others. Total weed weight was significantly lower in the corn and sorghum plots than in the rice and mung bean plots.

In the second crop of the rotation there was a dramatic change in the weed flora (Table 31). When rice had been grown previously *Ipomoea triloba* became the dominant weed species, and *A. spinosus* became unimportant. In the other cropping sequences, *A. spinosus* still dominated and *I. triloba* and the other weeds made up a relatively small proportion of the weed flora. *C. rotundus* tended to build up in the corn-corn and mung bean-mung bean rotations. *Digitaria* species were more important in the corn-corn rotation than in the rotations that had rice as a

Table 30. Effect of different crop rotations on the weight of weeds growing in association with the first crop in the sequence. IRRI, 1977 wet season.

Crop sequence	Weed wt[a] (g/0.25 m²)				
	Amaranthus spinosus	*Eleusine indica*	*Cyperus rotundus*	Other weeds	Total
Rice-corn	146.4 cd	12.9 d	11.1 b	4.3 a	174.8 cd
Rice-sorghum	103.9 b	13.1 d	14.8 bc	5.5 a	137.3 bc
Rice-corn	156.8 d	12.5 d	13.0 bc	4.4 a	186.8 de
Corn-rice	93.9 ab	1.9 a	13.5 bc	2.7 a	112.0 ab
Corn-corn	72.6 a	3.1 ab	14.4 bc	4.4 a	94.5 a
Mung bean-rice	220.7 e	2.2 a	15.0 c	4.0 a	241.8 e
Mung bean-mung bean	159.3 d	6.4 c	6.2 a	4.2 a	176.0 cd
Sorghum-sorghum	106.8 bc	12.5 d	15.7 c	3.6 a	131.0 b

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

Table 31. Effect of different crop rotations on the weight of weeds growing in association with the second crop in the sequence. IRRI, 1977 wet-dry season.

Crop sequence	Weed wt[a] (g/0.25 m²)								
	Amaranthus spinosus	*Ipomoea triloba*	*Echinochloa colona*	*Cyperus rotundus*	*Eleusine indica*	*Digitaria* sp.	*Rottboellia exaltata*	Other weeds	Total
Rice-corn	2.2 a	43.0 b	0.9 a	6.3 a	0.1 a	0.1 ab	0.2 a	0 a	52.7 a
Rice-sorghum	0.4 a	32.1 b	6.6 a	3.5 a	0.1 a	0.3 ab	24.8 b	0 a	57.7 ab
Rice-corn	1.8 a	30.4 b	5.9 a	6.0 a	1.4 ab	0.3 ab	22.9 b	0.3 ab	68.5 ab
Corn-rice	118.5 b	0.7 a	1.6 a	3.0 a	4.2 ab	1.6 ab	4.2 ab	0.7 ab	134.4 b
Corn-corn	78.3 b	0 a	21.3 b	2.4 a	10.3 b	4.8 b	2.0 ab	2.0 ab	121.1 b
Mung bean-rice	86.8 b	0.1 a	2.4 a	1.1 a	1.6 ab	0 a	0 a	7.0 b	99.1 b
Mung bean-mung bean	43.0 a	0.2 a	0.6 a	5.1 a	8.7 b	4.2 ab	0 a	1.4 ab	63.2 ab
Sorghum-sorghum	68.0 b	0.4 a	0.2 a	1.8 a	2.0 ab	2.7 ab	17.3 ab	0.3 ab	92.7 ab

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

first crop and in the mung bean-rice rotation.

The amount of weeding required for optimum yield varied among crops. As first crops, corn required no weeding, but mung bean and sorghum required one (Table 32). There was some variation between crop rotations with rice, but no first crop yield was obtained if the rice crop was not weeded. Two of the rice rotations needed more than two weedings for optimum rice yield, while the third needed only one.

As a second crop, corn after rice required two weedings or herbicide followed by a hand weeding for optimum yield, but corn after corn needed only one weeding (Table 33). The mung bean crop needed only one weeding. Sorghum after rice required two weedings, but for sorghum after sorghum one weeding was adequate. The rice in the corn-rice and mung bean-rice rotations failed because of drought.

In a second upland-crop rotation trial the number of weed species growing in association with the different upland crops gradually decreased as the length of cropping increased. In the first crop, 21 weed species were observed. By the fourth crop, the number had decreased to 13. The number of grass and broadleaf weed species decreased, but the number of sedge species remained unchanged (Table 34).

A decrease of 52 plants in the total number of weeds per 0.25m² occurred between the first crop and the second. Thereafter, the number of weeds remained relatively stable. The weight of weeds growing in association with dry-seeded rice was almost the same in both years. There was a substantial decrease, however, in weight of weeds growing in association with corn after dry-seeded rice and a further substantial decrease between corn and mung bean (Table 34). The low weed weight in mung bean was probably due to dryness of the soil, which was unfavorable for weed growth.

Table 32. Grain yield in the first crop of a rotation as affected by different weed control treatments. IRRI, 1978 wet season.

Treatment	Grain yield (t/ha) in first crop of rotation[a]							
	Rice-corn	Rice-sorghum	Rice-corn	Corn-rice	Corn-corn	Mung bean-rice	Mung bean-mung bean	Sorghum-sorghum
Weed free	2.4 a	2.6 a	1.5 a	3.6 a	3.2 a	0.9 a	1.1 a	3.1 a
Herbicide[b] fb[c] hand weeding[d]	1.9 ab	1.5 b	1.6 a	3.7 a	3.5 a	1.0 a	1.1 a	2.7 ab
Weeded twice[e]	1.6 b	0.9 b	1.1 a	3.1 a	2.8 a	0.8 a	1.1 a	3.0 a
Weeded once[f]	1.1 c	1.3 b	1.0 a	3.0 a	2.4 a	1.0 a	1.0 a	3.0 a
No weeding	0 d	0 c	0 b	3.3 a	3.0 a	0.2 b	0.3 b	1.8 b

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Atrazine at 2.0 kg active ingredient (a.i.)/ha for corn and sorghum; butachlor at 2.0 kg a.i./ha for rice and mung bean. [c]Followed by. [d]21 days after crop emergence (DE) for mung bean, 28 DE for corn, rice, sorghum. [e]7 and 28 DE for sorghum and corn, 7 and 21 DE for mung bean, 14 and 28 DE for rice. [f]21 DE for rice, corn, and sorghum; 14 DE for mung bean.

Table 33. Grain yield of the second crop of a crop rotation as affected by different weed control treatments. IRRI, 1977 wet-dry season.

Treatment	Grain yield (t/ha) from 2d crop of rotation[a]					
	Rice-corn	Rice-sorghum	Rice-corn	Corn-corn	Mung bean-mung bean	Sorghum-sorghum
Weed free	3.5 a	3.4 a	3.8 a	3.7 a	0.5 a	3.9 a
Herbicide[b] fb[c] hand weeding[d]	3.5 a	2.7 a	3.7 a	3.3 ab	0.7 a	3.7 a
Weeded twice[e]	3.4 a	2.5 a	3.0 a	3.7 a	0.5 a	2.9 b
Weeded once[f]	2.4 b	1.2 b	2.7 b	2.9 ab	0.5 a	3.3 ab
No weeding	1.0 b	0.1 b	0.9 c	2.5 b	0.2 b	0.9 c

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Atrazine at 2.0 kg active ingredient (a.i.)/ha for corn and sorghum, butachlor at 2.0 kg a.i./ha for mung bean. [c]Followed by. [d]21 DE for mung bean, 28 DE for corn and sorghum. [e]7 and 28 DE for sorghum and corn, 7 and 21 DE for mung bean. [f]21 DE for corn and sorghum, 14 DE for mung bean.

The dominant weed species in the first dry-seeded rice crop was *Paspalum dilatatum* but in the second (grown 1 year later) it was *D. ciliaris*. *C. rotundus* was the dominant weed species in green corn and mung bean in terms of number per 0.25 m², but in terms of weight the dominant species were *D. ciliaris* and *E. indica*.

Nine weed species were common to all crops. The number and weight of *P. dilatatum*, *E. indica*, and *D. aegyptium* decreased rapidly between the first crop and the second. Thereafter the weight remained relatively stable at a low level. The number and weight of *D. ciliaris*, *C. rotundus*, and *A. spinosus* tended to increase with time, with a dramatic weight increase in *D. ciliaris* and *A. spinosus* between the third and the fourth crops. *I. triloba*, *I. pes-tigridis*, and *Euphorbia hirta* remained relatively stable across the four-crop period.

The coefficient of similarity of the weed communities in association with the four crops is given in Table 35.

The weeding regimes applied to the previous four crops produced a dramatic change in the number of weeds growing in association with the fifth crop (corn) in the cropping system (Table 36).

The weeding regimes also affected the weed seed reserve in the soil (Table 37). The number of seeds that germinated increased by 8.2% in the unweeded check plots, but decreased by 35.7 to 41.7% in the weeded plots. The highest decrease was in the weed-free plot, the lowest was in the plots weeded once or twice per crop.

In both years the dry-seeded rice in the unweeded plots gave no yield. The weeded plots yielded significantly more than the unweeded plots, but the difference between the weeding treatments was not significant. Weeding produced no significant yield increase in corn and mung bean.

Screening herbicides for upland crops. In 1978, wet-season experiments at IRRI and in a farmer's field in Batangas province compared

Table 34. Effect of crop and season on the number of weed species, their total number and weight per 0.25 m² at maximum crop flowering in the unweeded plots in a well-drained upland soil.[a] IRRI, 1977–78.

Crop, season	Species[b] (no.)				No./0.25 m²	Wt (g/0.25 m²)
	G	S	B	Total		
1st: dry-seeded rice, 1977 wet season	8	1	12	21	99.7	98.3
2d: green corn, 1977 wet season	5	1	12	18	47.8	43.2
3d: mung bean 1978 dry season	4	1	9	14	48.5	17.2
4th: dry-seeded rice, 1978 wet season	5	1	7	13	50.5	102.0

[a]Av of 3 replications. [b]G = grasses, S = sedges, B = broadleaf weeds.

Table 36. Coefficient of similarity of the weed communities growing in association with different crops grown at different seasons in a well-drained upland soil.[a] IRRI, 1977–78.

Crop, season	Coefficient of similarity (%)		
	Green corn 1977 wet season (2d crop)	Mung bean 1978 dry season (3d crop)	Dry-seeded rice 1978 wet season (4th crop)
Dry-seeded rice, 1977 wet season (1st crop)	36.2	44.5	26.0
Green corn, 1977 wet season (2d crop)	—	69.6	75.3
Mung bean, 1978 dry season (3d crop)	—	—	35.0

[a]Determined on the basis of the importance value of species in each crop.

Table 36. Effect of weeding regime on number of weeds occurring in the fifth crop (a corn crop) compared to those in the first crop, in a well-drained upland soil.[a] IRRI, 1978 wet season.

Weeding regime and crop	Weeds[b] (no./0.25 m²)			
	Broadleaf weeds	Grasses	Sedges	Total
No weeding				
1st crop	15	41	15	71
5th crop	0	3	72	75
	(−100.0)	(−92.7)	(+480.0)	(+5.6)
Weeded once or twice per crop				
1st crop	24	41	8	73
5th crop	0	7	41	48
	(−100.0)	(−82.9)	(+412.5)	(−34.2)
Weeded 2 or 3 times per crop				
1st crop	26	64	10	100
5th crop	1	5	17	23
	(−96.2)	(−92.2)	(+70.0)	(−77.0)
Weed free				
1st crop	23	107	22	152
5th crop	1	7	12	20
	(−95.7)	(−93.5)	(−45.5)	(−86.8)

[a]Sampled 2 weeks after crop emergence. Av of 3 replications and 3 samples/plot. [b]Values in parentheses indicate percentage change.

eight herbicides with hand-weeded and untreated checks for weed control and selectivity in rice, corn, sorghum, soybean, mung bean, and peanut.

Table 37. Effect on weed seed reserve in the soil of weeding regimes applied consecutively to 4 crops in a well-drained upland soil.[a] IRRI, 1977–78 wet season.

Weeding regime	Weed seeds (thousand/1.0 m² of surface soil)		Change (%)
	Before cropping	After cropping	
Unweeded check	99.5	107.7	+ 8.2
Weeded once or twice	99.5	64.0	−35.7
Weeded 2 or 3 times	99.5	58.0	−41.7
Weed free	99.5	36.0	−63.8

[a]Av of 3 replications.

The major weed species common at both sites were *D. ciliaris*, *E. indica*, *E. colona*, *C. benghalensis*, and *I. triloba*. In addition, *R. exaltata*, *C. rotundus*, *Calopogonium mucunoides*, and *A. spinosus* were present at IRRI, and *Bidens pilosa*, *Cyperus iria*, *C. compressus*, and *Celosia argentea* occurred at Batangas.

At both sites, most of the herbicides controlled the grassy weeds adequately but a number drew a tolerant response from *R. exaltata* and *C. mucunoides*. Oxadiazon and dichlofop-methyl gave outstanding control of *R. exaltata*. Butralin, dinitramine, and pendimethalin were the most consistent in controlling the existing weed flora at both sites.

Herbicide toxicity varied between the two sites. At IRRI, butachlor and butralin were

selective; X-150, oxadiazon, and oxyfluorfen were moderately toxic to all crops. Rice and peanuts were most tolerant of nearly all herbicides; sorghum was the most susceptible.

The herbicide-treated plots at Batangas did not significantly differ from each other in rice yield, but only plots treated with butralin and pendimethalin yielded significantly more than the untreated check (Table 38). Control of *E. colona*, the major weed present, was poorest with butachlor and piperophos – dimethametryn. Oxadiazon, oxyfluorfen, and X-150 were slightly toxic to rice. At IRRI all herbicide treatments failed to control a second flush of *C. mucunoides*, which smothered the crops. As a result significant yield was obtained only from the hand-weeded treatments.

Corn yields from all herbicide-treated plots, except those treated with dichlofop-methyl and dinitramine, were significantly higher than yields in the untreated plot. However, only yields from plots treated with X-150 were statistically similar to those from the hand-weeded treatment. Dichlofop-methyl killed all the corn plants, and dinitramine, in addition to being toxic to corn, controlled *R. exaltata* poorly. Oxadiazon and oxyfluorfen were also toxic to corn. In Batangas where the corn crop was severely attacked by earworm, no yield was obtained.

Despite the moderate toxicity of dinitramine and X-150 to sorghum at IRRI, yields from plots treated with those herbicides and with butralin, pendimethalin, and dichlofop-methyl were not significantly different from those obtained from the hand-weeded check. Butachlor failed to control *R. exaltata;* as a result no yield was obtained from butachlor-treated plots. In Batangas yields from plots treated with a number of herbicides were not significantly different from those of the hand-weeded treatment, but only the butralin-treated plot yielded significantly more than the untreated check.

At IRRI and Batangas, soybean yields from herbicide-treated plots were not significantly greater than those from the untreated check. At IRRI the herbicides failed to control *C. rotundus*, which took over after the susceptible weed species had been controlled. In Batangas weed growth was light, and dinitramine, oxadiazon,

Table 38. Effect of preemergence herbicides on yields of upland crops at IRRI and in a farmer's field, Batangas province, Philippines, 1978 wet season.

Herbicide treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)														
		IRRI							Batangas							
		Corn	Sorghum	Soybean	Mung bean	Peanut	Rice	Sorghum	Soybean	Mung bean	Peanut
Hand weeded twice[d]	—	4.9 a	2.5 a	1.4 a	1.2 a	1.9 a	2.7 ab	2.2 abc	1.9 a	0.5 abc	1.8 ab
Butralin	2.0	2.8 bcd	2.0 a	0.4 b	0.4 b	1.5 ab	3.1 a	2.9 a	1.5 c	0.5 abc	1.4 abc
Dinitramine	1.5	1.0 de	1.9 a	0.6 b	0.1 bc	2.2 a	2.7 ab	2.2 abc	0.4 b	0.4 bc	2.0 a
Pendimethalin	2.0	2.5 cd	1.8 a	0.2 b	0.1 bc	1.7 a	3.3 a	2.0 bc	0.2 b	0.4 bc	1.7 abc
Oxadiazon	1.0	2.8 bc	0.4 bc	0.5 b	0 c	2.1 a	2.9 ab	2.7 ab	0.2 b	0.7 ab	1.8 ab
Piperophos – dimethametryn	1.6–0.4	2.6 bcd	0.8 b	0.4 b	0 c	1.6 ab	2.3 ab	2.1 bc	1.5 a	0.4 bc	1.3 bc
X-150	4.0	3.3 ab	0.5 b	0.6 b	0 c	1.9 a	2.4 ab	2.2 abc	0.3 b	0.4 bc	1.3 bc
Dichlofop-methyl	0.8	0 e	2.0 a	0.1 b	0.5 b	1.4 ab	1.9 ab	1.5 c	2.3 a	0.8 a	1.2 bc
Oxyfluorfen	0.25	2.7 bcd	0 d	0.6 b	0 c	1.9 a	2.3 ab	2.4 abc	0.3 b	0.4 bc	1.6 abc
Butachlor	2.0	1.3 cd	0 d	0.1 b	0 c	0.9 ab	2.4 ab	2.4 abc	1.6 a	0.3 c	1.5 abc
Untreated	—	0 e	0.1 cd	0.1 b	0 c	0.3 b	1.4 b	2.1 bc	1.5 c	0.2 c	0.4 d

[a]A special dash (—) means that the 2 herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Av of 3 replications/crop per date. In each column, means followed by the same letter are not significantly different at the 5% level. [d]10 and 22 days after crop emergence (DE) at IRRI; 22 and 41 DE at Batangas.

and oxyfluorfen were toxic to soybean.

Piperophos — dimethametryn, X-150, oxyfluorfen, and oxadiazon were very toxic to mung bean at IRRI, and only butralin and dichlofop-methyl controlled the weeds. Yields from plots treated with dichlofop-methyl and butralin were significantly higher than those from the untreated check, but significantly lower than those from the hand-weeded treatment. Herbicide toxicity to mung bean was less severe in Batangas; however, only plots treated with dichlofop-methyl yielded significantly more than the untreated check.

At IRRI, oxadiazon, oxyfluorfen, and X-150 caused temporary injury to peanut; at Batangas pendimethalin and piperophos — dimethametryn caused injury. Yields from all herbicide-treated plots were not significantly different from those from the hand-weeded treatment at IRRI, but yields from plots treated with butralin, piperophos—dimethametryn and dichlofop-methyl were not significantly higher than those from the untreated check. The plots had a high incidence of *C. rotundus;* in addition the herbicides failed to control a second flush of *C. benghalensis.* In Batangas, yields from all herbicide-treated plots were similar to those obtained from the hand-weeded treatment and significantly higher than that from the untreated check.

PLANT PROTECTION

Cropping Systems Components of Plant Pathology, Entomology, and Soil Microbiology Departments

Screening chemicals for seed treatment to control damping-off of legumes *(Plant Pathology).* Damping-off of grain legume seedlings caused by *Sclerotium rolfsii, Rhizoctonia solani,* and *Pythium debaryanum* occurred in Iloilo and Pangasinan and at IRRI. Fungicides to protect seedlings against such soil-borne pathogens were tested in an artificially infested soil in an IRRI greenhouse.

In a seed-treatment experiment with *P. debaryanum,* 10 fungicides — 4 of which are on local markets — were tried on cowpea, mung bean, and soybean. Although only 31.06% infection was obtained, the data still showed that mancozeb, a commercially available fungicide, was most promising against

Table 39. Effect of fungicide treatments on the incidence of damping-off caused by *Pythium debaryanum* on three grain legumes. IRRI, 1978.

Fungicide	Rate[a] (a.i./kg seed)	Damping-off[b] (%)					
		Preemergence			Postemergence		
		Cowpea	Mung bean	Soybean	Cowpea	Mung bean	Soybean
Mancozeb	1.92 g	1.00	11.34	5.68	0	16.11	3.62
Terra-Coat ZN-2055	1.12 g — cowpea and mung bean, 1.50 g — soybean	2.00	9.62	6.44	5.99	10.72	8.94
CGA 48988	0.63 g	2.00	8.94	12.12	0	0.37	5.27
Zinc omadine	1.39 ml — cowpea and mung bean, 2.08 ml — soybean	2.00	13.40	8.71	21.62	26.91	6.23
Captex 50 WP	1.10 g	5.67	13.40	5.30	19.75	10.24	10.50
Thiram	2.33 g	3.67	14.09	9.09	17.20	12.75	10.00
Vitavax R	0.66 ml — cowpea and mung bean, 0.88 ml — soybean	4.33	9.28	29.55	1.02	12.75	2.65
Seedkom	0.012 ml — cowpea and mung bean, 0.014 ml — soybean	2.67	16.49	28.79	6.83	25.46	12.28
Terra-Coat L-205	0.84 ml — cowpea and mung bean, 1.26 ml — soybean	3.33	17.52	17.80	3.50	23.60	6.91
Benlate	1.10 g	4.67	15.81	27.65	18.94	12.23	12.28
Control	—	8.33	24.74	31.06	21.36	28.22	12.62

[a]a.i. = active ingredient. [b]Determined by the ratio of infected plants to the total population; preemergence damping-off was determined 11-13 days after sowing (DS); postemergence damping off, 19 DS. Each figure represents mean of 3 replications.

Table 40. Effect of fungicide treatments on the incidence of damping-off caused by *Rhizoctonia solani* on cowpea, mung bean, and soybean. UPLB, 1978.

Fungicide	Rate[a] (a.i./kg seed)	Damping-off[b] (%)					
		Preemergence[c]			Postemergence[d]		
		Cowpea	Mung bean	Soybean	Cowpea	Mung bean	Soybean
Mancozeb	1.92 g	31.82	38.10	3.58	92.20	94.73	16.98
CGA 48988	0.63 g	80.30	81.19	60.95	97.09	96.64	28.20
CGA 49104	0.63 g	60.11	63.43	46.79	84.45	92.02	25.76
Terra-Coat ZN-2055	1.12 g — cowpea and mung bean, 1.50 g — soybean	20.20	18.04	7.90	97.77	98.57	47.22
Terra-Coat L-205	0.84 ml — cowpea and mung bean, 1.26 ml — soybean	8.84	8.50	5.00	95.76	98.33	40.58
RH 2161	0.24 ml — cowpea and mung bean, 0.32 ml — soybean	73.23	70.89	65.53	90.58	90.73	21.08
Thiram	2.33 gm	52.27	64.95	10.79	80.68	97.67	16.90
Captex 50 WP	1.10 g	58.87	63.40	10.53	96.54	97.59	45.03
M7007	0.71 g — cowpea 0.51 g — mung bean 1.16 g — soybean	60.15	86.05	56.32	90.16	83.83	26.57
Control	—	94.19	93.04	79.74	81.74	85.42	25.87

[a]a.i. = active ingredient. [b]Each figure represents mean of 4 replications. [c]Determined 7 days after sowing (DS). [d]Determined 14 DS.

preemergence damping-off, and CGA 48988 was most promising against postemergence damping-off (Table 39). Thiram, a conventional seed-treatment fungicide, did not perform satisfactorily.

In the tests with *R. solani*, much higher disease incidences were recorded (Table 40). Terra-Coat L-205, an experimental fungicide, was best against preemergence damping-off of the three grain legumes. Terra-Coat ZN-2055 and mancozeb also gave considerable protection. None of the candidate fungicides controlled postemergence damping-off; in fact they may have promoted its development.

Unsatisfactory results were observed in trials against *S. rolfsii* because disease incidence was low.

Control of downy mildew of corn before rice *(Plant Pathology)*. In Pangasinan province, early planting helps corn avoid downy mildew infection, but it is not practiced in rainfed fields because of the absence of rain. Seed treatment with Ridomil 25 WP at rates ranging from 0.5 to 2.0 g a.i./kg seed provided excellent control of downy mildew in studies at UPLB and IRRI.

A 1978 study in Pangasinan involved determining the efficacy of low rates of Ridomil on the local corn variety Macapuno and Hawaii Supersweet #6, a sweet corn. The trial with Macapuno showed satisfactory control of downy mildew, but the rates were not correlated with the percentage of infection observed (Table 41). The amount of fungicide was insufficient when the trial on Macapuno was set, hence, the 1-g rate was deleted. On sweet corn, the lower rates of Ridomil also provided considerable control of downy mildew and the rates were inversely proportional to the percentage of infection as expected. No data on yield were taken because the experiment was destroyed by a typhoon.

Effect of corn and mung bean intercrop on powdery mildew of mung bean *(Plant Pathology)*. Powdery mildew is an important foliage disease of mung bean. Mung bean was intercropped with corn at two row spacings at IRRI to determine the effect of intercropping on the disease.

Intercropping had no effect on powdery mildew at 44 DE, but at 58 DE it favored the disease (Table 42). The slightly higher infection at 1.5-m corn row spacing suggests that closer spacing of corn plants favors the disease. Although the amounts of inoculant deposited on the leaves in intercropped and monoculture systems are similar, the subsequent stages of

Table 41. Effect of fungicide treatments on incidence of downy mildew on 2 corn varieties at various observation dates. Dagupan, Philippines, 1978.

Fungicide	Rate[a] (g a.i./kg seed)	Infection[b] (%)					
		Macapuno[c]			Hawaii Supersweet #6		
		20 DE	30 DE	40 DE	20 DE	30 DE	40 DE
Ridomil 25 WP	1.0	—	—	—	0	0.81	5.78
Ridomil 25 WP	0.5	0	2.00	2.34	0.77	4.11	19.23
Ridomil 25 WP	0.25	0	0.80	2.57	3.28	18.48	31.95
Ridomil 25 WP	0.125	0.75	0.42	1.67	0.71	28.48	34.72
Control	—	51.12	54.64	57.24	71.70	87.37	89.59

[a]a.i. = active ingredient. [b]Based on the ratio of infected plants to the total population in 5 middle rows/plot; each figure represents mean of 4 replications. DE = days after crop emergence. [c]The 1-g level was deleted.

disease development in the two systems may differ because of environmental conditions such as relative humidity, temperature, and light.

The yields of mung bean with intercrop were lower than those in monoculture because corn competition depressed yield (Table 42). The yield reduction due to intercropping did not vary much between the treated and untreated plots. Yield reduction due to powdery mildew was inconsistent among the treatments.

Insect control *(Entomology)*. Populations of insects and their natural enemies were monitored within a continuous-rice planting system and compared with data gathered from a conventional double-cropping system. Both systems grew IR36, which is resistant to several insects (brown planthopper, green leafhopper, and stem borer), and IR1917, which is completely susceptible to insect damage but is resistant to virus diseases. No insecticide was applied to either system to allow the arthropods (predators) to freely respond to the cropping effects. Arthropods were monitored in a separate continuous planting of IR36 that received insecticides. All fields received the same management inputs except insecticide.

Yields of both systems, averaged for 14 planting dates (17 March-16 June 1978), were 5.0 t/ha for IR36 with insecticide, 4.5 t/ha for untreated IR36, and 4.0 t/ha for IR1917 without insecticide. Insect pest pressure came from only the rice whorl maggot and yellow and striped stem borers. A 0.5-t/ha yield loss from those insects—normal at IRRI—indicates that continuous cropping behaves no differently from double-cropping.

Table 42. Effect of intercropping on the severity of powdery mildew and on grain yield of mung bean. IRRI, 1978.

Treatment	Disease rating[a]		Grain yield		Yield reduction (%) due to	
	At 44 DE	At 58 DE	Kg/12 m²	T/ha	Intercropping	Powdery mildew
		Untreated				
Mung bean	2.60	2.67	1.73	1.44	—	14.79
Mung bean with corn in 1.5-m rows	2.66	3.94	0.85	0.71	50.69	12.34
Mung bean with corn in 3.0-m rows	2.32	3.56	1.22	1.01	29.86	19.84
		Treated[b]				
Mung bean	0.66	0	2.03	1.69	—	—
Mung bean with corn in 1.5-m rows	0.62	0.45	0.97	0.81	52.07	—
Mung bean with corn in 3.0-m rows	0.66	0.28	1.51	1.26	25.44	—

[a]Each leaf was rated as follows: 0 = no infection, 1 = 1 to 5% leaf area affected, 3 = 6 to 25%, 5 = 26 to 50%, 7 = 51 to 75%, and 9 = 76% infection. At 44 DE (days after emergence), based on 4 lower main leaves (leaves arising directly from the main stalk) because upper leaves were still free from infection; sample of 6 plants/plots. At 58 DE, based on the leaves at the upper half portion of the plant using 3 plants/sampling area of 6 in each plot. [b]Benlate at the rate of 0.25 lb/100 gal water was sprayed at 37 DE.

Table 43. Rice insect incidence in untreated continuously cropped (weekly) and double-cropped IR36 and IR1917 transplanted 16 June 1976 at IRRI.[a]

Cropping system	Whorl maggot score[b]		Stem borers: Deadhearts (%) 50 DT[c]		Stem borers: Whiteheads (%)	
	IR36	IR1917	IR36	IR1917	IR36	IR1917
Continuous (weekly)	3	4	4.5	5.0	5.5	4.5
Double-cropped (twice yearly)	4	5	1.0	3.5	2.0	2.5

[a]Not replicated. [b]Damaged leaves per hill: 1 = 0-1, 3 = 2 or more but less than one-third, 5 = one-third to one-half, 7 = more than one-half but no broken leaves, 9 = more than one-half with some broken leaves. [c]Days after transplanting.

The whorl maggot damage rating (1–9 scale) averaged 5.0 for IR36 and 5.2 for IR1917 over the 14 planting dates in the untreated plots. Stem borer deadhearts at 55 days after transplanting averaged 8.1% for IR36 and 8.8% for IR1917. Whiteheads for the same period averaged 5.4% for IR36 and 6.6% for IR1917.

The leafhopper and planthopper populations were low in the continuous rice system without insecticide. The brown planthopper and green leafhopper were the most prevalent species, but the number was never more than 3 nymphs/hill for each species on any sampling date or variety.

Parasitization of hopper eggs in IR36 and IR1917 was consistently high, averaging 40–53% for each species (including the whitebacked planthopper) from April to August in random plots of the continuously cropped fields without insecticide. The results are consistent with those for the whole IRRI research farm. Spiders were the most dominant predators.

The populations of the same pests from the double-cropped fields and the continuous plantings transplanted in the same week (16 June) were compared to provide a point of reference as to cropping effects.

Whorl maggots were slightly less abundant in continuous planting than in double-cropping (Table 43). Stem borer deadhearts and whiteheads, however, were twice as abundant in the continuous planting of both varieties.

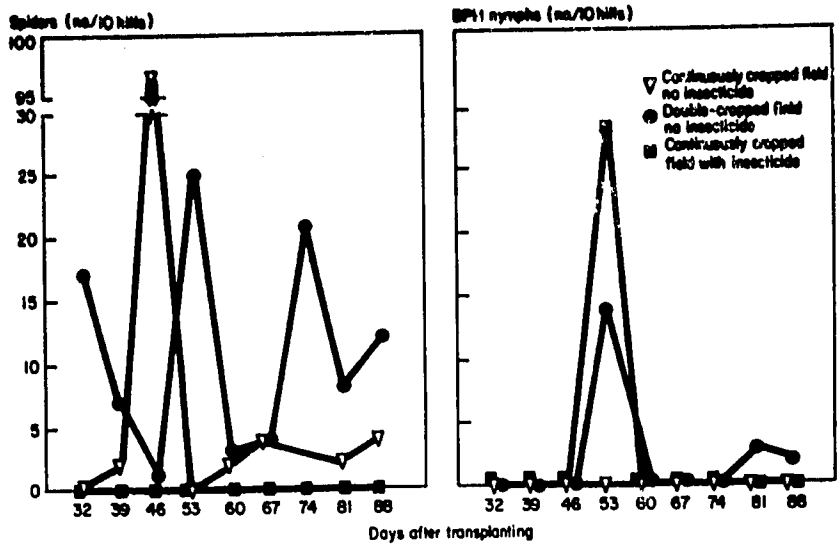
The brown planthopper population was lower in the continuous planting than in the double crop of IR36 without insecticide (Fig. 21). Spider populations were high in both fields without insecticide. The insecticide-treated continuous planting suppressed spiders completely and the treated field had the highest brown planthopper numbers.

The data indicate that the continuous availability of rice in all stages of growth does not cause instability in whorl maggot and hopper populations. There is evidence that the continuous cropping system may favor stem borers. More data are needed, however, to substantiate these observations.

Yield loss in dry-seeded rice. Rice was directly seeded into furrows at the onset of monsoon rains in Iloilo and Pangasinan provinces to get early crop establishment and facilitate rice double-cropping in rainfed wetland fields.

Intensive sampling found no significant insect problems on the early season rice crop because the crop was planted after a 2–6 month rice-free dry season and insect numbers were low. Populations of stem borers and hoppers increased slowly and remained at the subeconomic levels. Whorl maggot and rice caseworm, which prefer early growth stages and require standing water in the paddies, were never observed in dry-seeded rice fields, even in wetland culture, where flooding did not occur until the later growth stages. Leaf folder, rice bug, and armyworm, which normally achieve an early start on grassy weed alternate hosts and volunteer rice, were prevalent on transplanted rice, but attained only moderate population levels on dry-seeded rice.

In dryland direct-seeded rice in Batangas province, neither insect pest problems nor measurable yield differences between plots with and without insecticide protection were observed in 3 years of testing with the local variety Dagge (Table 44). In 1978, however, a



21. Population fluctuations of brown planthopper nymphs and spiders on IR36 in continuously cropped and double-cropped fields without insecticide and in a continuously cropped field with insecticide. IRRI, 1978 wet season.

new high yielding variety, C171-136, was introduced and a significant yield response to insecticide was recorded for the first time. The two varieties did not differ in susceptibility to insect damage.

Similar 1977–78 dry seeded rice experiments with IR36 in Iloilo and Pangasinan resulted in significant yield differences between treated and untreated plots in three out of four trials, again in the apparent absence of pests (Table 44).

In all cases the yield responses were to carbofuran granules applied in seed furrows. The absence of any yield response to two other granular soil insecticides — diazinon and lindane — tested in seed furrows ruled out soil insects. Carbofuran is also a nematicide, but no nematode pests of rice are known to occur in the Philippines. Surface-inhabiting insects and seedling pests such as beetles, crickets, or seedling maggots were not ruled out, but results of a close check for symptoms of damage were negative. Carbofuran-treated plots tillered more and the crop canopy closed earlier than that in untreated plots. Carbofuran or its metabolites may directly stimulate plant growth.

Legume crop establishment practices after rice. Bean fly populations are greatly reduced by minimum tillage for cowpea establishment after rice in Iloilo (1977 Annual Report). It

Table 44. Yield response to carbofuran granular insecticide in dry-seeded rice in rainfed dryland and wetland fields. Philippines, 1976–78.

Dryland environment (Batangas)						Rainfed wetland environment (Iloilo, Pangasinan)					
			Yield (t/ha)						Yield (t/ha)		
Year	Fields (no.)	Variety	Treated	Untreated	Difference	Year[a]	Fields (no.)	Variety	Treated[b]	Untreated	Difference
1976	6	Dagge	3.1	3.0	0.1	1977 I	4	IR36	5.5	3.9	1.6*
1977	4	Dagge	2.8	2.6	0.2	P		IR36	6.2	5.5	0.7*
1978	6	Dagge	2.7	2.9	−0.2	1978 I		IR36	4.8	4.0	0.8*
	6	C171-136	3.7	3.3	0.4*	P		IR36	3.7	3.6	0.1

[a]I = Iloilo province, P = Pangasinan province. [b]0.5 kg active ingredient carbofuran granules/ha applied in seed furrows.

Table 45. Effect of rice stubble management and tillage systems on preflowering insect pests of cowpea established after flooded rice.[a] IRRI, 1978.

Rice stubble	Tillage	Insects[b] (no./15 plants)			Yield (kg/ha)	
		Bean fly larvae + pupae 13 DE	Thrips 20 DE	*Empoasca* 20 DE	With preflowering insecticide[c]	Without preflowering insecticide
None	Plowed and harrowed twice	17 a	83 a	36 b	687 bc	316 e
Mulch	Plowed and harrowed twice	15 a	8 b	13 c	571 cd	354 e
2 cm high	Furrows plowed between rice rows	15 a	82 a	63 a	480 d	532 d
2 cm high	Dibbling in rows	12 b	9 b	53 ab	775 b	575 cd
15 cm high	Furrows plowed between rice rows	9 bc	6 b	13 c	815 b	621 c
15 cm high	Dibbling in rows	8 bc	15 b	9 cd	944 a	799 b
30 cm high	Furrows plowed between rice rows	6 c	1 b	6 cd	626 c	380 e
30 cm high	Dibbling in rows	5 c	1 b	2 d	964 a	525 d

[a]Av of 3 replications. IR36 was transplanted at 25 × 25 cm. Means followed by a common letter are not significantly different at the 5% level. [b]Without insecticide. DE = days after emergence. [c]1% wt/wt carbofuran seed treatment, 0.5 kg active ingredient monocrotophos/ha and 1.0 kg a.i. carbaryl/ha sprays. All plots received a similar postflowering protection of 1.0 kg a.i. monocrotophos/ha spray.

was suspected that rice stubble remaining after minimum tillage camouflaged the cowpea plants against bean fly attack during early crop growth.

The effect on preflowering cowpea insect pests of stubble height (2, 15, 30, 45, and 60 cm) of transplanted IR36 (25 × 25 cm) grown under 2 tillage systems was studied. In one system seeds were dibbled in stubble to simulate zero tillage; in the other — a minimum tillage method — furrows were opened between alternate rows of rice stubble. The systems were compared with planting after conventional tillage, with and without rice straw mulch. All plots received postflowering insecticide protection, but only one-half of each main plot received preflowering protection.

Three preflowering insect pests were prominent in the trial. In addition to bean fly, thrips (*Thrips palmi*) and a leafhopper (*Empoasca biguttula*) attacked the young cowpea plants. All caused plant stunting and reduced the number of pods per plant. The thrips invasion was unexpected because the insect is a newly recorded grain legume pest in the Philippines.

The highest insect pest incidence was in the high-tillage plots that had no stubble or mulch (Table 45). Rice straw mulch dramatically suppressed the leafhopper and thrips populations. Bare ground evidently highlights the legume crop, but the mulch is either repellant or nonattractive. This crop background effect occurs in aphids.

The erect rice stubble reduced the number of all three pests. The effect was most pronounced in plots with tall stubble, particularly within the 15- to 30-cm range. Differences in stubble higher than 30 cm were not significant.

There were response differences in bean fly and thrips between the zero- and minimum-tillage plots within the plots with 2-cm-high stubbles. The furrows made during minimum tillage reduced the stubble density and opened bare soil. These effects were nullified at stubble heights of 15 cm and taller.

The differential responses of the three grain legume insect pests to rice straw and rice stubble suggest that different mechanisms and economic damage thresholds exist between species.

Rice stubble height directly affected cowpea yield. The differences were noted in the fully protected plots. Plants in the 45- and 60-cm stubble did not yield well. Yield, however, was affected by an unexpected thrips invasion that was not adequately controlled with insecticide. Carbofuran seed treatment did not control thrips.

Effect of cropping patterns on mung bean insects. The introduction of dry seeding as a technique for early crop establishment to facilitate double-cropped rice in Pangasinan allows a

farmer to either plant a second rice crop followed by a January mung bean planting, or grow one rice crop and establish an early mung bean crop in November. Farmers who transplant a single rice crop plant mung bean in December. The performance of the recommended insecticide regime (0.25 kg a.i. monocrotophos/ha at 2 and 12 DE for preflowering pests and 0.75 kg a.i. endosulfan/ha at 35 and 45 DE for postflowering) and that of a higher level of insecticide protection (0.50 kg a.i. monocrotophos/ha at 2, 12, and 25 DE and 1.0 kg a.i. endosulfan/ha at 35 and 45 DE) were compared in plantings at 3 different dates. Insect pest populations during the preflowering and postflowering periods were monitored.

Some insect pests of the preflowering period responded to planting date. Insect pest incidence for each date was significant and justified insecticide usage. The recommended insecticide protection was as effective as the higher level during each month and no changes in insecticide recommendations were warranted.

The bean fly (*Ophiomyia phaseoli*) population progressively increased from the November to January plantings and was above economic damage thresholds during all 3 months. The leafhopper (*Empoasca biguttula*) was most abundant in the December planting. Flea beetle (*Medythia suturalis*) and leaf miner (*Stomopteryx subsecivella*) populations were high and showed no response to planting date.

The greatest seasonal effect occurred on the postflowering pod borers (Table 46). *Maruca testulalis* predominated in the November planting and *Etiella zinckenella* in the January planting. The recommended control was warranted in each case and was equal to the high level. The December planting, however, was overwhelmed by *Heliothis armigera* and the recommended control was insufficient. In the untreated plots *Heliothis* larvae, along with other pod borer species, first consumed the flowers and developing pods, then stripped the plants of foliage.

Insecticide granules versus sprays for bean fly control. Carbofuran was tested at 0.5 and 1.0 kg a.i./ha on mung bean grown after flooded rice in Pangasinan and its performance compared with that of monocrotophos at 0.25 kg a.i./ha applied as a spray 2 and 12 DE.

Along with the bean fly, the flea beetle is a serious preflowering insect pest of mung bean in Pangasinan. In the tests the carbofuran dosage of 0.5 kg. a.i./ha was inferior to the monocrotophos sprays in controlling the 2 pests (Table 47). Carbofuran at the higher dosage was equal to monocrotophos in performance, but was twice as expensive as the spray.

Continuous cropping of dryland rice and other crops *(Soil Microbiology and Plant Pathology)*. During 1978, studies on the development of *soil sickness* in upland rice and mung bean after continuous cropping were conducted with the Nematology Section of the Plant Pathology Department of UPLB.

Soil sickness in dryland rice. Rice plants were grown in *sick* (continuous cropping) and *healthy* (rotation cropping) upland soils during the 1978 wet season. Although seedling growth on the sick soil was normal, plant height showed increasing effects with age, but tillering and root development did not. Number of panicles was not affected, but number of spikelets and grain filling were markedly reduced.

The effect of plant residues in the soil on the

Table 46. Effect of planting date on mung bean pod borers and their control with different levels of insecticide.[a] Pangasinan, Philippines, 1977–78.

Insecticide protection	Defoliation (%) from *Heliothis* 45 DE			Pods (million/ha)		
	Nov	Dec	Jan	Nov[b]	Dec[c]	Jan[d]
High level[e]	3 a	5 a	5 a	1.71 a	2.42 a	1.04 a
Recommended level[f]	4 ab	64 b	12 ab	1.68 a	0.90 b	0.86 a
Untreated	13 b	81 c	25 a	0.66 b	0.05 c	0.14 b

[a]Av of 4 fields/planting date. DE = days after crop emergence. In a column means followed by a common letter are not significantly different at the 5% level. [b]*Maruca testulalis*. [c]*Heliothis armigera*. [d]*Etiella zinckenella*. [e]0.50 kg active ingredient monocrotophos/ha at 2, 12, and 25 DE, 1.0 kg a.i. endosulfan/ha at 35 and 45 DE. [f]0.25 kg. a.i. monocrotophos/ha at 2 and 12 DE, 0.75 kg a.i. endosulfan/ha at 35 and 45 DE.

Table 47. Comparison of granular and sprayable insecticides against preflowering mung bean pests after flooded rice.[a] Pangasinan, Philippines, 1977–78.

Insecticide[b]	Dosage[c] (kg a.i./ha)	Timing	Insecticide cost ($/ha)	Bean fly: Larvae + pupae (no./25 plants) 12 DE	21 DE	Bean fly: Infected plants (%) 12 DE	21 DE	Flea beetle defoliation (%) 21 DE	Yield (t/ha)
Carbofuran 3G	0.5	Basal	15.30	1.5 a	1.5 a	19 a	30 b	9 b	1.10 a
Carbofuran 3G	1.0	Basal	30.60	1.0 a	1.2 a	18 a	24 b	7 ab	1.14 a
Monocrotophos 16.8 EC	0.25	2 and 12 DE	15.00	0.7 a	1.0 a	8 a	10 a	3 a	1.16 a
Untreated	—	—	—	5.2 b	4.2 b	40 b	57 c	13 bc	0.75 b

[a]Av of 4 fields. In a column means followed by a common letter are not significantly different at the 5% level. DE = days after emergence. [b]G = granular, EC = emulsifiable concentrate. [c]a.i. = active ingredient.

growth of dryland rice (IR2061-464-2-4) was demonstrated and the participation of microorganisms in dryland rice soil sickness was confirmed. Root residues of a previous dryland rice crop were removed from the continuously cropped plot and incorporated into the healthy soil plot. Sterilized rice roots were also incorporated into the healthy plot. Growth and dry matter production were reduced more by the addition of unsterilized roots, which suggested that the decomposition of rice root residues influences the appearance of soil sickness.

The growth-inhibiting effect of nematodes in a continuous cropping pattern was examined. Nematodes in the root zone and on the roots of 1-month-old and flowering plants were determined. In both growth stages, no appreciable nematode population was found (Table 48).

The possible role of fungus in dryland rice soil sickness was studied. The dominant fungal genera in the microflora on the root surfaces of IR2061-464-2-4 and IR5 from the sick and healthy plots were *Fusarium* (22%), *Curvularia* (18%), *Aspergillus* (13%), and *Penicillium* (5%). *Fusarium* was noticeably numerous on the basal and lateral rice roots in all plots. Bacteria, which appeared as white colonies, constituted about 25% of the microbial population.

It is speculated that continuous cropping causes the microbial balance to tip toward a specific organism, which directly infects a crop or produces substances that inhibit crop growth. It is suggested that dryland rice soil sickness is caused primarily by a fungus that produces substances toxic to the rice plant. The fungus is aerobic, has specific affinity to the rice plant, resides in the root residues after the rice harvest, and is associated with crop residue decomposition. It causes reduction in plant growth that becomes apparent at late growth stages.

Soil sickness in mung bean. The behavior of mung bean soil sickness in terms of seedling growth was studied. Fungi and nematodes were suspects. Roots were collected from the continuous-mung bean plots and blended with distilled water (1:5); the homogenate was filtered and adjusted to pH 6.2-6.7. Mung bean seeds were germinated in the root extract. Soil from a fallow plot, treated the same way, served as a control. In many of the extracts germination took place normally, but the growth of radicles and hypocotyls was inhibited. The addition of sick soil lessened the toxicity of the extract, implying that the causal agents were in the root residues. Root washings had greater growth-inhibiting effect than the blended roots, indicating that the inhibitory agents are on the root surface. Toxic root extracts were found at the first harvest of pods and at different periods of decomposition.

Despite the addition of carbofuran (2 kg a.i./ha as a nematicide) at planting time, nematodes in mung beans increased (Table 48). *Rotylenchulus* was the predominant genera in the soil and a large number of reproducing females were found in feeding position in the plant roots. *Rotylenchulus* was abundant in the continuous mung bean soil, but there were few in the mung bean-rice rotation and none in the continuous rice soil. The genus appears to have specific affinity to mung bean. *Rotylenchulus* in the soil and on mung bean roots is believed to be

Table 48. Plant parasitic nematodes in the soil from continuous dryland rice and mung bean plots. IRRI, July-November 1978.

Crop history	Present crop	Nematodes[a] (mean no./200 cm³ soil + 1 g roots)		
		Rotylenchulus	*Meloidogyne*	Total of 5 genera[b]
			1 month after planting	
14 crops continuous mung bean	Mung bean	263	1	272
1 year fallow	Rice	5	0	50
1 crop mung bean	Rice	23	0	59
10 crops continuous rice	Rice	0	0	9
			Flowering stage	
14 crops continuous mung bean	Mung bean	913	73	991
1 year fallow	Rice	0	0	37
1 crop mung bean	Rice	0	0	2
10 crop continuous rice	Rice	0	0	25

[a]Soil and roots from 5 places on every plot were pooled. Each treatment had 4 replicated plots. Nematodes were extracted from the pooled soil by the sieving-Baermann funnel technique and roots were stained in acid fuchsin-lactophenol. [b]*Rotylenchulus, Meloidogyne, Helicotylenchus, Tylenchorhynchus,* and *Criconemoides.*

a factor in the reduction of mung bean yields.

Allelopathy in mung bean-mung bean pattern. In trials to determine the effects of allelopathy on yield and other agronomic characteristics of mung bean, 15 promising varieties were planted in upland plots that had no previous mung bean crop (fallow-mung bean) and that had CES ID-21 as a previous crop (mung bean-mung bean). Yields ranged from 0.7 to 1.2 t/ha in the fallow-mung bean plots and 0.4 to 0.9 t/ha in the mung bean-mung bean plots. Yield reduction in mung bean-mung bean plots ranged from 20% in CES X-10 to 78% in EG-MG 174-3. The entries in fallow-mung bean plots matured later, had less senescence, more pods per plant, and heavier seed weight than those in the mung bean-mung bean plots. There were no differences in plant height, number of seeds per plant, powdery mildew rating, and Cercospora leaf spot rating.

VARIETAL TESTING

Multiple Cropping Department and Rice Production Training and Research Office

The food crops involved in IRRI cropping systems research are rice, corn, sorghum, soybean, mung bean, cowpea, peanut, and sweet potato. Varieties are tested at the time a crop fits the system at each research site. The upland trials use elite cultivars from the University of the Philippines at Los Baños (UPLB) and the UPLB Institute of Plant Breeding. The rice entries are from UPLB, Philippine Bureau of Plant Industry (BPI), and IRRI. The 1978 tests were at IRRI (lowland and upland) and at research sites in Cale, Batangas (upland); Manaoag, Pangasinan (lowland); and Oton, Iloilo (lowland).

Rice. In 1978 IR1529-430-3 and C171-136 were the outstanding dryland rice entries in both open-field and in-shade trials (Table 49). IR1529-430-3 has the same maturity as C171-136 but has shorter plants, more tillers, shorter panicles, and lower percentage of filled grain.

Among direct-seeded dryland entries in lowland fields in Pangasinan, the highest yielder was also IR1529-430-3 (5.7 t/ha), followed by C171-136 and IR9575 (Table 50). These varieties were significantly better yielders than IR36 (3.9 t/ha), which was used in the cropping pattern trials. However, IR36 matures 4 days earlier than IR9575, 6 days earlier than C171-136, and 12 days earlier than IR1529-430-3.

The best 13 entries among 24 in a 1977 direct-seeding yield trial were tested in the 1978 wet season. IR2823-399-5-6 was a significantly better yielder than IR36, which was the top yielder in 1977 and is currently recommended for dry seeding (Table 51). IR2823-399-5-6 was taller, matured later, had more filled grains per panicle, and did not lodge as much as IR36. IR2058-78-1-3-2-3 showed the highest ratoon yield, but IR2823-399-5-6 gave the highest total yield (main crop and ratoon). In general,

Table 49. Yield and agronomic characteristics of outstanding dryland rices planted in upland fields in Batangas, Philippines, 1978 wet season.

Entry[a]	Open			In shade		
	Yield (t/ha)	Maturity (days)	Plant ht (cm)	Yield (t/ha)	Maturity (days)	Plant ht (cm)
IR1529-430-3	4.91	123	84	4.34	123	96
C171-136	4.56	123	116	4.02	123	121
C166-136	4.24	123	118	3.87	122	126
IR9575	4.32	119	115	3.66	124	112
IR36 (check)	2.12	111	62	3.78	108	76
C22 (check)	3.68	129	119	3.32	129	129
Dagge (check)	3.13	109	141	2.17	110	144

[a]C22 is the recommended dryland variety; Dagge is the local dryland variety.

the early-maturing entries gave the lowest ratoon yields. The ratoon crop had fewer tillers and panicles per square meter in all cases although reduction varied among entries.

On-farm comparisons. In 1978, C171-136 was distributed to 30 farmers to compare its performance with Dagge, a popular local variety. C171-136 yielded 3.7 t/ha, Dagge 2.7 t/ha. Four farmers planted C171-136 under coconut trees and 26 planted it in open fields. The average yield from open fields was 4.6 t/ha, that from under trees (partial shade), 2.4 t/ha. Dagge required 103% more labor than C171-136, which suppressed weeds and reduced labor needed for weeding. Less weeds were observed in C171-136 fields after harvest. C171-136 matured about 1 week after Dagge but that did not affect the date of planting of the second crop in the pattern. Both varieties lodged during a typhoon and Dagge panicles sprouted, but those of C171-136 did not. The farmer cooperators claim that the eating quality of C171-136 is better than that of Dagge.

Mung bean. Fourteen mung bean entries were tested in 1978 on an upland field with high tillage at IRRI and Batangas; in lowland fields with zero tillage in Pangasinan, IRRI, and Iloilo; and in a lowland field with high tillage in Pangasinan. After the zero-tillage treatment the seeds were dibbled at the base of rice stubble at IRRI and drilled in furrows in Pangasinan and Iloilo. There was no land preparation in both situations.

In the upland high tillage treatment, the highest yielder was CES U-1 (1.9 t/ha) in Batangas and CES 1T-2 (1.6 t/ha) at IRRI. The best five varieties in both locations were CES 55, EG-MG 174-3, CES 1T-2, Bhacti, and CES U-1. The 1978 performance of CES 1D-21, which had the highest yield in 1977 trials and is recommended in cropping pattern trials, was poor. CES U-1, the most promising variety in 1978, is small seeded and early maturing. It has the same number of pods per plant and number of seeds per pod as CES 1D-21.

CES 55, a recommended variety, had highest yields in lowland fields with zero tillage at IRRI (0.8 t/ha) and in Iloilo (1.2 t/ha). The yields in zero-tillage trials were good (0.7-1.9 t/ha in Pangasinan, 0.6-1.2 t/ha in Iloilo, and 0.4-0.8 t/ha at IRRI) compared with those in 1977 trials. The low yield at IRRI was caused by too much moisture at flowering.

Table 50. Yield and agronomic characteristics of dryland rices directly seeded on lowland fields in Pangasinan, Philippines, 1978 wet season.

Cultivar	Yield (t/ha)	Maturity (days)	Plant ht (cm)	Tillers (no./m²)	Panicles (no./m²)	1,000-seed wt (g)
IR1529-430-3	5.66	119	88	357	345	23.4
C171-120	5.55	112	111	325	288	22.8
C171-136	5.29	113	115	200	183	25.1
IR9575	5.29	111	109	364	332	22.9
C166-135	4.86	109	120	305	249	26.9
IR3880-10	4.69	113	107	364	331	20.9
IR2035-242-1	4.58	111	87	215	210	27.4
MRC348	4.40	114	97	308	292	23.9
IR3839-1	4.20	106	98	296	281	29.6
IR36	3.92	107	61	389	332	26.3
IR3304-23	3.82	108	120	355	309	30.5
IR3880-13	3.80	108	101	381	316	27.2
C22	3.71	114	109	285	265	24.7

Table 91. Mean yield and agronomic characters of the main and ratoon crops of 11 rice cultivars grown under dry-seeded rainfed wetland conditions, IRRI, 1978 wet season.

Cultivar	Grain yield[a] (t/ha)		Maturity[b] (days)		Plant ht (cm)		Tillers (no./m²)		Panicles (no./m²)		Filled grain (% panicle)	
	Main	Ratoon	Main	Ratoon	Main	Ratoon	Main	Ratoon	Main	Ratoon	Main	Ratoon
IR2423-388-5-6	4.65	1.92	134	68	100	73	662	400	540	383	79	80
IR4722-38-1	3.60	2.09	133	79	97	78	684	627	607	586	77	88
IR4432-52-6-4	3.46	1.49	128	79	100	74	590	354	532	314	76	82
IR2058-78-1-3-2-3 (IR46)	3.46	2.57	129	79	99	80	636	537	537	463	76	88
IR36	3.41	0.48	117	54	78	60	660	431	579	366	74	83
IR4427-119-6-1	3.11	0.40	126	45	89	55	518	382	457	322	75	81
IR2863-38-1-2 (IR44)	3.02	2.33	138	74	100	75	813	627	638	577	79	89
IR38	2.91	0.74	127	66	93	69	630	334	546	273	70	87
IR42	2.87	—	150	—	102	—	596	—	547	—	85	—
IR4744-295-2-3	2.86	0.82	117	59	96	71	574	382	486	296	72	74
IR3880-13	2.31	1.62	128	56	111	85	539	421	416	378	78	74
IR28	2.28	0.31	99	64	80	58	522	218	462	174	76	78
IR1561-228-3-3	2.19	0.87	118	58	85	61	697	425	610	371	66	82
Mean	3.09	1.30	126	65	95	70	625	428	535	372	77	82

[a]Means of 6 replications (14% moisture content). [b]Reckoned from seeding (9 May 1978).

At Pangasinan, CES X-10 was the best entry. CES 1D-21, the most outstanding in 1977 trials, performed poorly, and its resistance to powdery mildew is breaking down. In the high-tillage trials in a lowland field at Pangasinan the yields, despite delayed planting, ranged from 1.1 to 1.5 t/ha. CES X-10 and EG-MG 174-3 were the most promising.

The mung bean plots without insect and disease control had lower yields than plots with control. The highest yields without pest control were 0.2 t/ha at IRRI, 0.5 t/ha in Iloilo, 0.2 t/ha in Batangas, and 1.1 t/ha in Pangasinan.

Sorghum. Fourteen elite cultivars from the UPLB and BPI breeding programs were evaluated at IRRI and in Batangas on upland fields with good tillage. The 1978 yields were not as good as those in 1977. Yields ranged from 2.8 to 3.7 t/ha in Batangas and from 0.7 to 4.7 t/ha at IRRI. The outstanding varieties were CS 120 and IS 2940 in Batangas, and Pioneer 8417 (a hybrid) and CS 90 at IRRI. UPLB-SG 5, CS 120, and IS 2940 gave the most stable yields after 2 years of tests in upland fields UPLB-SG 5 is now recommended in cropping pattern trials. It matures at the same time as Cosor 3, a nationally recommended cultivar, but yields 21% more, is taller, and has a more spreading head type.

The same 14 entries were tested at IRRI, Iloilo, and Pangasinan in lowland fields with zero tillage. After rice was harvested, the sorghum seeds were dibbled in straight rows near the rice stubble at IRRI and seeded in furrows in Iloilo and Pangasinan (no land preparation except furrowing). The outstanding entries were CS 137 and UPLB-SG 5 at IRRI, D67-4 and IS 2940 in Pangasinan, and Pioneer 8417 and D67-4 in Iloilo. After two seasons of tests with zero tillage, the most stable and highest yielding cultivars were CS 120 at IRRI, D67-4 in Pangasinan, and CS 174 in Iloilo. All performed significantly better than Cosor 3.

The same entries were planted in lowland fields with high tillage in Pangasinan. The yields were lower than with zero tillage because of late planting and limited moisture. The most promising entry was CS 174. After two seasons of tests, the best entry in upland fields with high tillage was UPLB-SG 5.

The average yield reduction with no insect control for all entries was 95% at IRRI, 75% in Pangasinan, but only 4% in Batangas.

Sweet potato. Fifteen sweet potato cultivars were tested in upland fields with high tillage in IRRI and Batangas, in lowland fields with high tillage in Pangasinan and Iloilo, and in the lowland field with zero tillage at IRRI. The yields at Batangas were low because of drought. The highest yield (that of Karja 381) was only 5.2 t/ha. In Iloilo Jewel had the highest yield — 75% higher than that of the local variety and

388% higher than that of BNAS 51, the recommended variety. The highest yielder in Pangasinan was Bangued — it yielded 29% more than the local check and 39% more than BNAS 51. Georgia Red and SP#45, with yields of 30 t/ha, were the most promising at IRRI.

In a lowland field with zero tillage at IRRI, sweet potato cuttings were planted at the base of rice stubble without land preparation. Rice straw was placed between the rows 1 week after planting. The yields ranged from 3.1 to 20.6 t/ha; Karja 381 gave the highest. Georgia Red and SP#45, which were promising in upland fields, were also promising in lowland fields with zero tillage.

Soybean. Fourteen soybean cultivars were tested at IRRI and in Batangas, Iloilo, and Pangasinan in upland fields with high tillage and in lowland fields with zero and high tillage.

The yields in a lowland field with zero tillage were less than 1.0 t/ha. The highest yields were from CES 76–8 and CES 70–68 at IRRI, CES 70–68 in Iloilo, and CES 70–68 and Clark 63 in Pangasinan. Yields were low because of drought and the photoperiod sensitivity of the entries.

In upland tests in Batangas the most promising entries CES 70–68 and Clark 63 yielded 1.0 t/ha. At IRRI, the yields of CES 70–68, CES 97–63, UPLB SY-2, and Clark 63 ranged from 1.5 to 1.6 t/ha. The promising entries in Batangas and at IRRI matured in 75–86 days.

The yields in lowland fields with high tillage ranged from 0.7 to 0.6 t/ha in Pangasinan and 0.20 to 0.40 t/ha in Iloilo. The most promising variety at both sites was Clark 63. Yields were low because of drought and the photoperiod sensitivity of the entries.

The most promising entry in all trials at all sites was CES 70–68. It is similar to Clark 63 and UPLB SY-2, the recommended varieties, in days to maturity, plant height, and number of pods per plant.

In plots without insect and disease control yield was reduced by 223% in Pangasinan, about 40% at IRRI, 65% in Iloilo, and 88% in Batangas.

Peanut. Fifteen peanut entries were evaluated at IRRI and 10 entries were evaluated in Batangas, Iloilo, and Pangasinan. In upland fields with high tillage, the best entries were Dixie Giant and Acc. 12 at IRRI and M10 and Dixie Giant in Batangas. M10 had low yields at IRRI because of poor germination, but it had the highest yields in 1977. The most promising entries in lowland fields with high tillage were M10, CES 101, and Dixie Giant in Iloilo, and M10, F334-33, and CES 101 in Pangasinan.

After two seasons of tests, the most promising entry at all the sites was M10, a variety from Burma. It was 26% better than Mocket and CES 101, the recommended varieties in Batangas cropping pattern trials; as good as Mocket and 17% better than CES 101 at Pangasinan; and 16% better than Mocket and 25% better than CES 101 at Iloilo. M10's seed is smaller than Mocket's and the same as CES 101's, but the shelling percentage of M10 is better than that of both. Plant height and days to maturity of M10 are the same as those of Mocket and CES 101.

Cowpea. Fourteen cowpea entries were tested at IRRI and in Batangas, Iloilo, and Pangasinan. In upland fields with high tillage, the most outstanding entries were EG#1, EG#2, and TVx 66-2-H in Batangas and TVx 66-2-H, TVx 1836-187-E, and All Season at IRRI. The yields in Batangas ranged from 0.6 to 0.9 t/ha because of drought; yields at IRRI ranged from 1.4 to 2.7 t/ha.

In lowland fields with zero tillage six entries at Iloilo and four entries in Pangasinan yielded significantly better than EG#2, the recommended variety in the cropping pattern trials. The most promising entries were PI-221731 and TVx-1836-187-E in Iloilo, and Pelungga and All Season in Pangasinan. The most promising varieties in Pangasinan in lowland fields with high tillage were TVx 1502-1C, PI-221731, and Pelungga, but their yields were not significantly different from that of EG#2.

Without insect and disease control, the average yield reduction was 314% in Pangasinan, 615% in Iloilo, 124% in Batangas, and 44% at IRRI.

Two uniform cowpea trials from the International Institute of Tropical Agriculture, Nigeria, were grown with high tillage in IRRI upland fields — 20 indeterminate cultivars in the

Cowpea Uniform Cultivar Trial No. 1 and 10 determinate cultivars in Trial No. 2. None of the entries in Trial No. 1 yielded significantly better than EG#3, the check cultivar, but four cultivars in Trial 2 performed significantly better than V39-41, a determinate check cultivar. The yields of Trial No. 1 ranged from 1.7 to 2.7 t/ha; those of Trial No. 2 ranged from 0.8 to 1.6 t/ha. The most promising cultivars in Trial No. 1 were Vita 1, Vita 3, and TVx 66-2H; the best in Trial No. 2 were TVx 7-5H and TVx 309-1G.

Corn. Fifteen corn entries were planted after rice in lowland fields at IRRI and Pangasinan and in upland fields at IRRI and in Batangas. Nine corn entries were planted before rice in Pangasinan. Ten glutinous corn entries (for green corn) were planted before lowland rice in Pangasinan and Iloilo and in upland fields in Batangas.

In lowland fields after rice, with zero tillage, 11 entries significantly outyielded the local check in Pangasinan and 13 entries outyielded Tinumbaga, a local check, at IRRI. The most promising varieties were TC#1, DMR x Penjalinan F_3, and Suwan Source #2 in Pangasinan, and Philippine DMR#2 and Indonesian Early DMR 1 x TC#1 DMR C_3F_1 at IRRI. The yields ranged from 1.0 to 1.6 t/ha in Pangasinan and 0.4 to 1.4 t/ha at IRRI. The promising entries had the same number of days to maturity as the local check.

The most promising cultivars in upland fields with high tillage were Tinumbaga, the local check, and Indonesian Early DMR x TC#1 DMR D_3F_1 in Batangas, and Indonesian Early DMR TC#1 DMR C_3F_1 and Suwan Source #2 at IRRI. Yields with high tillage ranged from 1.8 to 2.0 t/ha in Batangas and 1.1 to 2.1 t/ha in Pangasinan. The promising entries matured at the same time as the local checks.

When corn was planted before lowland rice in April 1978, the highest yield was from Philippine DMR Comp. #2 (4.5 t/ha). It was not, however, significantly different from the yield of Macapuno, the local check (3.7 t/ha). The two entries matured at the same time (78 days) and had the same plant height, but Macapuno had more plants infected by downy mildew.

In lowland fields planted to green corn before rice, the most promising entries, based on total number of marketable ears, were Glutinous Syn.#41 in Iloilo and the local check Macapuno in Pangasinan. In upland fields with high tillage, the most promising entry was EG Glutinous Comp.#3, followed by Macapuno.

Cropping systems program

Preproduction evaluation

Rice Production Training and Research Office

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APPLIED RESEARCH AND PILOT EXTENSION

Research in 1978 continued work started in 1977 on growing two crops of rice plus an upland crop, where possible, on rainfed wetland farms. Upland crops were again examined as a possible first crop in Central Luzon.

IR36 in rainfed areas. IR38, which has a slightly longer growth duration, was believed to be better adapted than IR36 to rainfed areas. IR28, which has a slightly shorter growth duration than IR36, has also been used in rainfed areas. During the 1978 wet season, IR28 was compared with IR36 at 11 sites in the Visayas and Mindanao (Table 1). IR38 was compared with IR36 at 17 sites in Luzon (Table 2). IR36 had an overall production advantage over IR28 and is apparently still the most productive variety for rainfed areas of the Philippines. The average yield of IR36 for the 28 sites was 4.5 t/ha.

Seeding rate for rainfed rice. The recommended seeding rate of 50 kg/ha has been generally satisfactory for growing a 5-t/ha crop of rainfed rice throughout the Philippines. A study of increased seeding rate showed that rates of 88 and 110 kg/ha did not substantially alter rice yields.

Confirmation of research plot yields. The us of production plots (1,000 m²) to confir results of research-managed plots was estab

Table 1. Grain yield[a] of IR36 and IR28 in cropping systems trials, first crop direct seeded in dry soil in rainfed wetland rice areas in 11 sites in Visayas and Mindanao, 1978 wet season.

Site	Yield (t/ha)[b]		
	IR36	IR28	Difference
Parara Norte, Oton, Iloilo	3.9 g	3.3 b	0.6**
Parara Norte, Oton, Iloilo	3.9 g	3.2 b	0.7**
Tacdangan, Cabatuan, Iloilo	6.1 cd	4.6 a	1.5**
Tacdangan, Cabatuan, Iloilo	5.4 de	4.0 ab	2.4**
Caputian, Malalag, Davao del Sur	4.6 fg	4.0 ab	0.6**
Taculen, Matalam, North Cotabato	6.4 c	4.3 a	2.1**
Matalam, North Cotabato	9.1 a	4.7 a	4.4**
Sto. Niño, Norala, South Cotabato	5.8 cde	4.4 a	1.4**
San Isidro, Norala, South Cotabato	7.4 b	4.5 a	2.9**
Balimbingan, Ladangar, Zamboanga del Sur	5.6 de	3.3 b	2.3**
Luya, Tuburan, Zamboanga del Sur	5.2 ef	4.0 ab	1.2**

[a]Av of 3 replications and 2 rates of seeding. [b]Means followed by a common letter are not significantly different at the 5% level.

Table 2. Grain yield[a] of IR36 and IR38 in cropping systems trials, first crop direct seeded on dry soil in rainfed wetland areas in 17 sites in Luzon, 1978 wet season.

Site	Yield (t/ha)[b]		
	IR36	IR38	Difference
ISU Campus, Echague, Isabela	3.1 def	2.3 ef	0.8**
Concepcion, Rosario, La Union	2.5 efg	2.7 de	−0.2
EPAC, Sta. Maria, Pangasinan	4.4 bc	4.1 ab	0.3
Sta. Maria, Pangasinan	4.7 b	4.2 ab	0.5*
San Jose, Urdaneta, Pangasinan	6.4 a	4.6 a	1.8**
Catablan, Urdaneta, Pangasinan	5.9 a	3.8 ab	2.1**
Lucap, Alaminos, Pangasinan	3.1 def	2.8 cde	0.3
Maloma, San Felipe, Zambales	3.3 de	3.4 bcd	−0.1
Sulipan, Apalit, Pampanga	4.4 bc	4.1 ab	0.3
San Juan, Apalit, Pampanga	1.8 g	1.7 f	0.1
San Matias, Guagua, Pampanga	3.1 def	3.8 ab	−0.7**
San Matias, Guagua, Pampanga	3.8 cd	3.6 bc	0.2
Bagbaguin, Sta. Maria, Bulacan	3.0 def	3.4 bcd	0.4*
Bagbaguin, Sta. Maria, Bulacan	3.7 def	4.2 ab	−1.1**
San Roque, Bula, Camarines Sur	3.7 cd	2.9 cde	0.3**
Sto. Domingo, Nabua, Cam. Sur	2.3 fg	2.6 de	−0.3
Tres Maria, Donsol, Sorsogon	3.7 cd	3.8 ab	−0.1

[a]Av of 3 replications and 2 rates of seeding. [b]Means followed by a common letter are not significantly different at 5% level.

Table 3. Yields of 8 upland crops and 1 dryland irrigated and 1 wetland rice crop grown during the dry season at IRRI and in Pangasinan, Philippines, 1978.

Crop	Yield (t/ha)		Daily production (kg/ha per day)	
	IRRI	Pangasinan[a]	IRRI	Pangasinan
Rice (dryland-irrigated)	6.6	4.2	56	37
Wheat	2.4	1.8	28	22
Corn	5.6	4.9	56	49
Sorghum	8.0	7.5	89	76
Soybean	2.7	3.3	31	33
Peanut (shelled)	3.2	2.4	29	21
Sweet potato	26.7	9.4	207	73
Rice (wetland)	6.9	—	75	—

[a]Planted 29-30 January, harvested April.

Table 4. Yield results from rainfed rice plots of first and second crops. Central Luzon, Philippines, 1974–78.[a]

Year	Yield (t/ha)	
	First crop	Second crop
1974	4.4 (18)	2.3 (6)
1975	3.2 (5)	3.8 (5)
1976	4.1 (2)	Drought
1977	3.7 (17)	0.57 (6)
1978	3.8 (11)	Not harvested
Av	3.9 (53)	2.2 (17)

[a]Numbers in parentheses indicate number of observations.

lished in 1977. Production plots with IR36 were used in 1978 to determine the areas where rainfed rice could be grown. Yields averaged 6.6 t/ha for 14 sites in South Cotabato, 5.0 t/ha for 17 sites in Pangasinan, 3.5 t/ha for 8 sites in Iloilo, and 3.1 t/ha for 5 sites in Isabela. The results reconfirmed the superiority of IR36 as a first crop in Luzon and South Cotabato.

Production of dry-season upland crops with irrigation. Current estimates indicate that the Central Luzon Irrigation Development Plan will irrigate about 439,400 ha. There is limited information on irrigated upland crops grown during the dry season when solar radiation is high and the area is free from destructive storms.

The yields of eight upland crops grown at IRRI and in Pangasinan during the 1978 dry season are shown in Table 3. All crops had a high yield potential during that period of high solar radiation and the crop yields were stabilized because of ideal weather conditions. Disease and insect problems were low but some rat damage was noted.

Cropping patterns for Central Luzon. During the last 5 years, a multilocation testing program on rice-based cropping patterns identified 7

Table 5. Summary of yields and income from first and second crop in the *Kabsaka* project, Iloilo, and the *Kasa-tinlu* program in Norala, South Cotabato, Philippines, 1977–79.

Crop season, funding	Farmers (no.)	Av farm area (ha)	Total area planted (ha)	Yield (t/ha)	Production cost (US$)	Net return (US$)
		Iloilo-Kabsaka[a] *1976*				
First						
Bank financed	88	1.7	149	4.8	227	367
Second						
Bank financed	86	1.6	147	1.6	116	38[b]
Self-financed	41	1.6	57	1.4	101	59
		1977[c]				
First						
Bank-financed	133	1.4	188	4.6	n.a.[d]	n.a.
Self-financed	184	1.6	293	4.2	n.a.	n.a.
Second						
Self-financed	267	1.6	427	4.6	n.a.	n.a.
		South Cotabato-Kasa-tinlu 1978				
First	244	1.0	251	4.7	130	391
Second	237	1.2	273	4.3	202	318

[a]Data based on analysis of answers to questionnaires, not on total farmers in the program. [b]Lower income due to severe drought during second crop growth stage. [c]Data based on progress report of *Kabsaka* municipal action committee. Other data not available. [d]Data not available at this time.

1st crop	Yield (t/ha)	BANI CLAY	2nd crop	Yield (t/ha)	Total of 2 crops
Rice	4.7 (6)		Rice	3.5 (3)	8.2
			Rice ratoon	4.2 (1)	8.9
			Rice	0.0 (2)	5.0
Rice	5.0 (20)		Rice ratoon	1.2 (1)	6.2

SAN MANUEL SILT LOAM

Dryland crops			*Dryland crops*		
Corn	0.8		Corn	2.1	2.9
Soybean	1.6		Soybean	[a]	1.6
Mungo	0.5		Mungo	1.4 (5)	1.9
Peanut	0.5		Peanut	1.4 (3)	1.9
Sorghum	1.5		Sorghum	[a]	1.5
Rice	3.7		Rice	0.0	3.7
			Corn	3.6 (18)[b]	3.6

[a]Not planted. [b]2–3 irrigations.

1. Yields (t/ha) of rice and dryland crops grown in the first and second season on Bani clay and San Manuel silt loam, Luzon, 1978. Figures in parentheses indicate number of sites.

major areas where 2 crops of rainfed rice can be grown. The areas have produced 9–10 t/ha from 2 crops in 1 wet season. All areas are in the Visayas and Mindanao where rainfall is stable and of longer duration.

In Central Luzon, however, it is not possible to consistently obtain 10 t/ha from 2 rice crops in a single wet season. Most of the soils are sandy or silty loam, and the water-holding capacity is such that rice often fails as a second crop because of drought and decreasing rainfall toward the end of the year. It has also been found that disastrous typhoons occur mainly in October-November and are a constant threat to crops grown in the latter half of the season.

It has been shown that rice direct seeded in dry soil in rainfed areas as the first crop grown as a rainfed crop during the first part of the rainy season (May-August) in Luzon (Table 4) can produce 4.0 t/ha. The 4.0 t/ha yield for rainfed rice is a substantial gain compared with the traditional average yields of 1.0–1.2 t/ha in the past years.

For second crops on San Manuel silt loam soils, peanut, sorghum, and mung bean are fairly stable crops. Peanuts are especially stable if planted in high areas that can be drained (Fig. 1).

Pilot production programs in rainfed rice areas. During 1977–78, pilot production programs with rainfed rice were established in the provinces of Iloilo and South Cotabato. The Iloilo program was code-named *Kabsaka* and that of Cotabato, *Kasa-tinlu*.

Because of severe drought in 1977, only 204 ha in the *Kabsaka* project was planted to second-crop rice, and there was concern as to whether the farmers would plant a second crop in that area for 1978–79. However, even though second-crop yields were low, most farmers made a small profit; some made more than double (Table 5). They planted 223 ha more in 1978–79, making a total of 427 ha out of a total of 777 ha planted to the second-crop rice.

The farmers' response suggests their strong acceptance of the two-crop rainfed rice system. Equally important is the fact that nearly 100% of the available area is now direct seeded.

Production results for the first crop in the *Kasa-tinlu* program also appeared to be acceptable to the farmers. Yields averaging 4.9 t/ha gave a net income of $389/ha.

Cropping systems program

Asian cropping systems network

Multiple Cropping Department

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Major efforts in the Asian Cropping Systems Network are in rainfed wetland and partially irrigated areas (those with as much as 7 months of adequate water to grow rice) but irrigated, dryland, and deepwater rice areas with potential for increased crop production also receive attention.

The research sites that have been established in the Philippines, Indonesia, Thailand, Malaysia, Nepal, Sri Lanka, and Bangladesh represent a broad range of climatic zones, soil type, soil texture, and socioeconomic conditions (Table 1). The cropping systems research methodology developed by IRRI and tested in country programs was adopted throughout the network in 1978, and national programs expanded their cropping systems research to non-network sites. Twenty-three sites were added to the 17 existing network sites (Fig. 1).

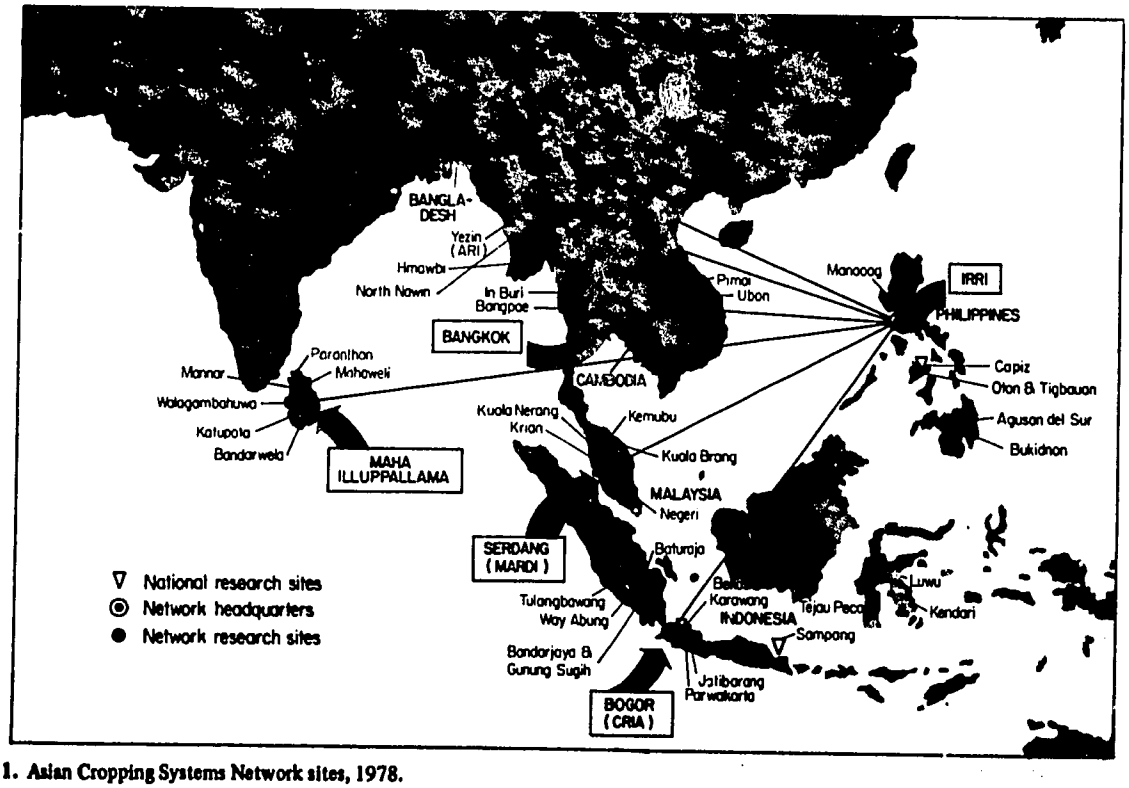
Table 1. Number of research sites and type of rice land under study in the Asian Cropping Systems Network, 1978.

Country	Sites (no.)	Sites with studies on rice land type (no.)				
		Rainfed wetland	Partially irrigated	Dryland	Irrigated	Deepwater
Philippines	3	2	2	1	—	—
Indonesia	2	—	2	1	1	—
Thailand	4	3	1	—	1	—
Sri Lanka	3	2	1	—	—	—
Bangladesh	1	1	—	—	1	1
Nepal	2	2	1	—	1	—
Malaysia	2	2	—	—	2	—
Total	17	12	7	2	6	1

TESTING OF CROPPING PATTERNS

The work at the research sites concentrates on design and testing of cropping patterns, and includes component technology research such as varietal testing, fertilizer rates, and pest control.

Philippines. The three research sites in the Philippines are directly managed by IRRI in cooperation with the Philippine Bureau of Plant Industry. Cropping pattern testing was discontinued March 1978 in Batangas but component technology research continued. The report of



1. Asian Cropping Systems Network sites, 1978.

the Philippine cropping pattern testing is in the section Testing of patterns.

Indonesia. *Bandarjaya and Gunung Sugih (partially irrigated, dryland).* The Bandarjaya and Gunung Sugih sites are managed directly by the Central Research Institute for Agriculture (CRIA). The farmers' dominant pattern in the 5-month irrigation category is wetland rice-fallow. The best cropping pattern observed after 2 years of tests was rice-rice-cowpea. In 1977–78 the pattern was tested on a 2.5-ha contiguous farm involving 9 farmers. The average first-crop yield (dry-seeded IR36) was 5.6 t/ha, the second crop (IR36) averaged 2.9 t/ha, and the cowpea yield was 0.68 t/ha. The rice yield was 3.7 t/ha in the farmer's rice-fallow pattern on 15 farms. The average income from the improved cropping pattern was 119% better than that from the farmers' pattern.

The dominant patterns on dryland farms were a corn-rice intercrop and cassava alone. The most promising pattern after 2 years of test was a corn-rice intercrop, with relayed cassava in corn rows and intercrop corn on cassava after rice harvest. This pattern was tested on a 2.5-ha contiguous area involving 9 farmers. The total yield of the improved pattern was 36 t/ha, that of the farmers' pattern was 1.8 t/ha. The net income from the improved pattern was about nine times that from the farmers' pattern.

Indramayu, West Java (irrigated, partially irrigated). The Indramayu site is directly managed by CRIA and the research is in 3 irrigation categories: 10, 7, and 5 months of irrigation. Traditionally 2 rice crops are grown in 10-month areas while in the 5- and 7-month areas, one rice crop or a rice-upland crop pattern is grown. An improved pattern of rice-rice-soybean was tested in all irrigation categories, with a 3-ha contiguous farm for each category. Six farms had 10-month irrigation; 8, 7-month irrigation; and 12, 5-month irrigation. The average yield of 2 rice crops was 11.8 t/ha for 10-month irrigation, 11.7 t/ha for 7-month irrigation, and 6.4 t/ha for 5-month irrigation. The third crop of soybean was affected by heavy rainfall. The 1 ha harvested in the 10-month irrigation area yielded 0.9 t/ha; the 1.6 ha in the 7-month irrigation gave 1.2 t/ha. Soybean was not planted in the 5-month irrigation area.

Thailand. Cropping pattern testing at Pi Mai, Ubon, and In Buri is implemented by either the Rice or the Technical Division, Department of Agriculture, in collaboration with the Agricultural Economics Division. At Bangpae research is done by Kasetsart University.

Pi Mai (rainfed wetland). At Pi Mai, the traditional pattern is rainfed rice-fallow, but sometimes farmers do not plant a rice crop because of limited moisture. The most promising patterns were mung bean-rice (av yield, 0.5 t mung bean/ha and 2.3 t rice/ha) and peanut-rice (av yield, 2.8 t peanut/ha and 3.9 t rice/ha).

Ubon (rainfed). The traditional pattern at Ubon is one rice crop. The patterns tested were yard-long bean-rice, rice-cowpea, rice-glutinous corn, rice-peanut, and rice-rice. The most promising patterns were rice-cowpea with 2.7 t rice/ha and 1.2 t cowpea/ha; rice-glutinous corn with 2.5 t rice/ha and 23,000 marketable ears/ha; and rice-peanut with 2.7 t rice/ha and 1.1 t peanut/ha.

In Buri (partially irrigated). Research at In Buri is on the light soil areas where the dominant pattern is rice-peanut. After 2 years of tests rice-peanut-sweet corn proved the most promising pattern. Its net income above variable costs was US$945.

Bangpae. The traditional crops grown before rice and after rice at Bangpae are mung bean and corn. In 1977–78, corn, mung bean, sweet corn, and glutinous corn were grown before rice, and mung bean, black gram, soybean, glutinous corn, and sweet corn were grown after rice. The most promising pattern was mung bean-rice-mung bean with the improved M7A mung bean and RD5 rice.

Bangladesh. The Bangladesh research is at the Joydebpur cropping systems site and is conducted by the Bangladesh Rice Research Institute. Work is on rainfed rice (Bhogra), irrigated rice in a lighter soil area (Laskarchala), and medium and low irrigated rice land (Salna). The cropping intensity in most of the test areas is high and the research seeks to increase the production of each crop in the system by introducing new varieties and good management, or by substituting new crops.

Farmers' use of high yielding rice-rice

(HYV-HYV) patterns at Bhogra increased from 12 to 34% in 1976. A third crop of watermelon was introduced.

The traditional patterns at Laskarchala include upland crops before and after rice. In depressed valleys, a rice-rice pattern is grown with irrigation. In 1977 the network project introduced wheat and barley in the pattern. About 69% of the farmers planted wheat in 1977, and 78% planted it in 1978.

At Salna the cropping intensity was already high with 2 or 3 crops in a pattern. In a HYV-HYV pattern IR8 and BR3 gave significantly higher yields than Muktahar, a local variety, and Chandina was significantly better than Pukhi, a local variety. The rice patterns local variety-HYV-HYV and HYV-local variety-HYV increased in 1978.

Nepal. Two network sites in Nepal are managed by the Department of Agriculture with the assistance of an International Agriculture Development Service team.

Parsa (irrigated, partially irrigated, rainfed). Parsa is in the *Terai* area at an elevation of 100–150 m. The traditional patterns are rice in summer and wheat or legumes in winter. Patterns with two and three crops were tested. The average yield of rice in an irrigated area was 4.6 t/ha. The yield range was from 1.0 to 6.4 t/ha. Wheat was best as the second crop (with 60-40-0 fertilizer) with average yields of 2.2 t/ha. Wheat intercropped with chick-pea was unsuitable. Intercropped corn and wheat for fodder appeared promising. Lentils in a rice-lentil pattern yielded only 908 kg/ha with 20-20-0 fertilizer. Intercropped potato-pea after rice was promising.

Pumdi Bhumdi (rainfed wetland). The Pumdi Bhumdi research site is at an elevation of 750–1,270 m. The wetland rice area is planted to rice during the summer monsoon, but only 30–40% is planted to wheat in winter. Some land is used for a maize-bean intercrop during spring. The yield of the test rice variety in the summer was much higher than the farmers' yield because the variety (CH45) was early maturing and escaped hail damage. The winter wheat crop yield on 6 farms ranged from 1.3 to 2.5 t/ha. Intercropped wheat and lentil, mixed wheat and peas, and mixed linseed and barley were promising as crops after rice.

Sri Lanka. Two network sites in Sri Lanka are managed by the Department of Agriculture. Work started in 1976.

Walagambahuwa (partially irrigated with small-tank irrigation). The Walagambahuwa site is partially irrigated from a small tank. Farmers grow upland crops and rice on land below the tank. The traditional practice is to wait for the tank to fill before preparing land for rice. Dry seeding of rice at the start of the rainy season before the tank is filled was introduced in 1976–77. It resulted in 2 or 3 crops per year after 11 years of no crop in the area. In 1977–78, rainfall at the start of the season was heavy and the project shifted to wet tillage. Most of the farmers planted 62-355 and BG34-8 rice. The average yield of 62-355 was 2.9 t/ha on 18 parcels; that of BG34-8 was 3.1 t/ha on 20 parcels.

In the next season, the farmers decided to grow a second rice crop instead of an upland crop because there was adequate water left in the tank. The yield of the second rice crop averaged only 2.5 t/ha because of weeds and insect damage. A third crop of cowpea and shallot (*Allium annum*) was planted on about 50% of the area, but farmers did not appear interested in the third crop and gave it only minimal management.

The total net income of farmers with two rice crops was US$291, a sixfold increase over that of 1976–77.

Katupota (rainfed wetland). The traditional cropping pattern at Katupota is rice-rice. The network research seeks to raise the yield of the rice-rice pattern and substitute upland crops for the second rice crop on higher bunds. Almost 85% of 2 test tracts was sown to improved rice varieties, but yields were low because of plant nutrient deficiencies and drought. Cowpea was observed to be adapted to the upper area of one tract.

CROPPING SYSTEMS WORKING GROUP

The seventh meeting of the cropping systems working group at IRRI in October 1978 brought together cropping systems coordinators from Indonesia, Thailand, Burma, Sri

Lanka, Philippines, Nepal, Malaysia, South Korea, and Bangladesh. A representative from India also attended. A committee was assigned to evaluate the IRRI cropping systems program in relation to national program needs. The working group discussed and planned collaborative research between IRRI and the network sites on varietal testing and screening, weed control, cropping systems economics, and cropping systems entomology.

Sharing of research information. The working group established a plan for sharing research information among cropping systems scientists in Asia. The network scientists will send their publications to IRRI for multiplication and distribution to all cropping systems scientists. During 1978, 32 papers, 2 reports of the working group, and the proceedings of the symposium on cropping systems research and development for the Asian rice farmer were distributed.

TRAINING

Training for scientists on cropping systems research in support of the network and national cropping systems research programs intensified. Thirty-eight trainees were in a 1977–78 course and 40 more started a 6-month regular cropping systems course in September. On-the-job training for 26 students from Thailand, the Philippines, and Indonesia was conducted at the Philippine network sites and at IRRI.

Machinery development and testing

Agricultural Engineering and Agricultural Economics Departments

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6- to 8-hp tiller with steering clutches. Use of a lightweight, high-speed diesel engine on the power tiller transmits an excessive amount of vibration to the operator. Vibration can be lowered to an acceptable level by using resilient engine mounts. Automotive rubber engine mounts were installed between the engine base and the tiller chassis, and a hold-down spring was used at the front of the engine to resist drive-belt pull. The system reduced vibration amplitude by about 75% at intermediate engine speeds, but vibration was still intense at rated engine speed.

The rubber mounts were replaced with coil springs. Clamping bolts and retaining washers fastened the engine to the tiller chassis through the springs (Fig. 1). A bar positioned between the tiller body and engine (through a flexible connector) prevented horizontal engine movement caused by belt pull. The springs reduced vibration transfer to an acceptable level; field tests are being conducted to determine their durability.

Two intermediate shaft failures and several final reduction chain failures occurred during dynamometer testing of the effects of steering clutch shock loads on the tiller transmission. Field tests of 1,830 hours on 2 prototypes produced 3 intermediate shaft failures and 2 chain failures. The intermediate shaft always failed near the weld joint of the shaft and drive sprocket. A production 2.54-cm-diameter shaft assembly was compared with assemblies using improved shaft-to-sprocket joining methods. Each shaft failed in less than 10 hours at 3 hp and a steering clutch engagement rate of 37 times/minute. A 3.32-cm-diameter shaft performed satisfactorily for 50 hours under the same conditions. This design is now specified on the drawings.

1. Power tiller engine mount. IRRI, 1978.

2. Rotary tiller attachment. IRRI, 1978.

Dynamometer evaluation of the use of springs to reduce clutch engagement shock loads continues. Springs with rates of 197, 76, and 23 kg/cm were tested at power inputs of 1.5, 3, and 5 hp. They had little effect on reducing peak shock loads.

Rotary tiller attachment for the 6- to 8-hp tiller. Development of the attachment for the tiller continued, with improvements made in the primary drive and tiller drive to correct problems encountered during testing. The intermediate tiller drive received a heavier chain and a heat-treated jaw clutch. The second belt of the primary drive was replaced with a two-speed chain drive to eliminate excessive belt slippage. For speed changes a toggle loosens the chain for easy movement to the second sprocket set. Excessive wear on the sprockets indicated a need for a dustproof shield to protect the drive. A new prototype incorporating all of the improvements is being built. Testing will begin in early 1979 (Fig. 2).

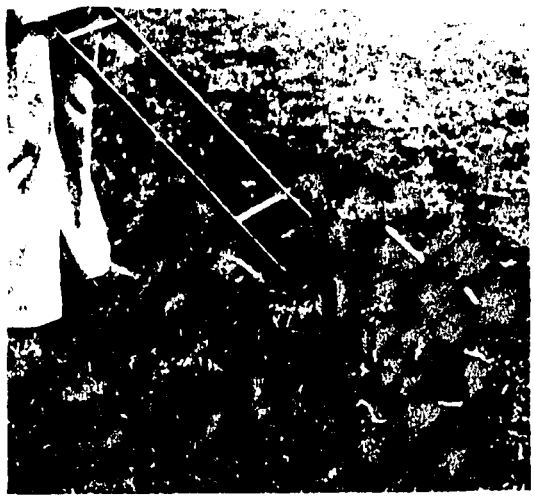
Multicrop upland seeder. The upland seeder has five seed-and-fertilizer hoppers. The meter-

ing plates are located under each hopper and are driven through a linkage by a cam on the press wheel axle. The plates meter seed and fertilizer, which pass alternately through a single tube to the furrow. To halt metering during transport and turning at the end of rows, the cam drive disengages when the furrow openers are lifted. Row spacing can be varied from 10 to 100 cm. Seed plate changes and other adjustments can be made without tools.

Laboratory and field tests of the metering plate to correct seed and fertilizer leakage problems were continued. Leakage was corrected by using a narrower metering plate enclosed on the sides by spacers (Fig. 3). The design allows use of plates of varying thickness in individual hoppers to further improve the seeder's ability to plant more than one crop simultaneously.

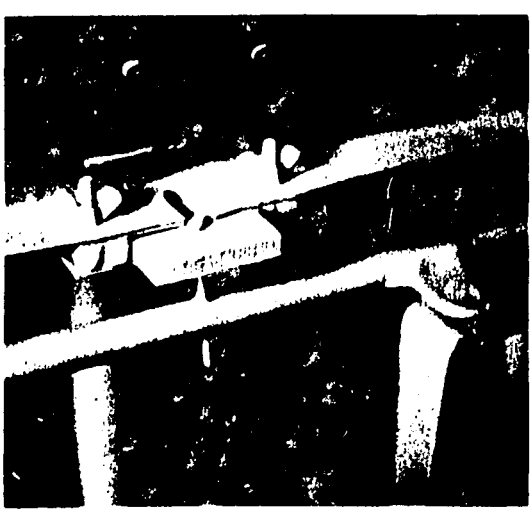
Field trials compared the seeder with an IITA/VITA no-till punch planter (Fig. 4) and a traditional broadcast method for planting rice, corn, and mung bean. Land preparation consisted of rototillage. But only weed mowing and herbicide application were used on the punch planter plots. The upland seeder had a field capacity of 9 hours/ha and 51% field efficiency; the punch planter had 17 hours/ha and 66%. For the planting operation the seeder required 18 labor-hours/ha; the punch planter, 17; and the broadcast method, 31.

Germination rates for seeds sown by each method are shown in Figure 5. The punch planter would probably produce better results in lighter tilled soils. The untilled plots produced 8–12 times more weed dry matter than the tilled plots. The upland seeder will be released early in 1979.

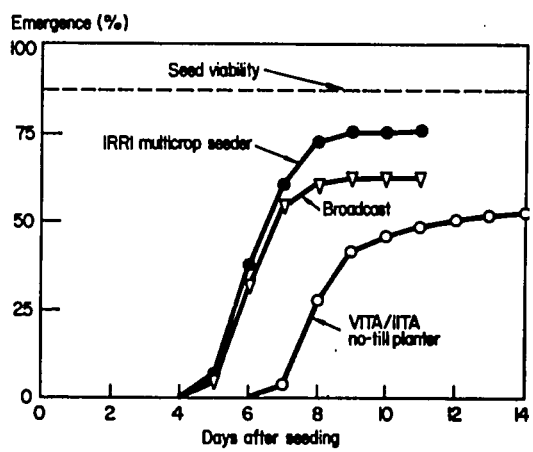


4. IITA/VITA punch planter. IRRI, 1978.

Rice transplanter. A prototype rice transplanter (Fig. 6) was field tested with wet bed seedlings, but it did not separate individual seedlings uniformly. Occasionally, several plants were removed from the tray, which caused the pickers to miss on the succeeding stroke. To overcome the problem, feeder-fingers for feeding the seedlings to the pickers were installed. A feeding frame was added to

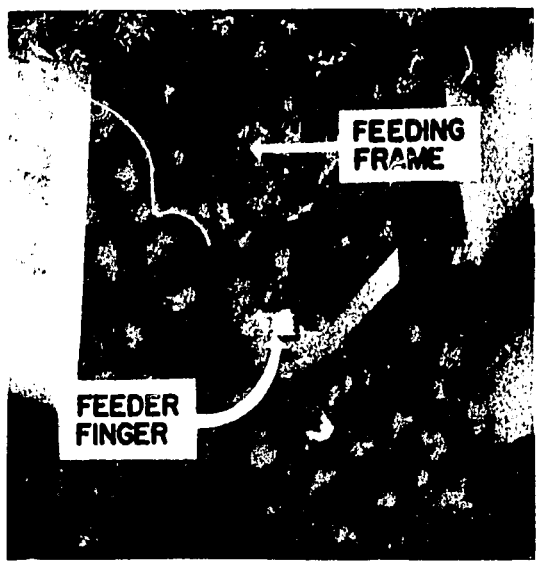


3. Upland seeder seed plate. IRRI, 1978.



5. Emergence (%) of dryland rice using three planting methods. IRRI, 1978.

6. Transplanter. IRRI, 1978.



7. Transplanter feeder finger and frame. IRRI, 1978.

hold the moving tray and provide exit holes on the front for the seedlings and at the rear for entry and withdrawal of the feeder-fingers (Fig. 7). Raising the planting handle causes the feeder-fingers to move forward through the holes of the feeding frame to push the seedlings into the path of the pickers. Pushing it down causes the feeder-fingers to withdraw from the frame to permit the lateral movement of the seedlings with the seedling tray.

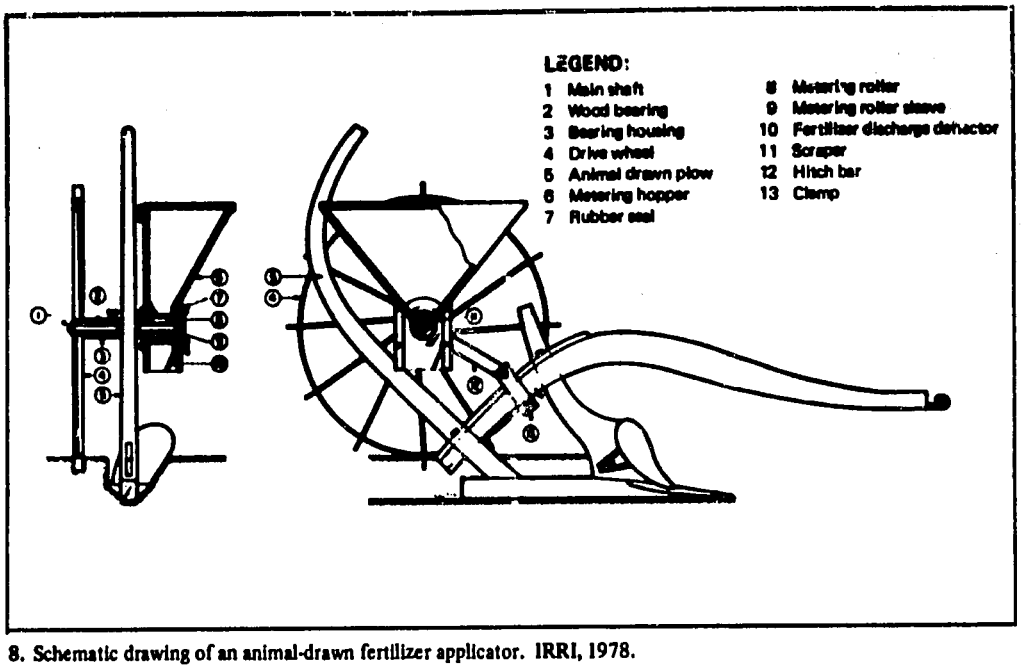
Several test runs were then conducted in the field. The machine worked satisfactorily only when the seedlings were hand separated and carefully aligned in the tray, an extremely time-consuming process. To eliminate the problem a laboratory evaluation determined the best combination of seedlings and pickers for reliable separation. Over 100 trials compared wet bed, dry bed and Japanese-type tray seedlings at various soil depths. Eighteen- to twenty-two-day seedlings grown in trays with 1 to 1.5 cm of soil showed the most promise. A system in which inexpensive frames were laid over fine wire mesh on a conventional wet bed and then filled with soil before seeding worked well, at substantial cost savings over purchased trays. The machine has been further simplified and will be field tested.

Plow sole granular-chemical applicator. Because most farmers in the developing countries use animal power for land preparation, the plow sole granular chemical applicator was modified to fit an animal-drawn plow (Fig. 8). The wooden hopper has a capacity of 9 kg of urea. A curved polyvinyl chloride (PVC) scraper was bolted inside the hopper, and a deflector was added to the discharge chute to ensure fertilizer placement at the bottom of the furrow. The hitch can accommodate both rolling and side movements of the plow. Drive wheel diameter was increased from 69 to 84 cm to make it adaptable to a wider range of animal-drawn plow designs. The new design also adapts to the power tiller plow.

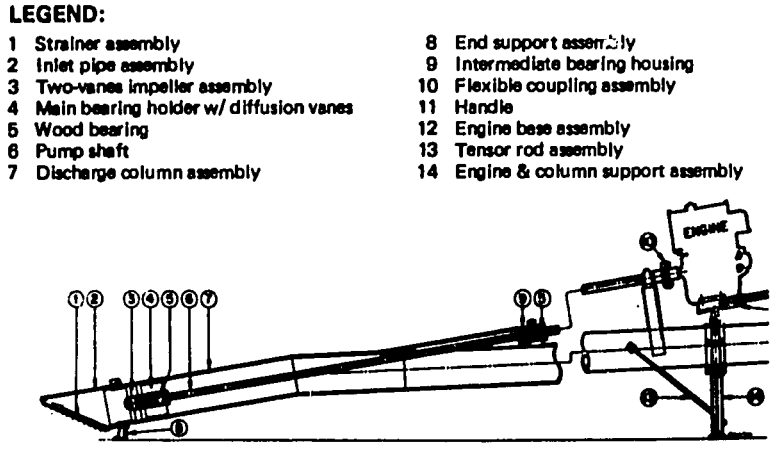
Various plastic materials are being evaluated for use as metering rollers because of poor calibration stability, high wear of some wooden metering rollers, and difficulty in specifying the proper hard wood.

Axial-flow pump. IRRI aims to develop a low-cost engine or electric-motor-driven portable axial-flow pump that can lift water 1 to 4 m.

The first prototype used a bamboo discharge tube 4.2 m long and 12 cm in diameter, a steel impeller, bamboo stator casing, and a 180° steel elbow. The lineshaft was supported by wooden bearings fixed to the bamboo tube with clamp-type bearing holders. When powered by a 5-hp engine, the pump was capable of pumping up to 1,350 liters/minute at a 1.5-m lift and per-



8. Schematic drawing of an animal-drawn fertilizer applicator. IRRI, 1978.



9. Schematic drawing of axial-flow propeller pump. IRRI, 1978.

formed satisfactorily during a 100-hour test; but because the bamboo cracked and bearings wore, a second prototype using a steel discharge tube was developed (Fig. 9). This design produced flows of up to 2,360 liters/minute at a total head of 2.8 m, with an overall efficiency of 40%. Revisions to reduce cost and correct minor durability problems will be checked in a final life test before the design is released.

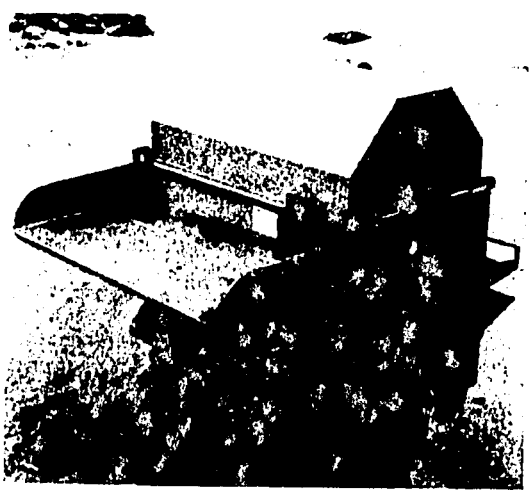
Portable axial-flow thresher with cleaning system. The portable thresher, released in early 1977, has become extremely popular. About 3,000 units have been sold in the Philippines. In response to requests from many cooperating manufacturers and IRRI thresher users, a cleaning system for the thresher was developed (Fig. 10).

The cleaning system of the first prototype consisted of a centrifugal blower, an oscillating screen, and a stationary grain chute. It used a common drive shaft for the blower and oscillating screen. Air delivery was adequate at 800 rpm, but the 2-cm stroke was too long at this

10. Portable thresher with cleaning system. IRRI, 1978.

speed. An idler shaft was added to reduce the speed to about 400 rpm for better screen performance. To reduce cost, a larger blower, which runs at 600 rpm, was used. That made it possible to use the common drive arrangement again.

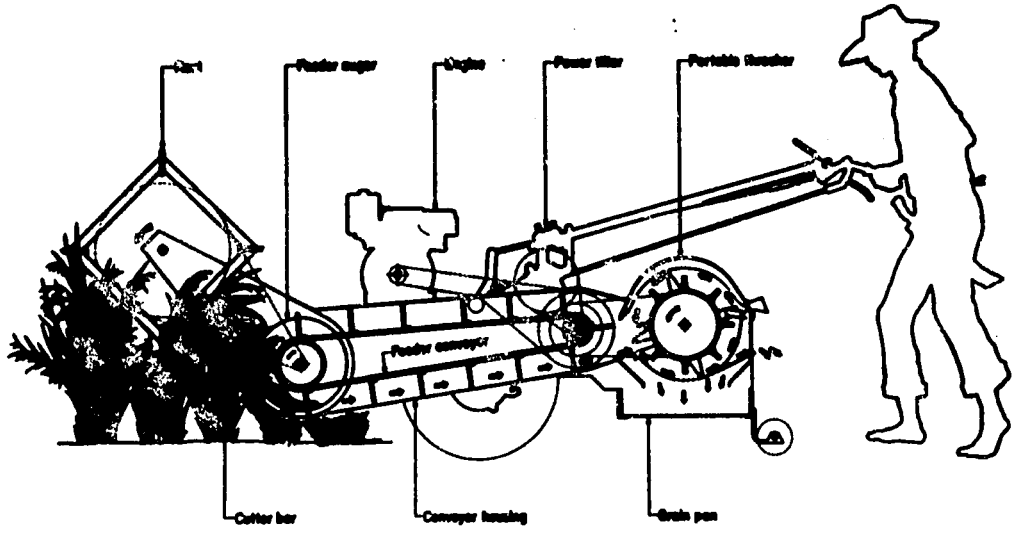
Use of a concave area 0.20 m^2 larger than that used with the portable thresher and a 7-hp engine, instead of a 5-hp engine, increased threshing capacity. Three-minute performance tests produced capacities of up to 850 kg/ha, with separation losses of about 0.5% and blower or screen losses approaching 1.0% with a purity of 95%. An open threshing drum is used to reduce blowback of straw and chaff at the feed inlet. In a 500-hour test the prototype showed an average field capacity of 450–500 kg/hour with no major problems.



11. Axial-flow thresher. IRRI, 1978.

Axial-flow thresher. The axial-flow thresher has been in production since 1973. Manufacturers and IRRI engineers have modified its cleaning system to improve cleaning when threshing wet paddy.

A new version of the thresher, which has two oscillating screens under the full length of the concave, is being developed (Fig. 11). The screens run at the same speed but in opposite directions to reduce oscillating assembly imbalance. The top screen has large holes for removing large impurities. The grain falls through an air stream from two blowers onto an inclined wind board and onto a second screen for final cleaning. An auger conveys the cleaned grain to one end of the thresher. An eccentric cam on the auger shaft oscillates the screens at 320 cpm, with a 2.5-cm stroke. An open threshing drum with a round bar grill concave is used.



12. Schematic of the harvester attached to a power tiller. IRRI, 1978.

The new cleaning system will provide improved multicrop capabilities. In short performance tests it showed a capacity of 1 t/hour with wet paddy. Long-term field tests will continue.

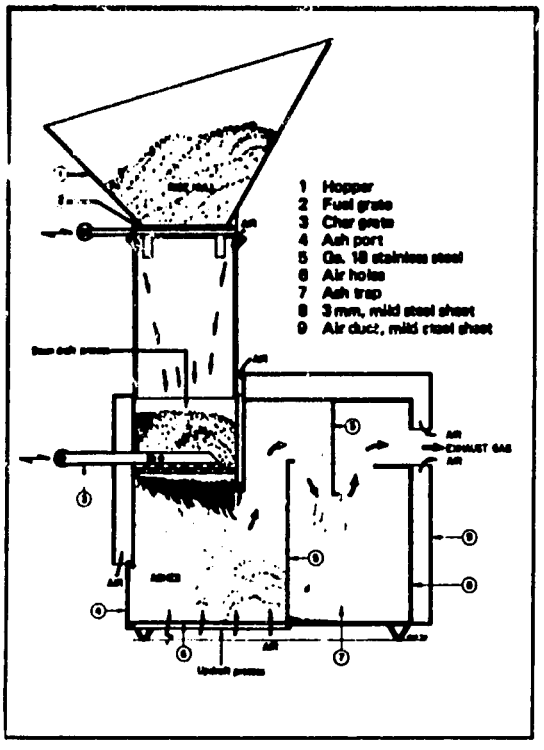
Harvester attachment for power tiller. A prototype of the harvester attachment for the power tiller has been completed (Fig. 12). Initial development concentrated on correcting problems in the transfer of paddy from the auger to the conveyor.

In a flooded field, there were no mobility problems when chains were wrapped around the tires as traction aids. Short field-harvesting trials at a speed of 1.5 km/hour, taking four 25-cm rows, produced clean cutting, but paddy collected on the cutter bar. The buildup caused the reel to dislodge the material in bunches, which jammed the auger and conveyor. The auger and conveyor belt had been placed on a common shaft to simplify construction and reduce costs. The belt, which was used to drive the auger and reel, was incapable of transmitting the required power; so a separate chain drive was added to drive the reel and auger. Work on correcting problems encountered thus far and additional field trials will continue at low priority.

Rice hull furnace. The rice hull furnace for the 2-t vertical bin dryer was developed. Furnace walls are made of 1.20-mm ASTM-304 stainless steel and 3-mm mild steel sheet instead of fire brick, thereby reducing cost by about 30% and weight by 70%. An air duct is built around the furnace to prevent overheating and to minimize wall warping (Fig. 13). Hull feeding and combustion rate are controlled by shaking the two grates. The furnace is designed to operate for about 6 hours (the normal drying time for one batch of grain) before the ash must be removed.

The furnace uses a combined downdraft and updraft combustion process to more completely burn the volatile matter (tar, oil, CH_4) and the fixed carbon in the rice-hull char. The downdraft process carbonizes rice hulls above the grate as the air flows downward across the fuel bed and burns the volatile matter below the steel grate. The high temperature generated allows the simultaneous combustion of the fixed carbon as air passing through small holes in the ash container moves upward through the char.

In early tests, channeling in the fuel bed allowed too much air for combusion and caused a smokey exhaust, but this was eliminated by reducing the clearance between grate bars from



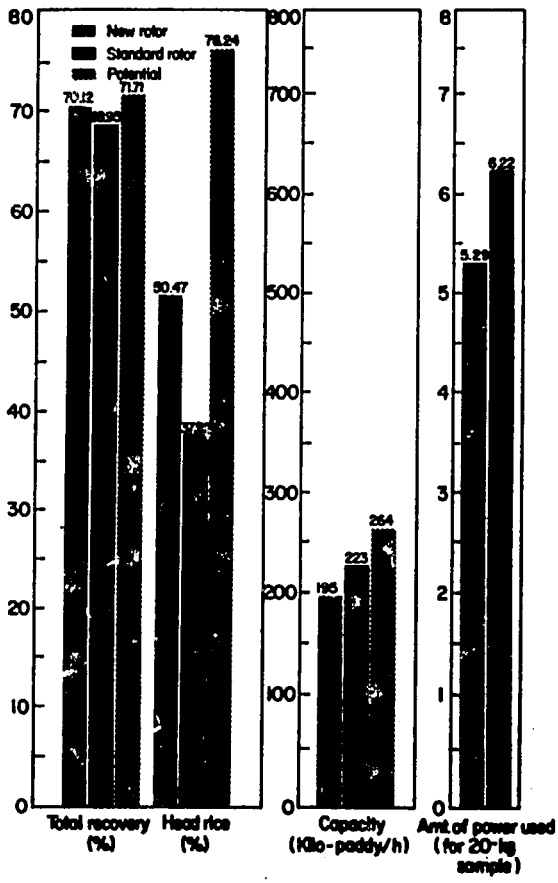
13. Rice hull furnace. IRRI, 1978.

6 to 2.5 mm and installing a rake above the fuel bed to level and break partially fused char. Efficient combustion was indicated by bluish flame and red char. Several 6-hour trials showed that 8 kg of rice hull/hour is required to maintain a drying temperature of 45° at an airflow of 100 m^3/minute. Extended performance and durability tests proved successful, but the grate, feed, and leveling controls require constant tending to maintain an even air temperature. Ways of reducing the need for close operator attention are being studied.

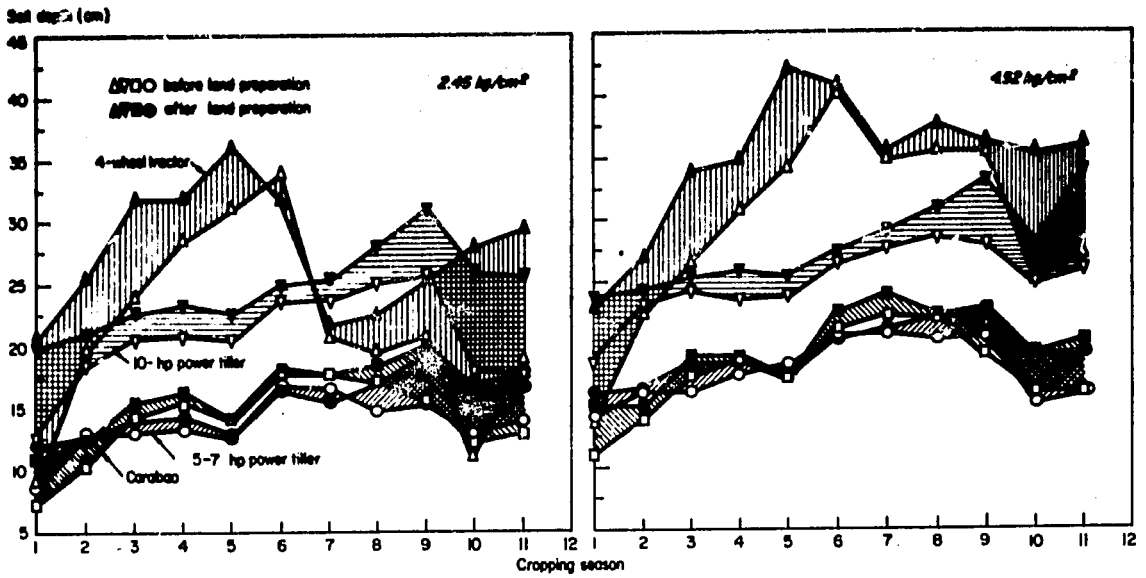
Engleberg rice mill project. A two-stage rotor was designed for the Engleberg mill because two-stage milling is believed to be most efficient. In the mill grains break largely where the paddy is hulled. The new rotor was compared with a standard rotor at selected blade clearances. Trials with IR36 and IR38 used homogenous grains and a standard screen (0.75- × 12-mm staggered slots), PVC blade, and weight-loaded outlet. The inlet and outlet gates were adjusted until there was no unmilled rice in the output and maximum power was consumed without erratic surges. In all trials the new rotor improved the total rice recovery slightly at approximately the same degree of whiteness (Fig. 14) and gave an average of 12.5% increase in head-rice recovery but a lower capacity. These results may be explained by the two-stage effect and the smaller pitch of the feeding screw, which tends to move the grain slowly. Much more improvement is necessary because the potential head rice recovery is over 70%.

MACHINERY TESTING AND USE

Compacted soils studies. Study of compacted soil is in its 12th and final season. The soil depths at which cone indices were measured remained fairly constant in the plots tilled by the



14. New rotor compared with standard rotor. IRRI, 1978.



15. Compacted layer depth under different tillage systems. IRRI, 1978.

5- and 7-hp tiller and the water buffalo (Fig. 15). Depths in the plots tilled by the 10-hp tiller and 4-wheel tractor were mixed. The 4-wheel tractor prepared each plot for crops 11 and 12 with no abnormal mobility problems, although the increasing "before land preparation" depths in the plot indicate that problems could develop soon.

A study in one soil type and one water regime precludes broad generalizations, but the results correlate with those in many Asian rice fields. Because double-cropped soils are saturated for longer periods, bogging with heavy tillage machinery can be expected. These tests and on-farm reports indicate that mobility problems with conventional 4-wheel tractors can occur after 2–3 years of continuous cropping. The 7-hp tiller, or an equivalent machine, presents little danger of bogging in most rice fields now capable of supporting this equipment. The 7-hp tiller appears to be capable of restoring a wetland soil to a condition in which at least limited use of the 4-wheel tractor is again possible.

Continuous cone index readings versus depth readings will be taken in each plot to determine possible effects of the tillage system on the location and profile of the plow pan.

Plow sole fertilizer-placement trials. Cooperative field trials with the Agronomy Department compared the yield responses to fertilizer applied with the plow sole applicator, with a Japanese deep-placement machine, by best-split broadcast, and as a basal treatment incorporated at final harrowing. Each application method was replicated 3 times in plots of about 460m². IR36 and IR42 were used, and all plots received 90 kg N/ha in the dry season and 30 kg N/ha in the wet season.

All plots were plowed and fertilizer was applied by the plow sole applicator 20 days before transplanting. The plots had standing water during plowing and were kept flooded during land preparation. Two-thirds of the fertilizer was applied during final harrowing and one-third at panicle initiation in the best-split plots. Fertilizer was applied with the Japanese applicator 7 days after transplanting. In the dry season, the plow sole applicator produced yields that were 11–13% higher than those of the best-split method, but the increase was significant only when compared with the yield of the basal treatment (Table 1). The wet season results are less reliable because the crop was damaged by typhoons.

Testing and evaluation. Field-life tests of the power tiller and portable thresher, which were released in 1977, and performance tests of the transplanter, portable thresher with cleaning system, pumps, and improved drying equipment, were completed. Two power tillers completed 1,000 hours in the field with acceptable service life, and a portable thresher logged

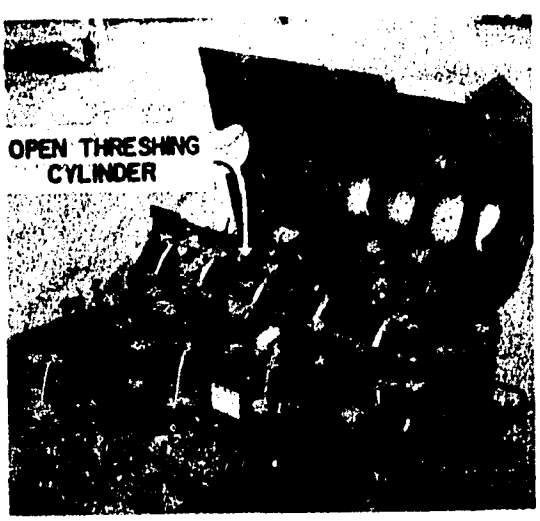
Table 1. Rice yields obtained with different fertilizer application methods. IRRI, 1978.[a]

Application method	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR36	IR42	IR36	IR42
Plow sole applicator	6.20 a	7.76 a	3.43 a	3.40 a
Japanese applicator	5.96 a	7.06 ab	3.55 a	3.82 b
Best-split broadcast	5.58 a	6.87 ab	3.12 a	3.46 a
Basal	4.29 b	5.96 b	3.11 a	3.16 a

[a]Application rate: dry season, 90 kg N/ha; wet season, 30 kg N/ha. [b]At 14% moisture content. In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

1,000 hours with a total repair cost of $300, which is lower than the initial estimates of $400–$500.

Several manufacturers have adopted an open threshing cylinder in place of the closed cylinder specified on IRRI drawings (Fig. 16). The open cylinder can reduce costs in some manufacturing situations and provides more convenient peg teeth replacement and easier straw removal when the thresher is clogged. The open and closed cylinders were compared for performance. Each cylinder was used in an IRRI portable thresher to thresh combinations of long, short, wet, and dry batches of IR36. The procedure was repeated with the new portable thresher with a cleaning system and IR42. There was no significant overall difference in performance. The open cylinder reduced blowback of material and dust into the face of the operators.



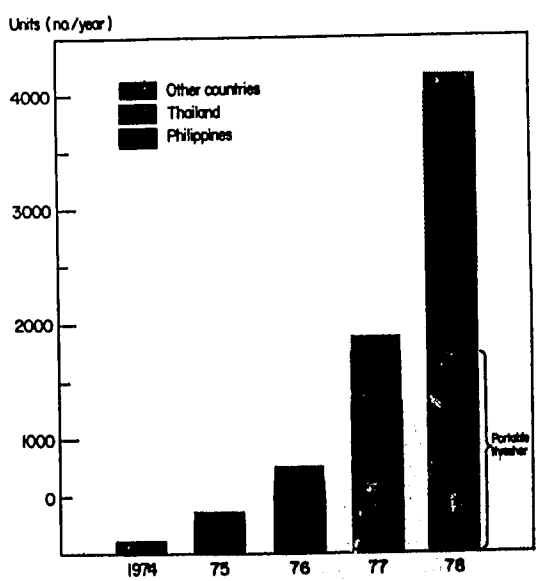
16. Open threshing cylinder. IRRI, 1978.

An analysis of the results of a large number of portable thresher performance tests shows that capacity is generally unrelated to the moisture content of the grain except over long operating periods when the wet material gradually clogs parts of the concave. The machine is sensitive to straw length. Its threshing capacity is 50–60% lower with 80-cm paddy than with 50-cm paddy.

INDUSTRIAL EXTENSION PROGRAM

The USAID-sponsored industrial extension projects in Thailand, Pakistan, and the Philippines continued to make progress in introducing IRRI machines and providing technical assistance. The industrial extension program was expanded in 1978 to include Indonesia, where the Directorate of Food Crop Production, Sub-directorate of Agricultural Mechanization, is the cooperating agency.

Production of the IRRI axial-flow thresher in Thailand increased substantially, with 1,574 machines manufactured in 1978 compared with 466 in 1977. Thresher production in the Philippines also increased sharply; portable threshers increased more than twofold (Fig. 17). There was increased interest in the dry seeding of rice in the rainfed areas of northeast Thailand with good potential for producing two crops a year.



17. IRRI axial-flow thresher production. IRRI, 1978.

An IRRI upland seeder was fabricated and is being evaluated in cooperation with the Thailand Rice Improvement Project.

The project staff in Pakistan continued to give most of its attention to the development and demonstration of the two axial-flow threshers they have adapted for wheat. The minithresher was also tested on soybeans and sunflower seed. Progress was made in introducing these designs to local manufacturers, and several firms have produced prototypes and begun commercial production.

A number of engine-powered 6-row Korean transplanters were imported by the Pakistan Government, but problems were encountered in metering and seedling placement. A cooperative project to improve the machine was organized by the IRRI-PAK Program in collaboration with the University of Agriculture, Faisalabad, and the Rice Research Institute, Kala Shah Kaku. Pakistani and Korean engineers helped modify the machines for Pakistan field conditions. After the design improvements, the machines were field tested at 48 locations in the Punjab region.

To improve the effectiveness of the technical assistance program in the Philippines, 48 cooperating manufacturers were surveyed. The information gathered was used in identifying 20 firms that could benefit most from IRRI assistance.

A time-budget analysis technique was developed to help characterize areas that can benefit from powered small-scale equipment. The technique was used, in cooperation with IRRI's Cropping Systems Program, to analyze data gathered from farmers located in the Iloilo, Philippines, project area to determine if power availability limits cropping intensity. In that rainfed rice-growing area, there is an average of 1 buffalo and about 3 farm workers/1.4-ha farm. In years of average rainfall the introduction of IRRI power tillers and portable threshers (at populations economically competitive with traditional practices) is predicted to increase the double-cropped area by 49% and to increase the second rice crop yield by 370 kg/ha. These increases come from reductions in crop establishment time for the first wet-seeded rice crop and in turnaround period between the two rice crops. Labor requirements per crop are also reduced, but because of the increase in double-cropped area, total labor requirements drop only an estimated 41 hours/year for each worker. That indicates that even in areas of small farms with relatively high animal and labor densities, machines that can speed crop establishment and reduce the idle time between crops are especially important to rainfed rice farmers. This conclusion is substantiated by an Iloilo survey showing that over half of the farmers now thresh their rice crop with IRRI threshers. There was no mechanical threshing in the area 3 years ago.

Associated formal training

Training at IRRI is either research oriented, production-extension oriented, or supportive of the international research networks. In 1978, a total of 380 scientists from 29 countries were trained. That involved 1,978.75 training months or 164.9 training years and represented an increase of about 39.4 training years over 1977 activity.

RESEARCH-ORIENTED TRAINING

Research fellows and scholars worked with IRRI scientists on specific research projects. The distribution of fellows and scholars by country and by IRRI department is in Tables 1 and 2. Most of the degree fellows and scholars were enrolled at the University of the Philippines at Los Baños. A number of the Ph D candidates had completed their course work at other universities and were at IRRI to do thesis research.

PRODUCTION AND EXTENSION-ORIENTED COURSES

The 6-month rice production training course in March 1978 was attended by 38 participants from 9 countries. Except one from Liberia, all participants came from developing countries of Southeast Asia.

Six 2-week rice production courses were offered:

- 20 February–3 March, for participants in the 4-month GEU training course;
- 31 July–11 August, for participants in a farm mechanization course;
- 21 August–1 September. Two courses were given simultaneously. One was for the second GEU training participants and the other, for private persons engaged in farming. The second course was taught primarily by the 6-month rice production trainees;
- 4–15 September, for participants in an

Table 1. IRRI research fellows and scholars, 1978.[a]

	Senior research fellows	Post doctoral fellows	Research fellows			Research scholars		Total
			Ph D	MS	N.D.	MS	N.D.	
Bangladesh	1	1	4	14	1	5	—	26
Burma	—	—	—	—	—	4	—	4
Colombia	—	—	—	—	—	1	—	1
Cuba	—	—	—	—	—	—	2	2
Germany	—	2	1	—	—	—	—	3
India	4	12	7	—	—	1	—	24
Indonesia	—	1	6	—	—	12	14	33
Japan	—	6	3	—	5	—	1	15
Kenya	—	—	—	—	—	—	1	1
Korea	—	2	1	—	—	3	6	12
Malaysia	—	1	—	—	—	1	1	3
Mexico	—	—	1	—	—	—	—	1
Nepal	—	—	—	—	—	2	—	2
Netherlands	—	1	1	—	—	—	—	2
Nigeria	—	—	—	—	—	—	2	2
Pakistan	—	—	2	—	—	1	1	4
Philippines	—	1	6	—	—	12	—	19
People's Republic of China	—	—	—	—	—	—	4	4
Senegal	—	—	—	—	—	—	1	1
Sri Lanka	—	2	—	—	1	2	5	10
Taiwan	—	—	—	—	—	2	—	2
Thailand	—	—	3	—	1	12	3	19
United Kingdom	—	—	1	—	1	—	1	3
United States	—	1	4	—	—	—	1	6
Venezuela	—	—	—	—	—	1	—	1
Vietnam	—	1	1	—	1	—	—	3
Total	5	31	41	14	10	59	43	203

[a]N.D. = nondegree.

Table 2. Classification of research fellows and scholars by IRRI department, 1978.[a]

Department	Senior research fellows	Post doctoral fellows	Research fellows			Research scholars		Total
			Ph D	MS	N.D.	MS	N.D.	
Agricultural Economics	—	2	7	3	—	11	4	27
Agricultural Engineering	—	1	1	—	—	7	1	10
Agronomy	1	5	6	1	—	5	3	21
Chemistry	—	1	2	—	2	—	2	7
Entomology	—	3	6	1	1	1	5	17
Experimental Farm	—	—	—	—	—	—	3	3
IRTP	—	—	1	—	—	—	—	1
Multiple Cropping	—	1	4	3	—	9	13	30
Plant Breeding	2	2	7	—	1	4	8	24
Plant Pathology	2	1	—	—	2	8	1	14
Plant Physiology	—	2	2	1	2	3	—	10
RPTR	—	—	—	2	—	2	—	4
Soil Chemistry	—	7	1	1	—	—	1	10
Soil Microbiology	—	4	1	—	1	—	1	7
Statistics	—	—	—	2	—	1	1	4
Training Office	—	1	—	—	—	—	—	1
Irrigation and Water Management	—	1	3	—	1	8	—	13
Total	5	31	41	14	10	59	43	203

[a]N.D. = nondegree.

Table 3. Participants in short formal courses,[a] 1978.

	CSTP (6 mo)	GEU (4 mo)	RPTR (6 mo)	Mech. (2 mo)	Irrig. (5 wk)	Ag. Eng. (2 wk)	Total
Bangladesh	8	7	6	—	—	1	22
Brazil	—	1	—	—	—	—	1
Burma	—	3	1	—	—	1	5
Colombia	—	—	—	—	—	1	1
Cuba	—	2	—	—	—	—	2
Dominican Republic	—	—	—	—	—	1	1
India	—	7	4	—	1	6	18
Indonesia	15	9	9	4	7	2	46
Liberia	—	—	1	—	—	—	1
Malaysia	3	2	2	—	1	1	9
Nepal	3	—	—	—	—	1	4
Pakistan	—	—	9	—	—	4	13
Philippines	3	1	4	2	4	2	16
People's Republic of China	—	4	—	—	—	—	4
Sri Lanka	2	5	2	—	2	2	13
Thailand	6	4	—	2	8	3	21
Total	40	45	38	8	21	25	177

[a]Does not include five 2-week rice production courses with 152 participants.

irrigation and water management training course; and

- 4–15 December, for IRRI scholars, junior researchers, and field technicians.

TRAINING SUPPORTIVE OF INTERNATIONAL NETWORKS

Courses supportive of international rice research networks included:

- two 4-month genetic evaluation and utilization (GEU) training programs;
- a 2-month mechanization consequences course;
- a 1-month irrigation and water management course; and
- a 2-week agricultural engineering training (Table 3).

Forty trainees from 7 countries attended the cropping systems training, which also provided on-the-job training for site coordinators in outreach sites in the Philippines.

The GEU course was given twice in 1978, instead of only once, as in 1977. The mechanization and irrigation courses were offered for the first time in 1978.

TRAINING PROGRAM PARTICIPANTS

A list of individuals who completed training programs in 1978, including their countries and research areas, follows. An asterisk (*) indicates completion of the MS degree; two asterisks (**) denote completion of the Ph D degree during the year.

RESEARCH SCHOLARS

Agricultural economics

Gerry Amoloza.* Philippines. The economic effect of management on upland rice production in Batangas, Philippines.

Nurzaman Bachtiar.* Indonesia. Cash liquidity

in the adoption of new cropping systems in Central Lampung, Indonesia.

Germelino M. Baustista.* Philippines. Factor shares and labor utilization in rice production: a study of two Pampanga barrios for the crop period 1976–77 wet season and 1976–77 dry season.

Cyril Bogahawatte.* Sri Lanka. Assessing the impact of rainfed upland rice project (RURP) on rice farming practices in Bulacan, Central Luzon.

Zulkifli Husin.* Indonesia. The economic impact of developing Sederhana (simple) irrigation in Indonesia.

Myint Soe.* Burma. Economics of production and procurement of paddy in Burma.

Kong Ming Yin.* Malaysia. An economic analysis of the factors affecting Sembilan, Peninsular Malaysia.

Agricultural engineering

Arsenio Resurrecion.* Philippines. Design of metering device for rootzone granular chemical applicators.

Ganesh Thapa. Nepal. An economic study of mechanized rice production in Nepal.

Agronomy

A.M. Fagi. Indonesia. Physiochemical soil factors affecting growth and yield of rainfed rice.

Luis Lopez Mendez. Venezuela. Improving cultural practices for increasing grain yield of upland rice (Thesis).

Hla Myint. Burma. Application methods for efficient use of nitrogen fertilizer in wetland rice.

J. Olofintoye. Nigeria. Effects of deep placement and other fertilizer management practices on changes in soil and plant nitrogen status and grain yield of wetland rice.

Patricio Vargas.* Colombia. Integrated practice for weed control in direct-seeded rice.

Entomology

M.C.S. Subasinghe. Sri Lanka. Effect of tillage and rice stubble on preflowering cowpea insect pest in Iloilo.

Achmad Yasin. Indonesia. (1) Varietal resistance studies. (2) Insecticide evaluation. (3) Ecology studies.

Irrigation and water management

A.S.M. Imdadul Islam.* Bangladesh. Irrigation water distribution process in spatially stratified areas of the G-K Project of Bangladesh.

Chd. Md. Amiruddin Khan.* Bangladesh. Determination of irrigation system performance: water use efficiency and water adequacy studies in the D-N-D irrigation project of Bangladesh.

Md. Shahid Talukder.* Bangladesh Water use studies for irrigated maize and mung production in Northeastern Thailand.

Multiple cropping

Pathic Sahu. Nepal. Effects of varietal type of nitrogen fertilizer management on rice crop intercrop.

Boonrawd Thongdonphum*. Thailand. Response of mung bean and sorghum to varying levels of nitrogen applied to preceding rice crop.

Plant breeding

Min Hwa Lin.* Taiwan. Genetic study of the relationship between the lowland rice varieties and the traditional upland rice varieties.

Plant pathology

Muhammad Machmud.* Indonesia. Variation of *Xanthomonas oryzae* and effect of mixed inoculum on lesion development.

Plant physiology

Chalit Setabutara.* Thailand. The importance of nodal tillers on deepwater rice.

Rice production training research

Nichai Thaipanich.* Thailand. Effects of fertilizer, inoculation, plant population, row spacing, and a previous soybean crop on soybean yield and dry matter accumulation.

Statistics

Thein Maung.* Burma. Factors affecting time of nitrogen application in rice.

RESEARCH FELLOWS

Agricultural economics

Md. Mukarram Hossain.* Bangladesh. Socioeconomic factors constraining higher yield from modern varieties of rice in BRRI pilot project.

William James. USA. An economic analysis of public land settlement: the case of the Philippines.

Alfian Lains. Indonesia. Regional concentration in expansion of rice production Indonesia.

Agronomy

Nizam-uddin Ahmed.* Bangladesh. Weeds in cropping systems as affected by hydrology and weeding regime with emphasis on dry-seeded rice.

Amal Chatterjee.** India. Biological constraints to high yields in selected wetland rice farmers in Camarines Sur, Philippines.

Entomology

Muhammad Iman.** Indonesia. Resistance to biotype 2 of the brown planthopper *Nilaparvata lugens* (Stal.) in rice varieties.

Plant physiology

Harunobe Inoue. Japan. Physiological analyses of the productivity of field crops.

Soil microbiology

Makoto Kimura. Japan. N_2/Ar ratio technique to measure N_2 fixation.

Statistics

Kamal Rahim.* Bangladesh. A technique to identify constraints to high rice yields in farmers' field.

POSTDOCTORAL FELLOWS

Agricultural economics

Masao Kikuchi. Japan. Research on the land tenure system in the Philippines.

Agricultural engineering

H. Takai. Japan. Physical, biological and chemical characteristics of modern rice varieties under small-scale storage conditions.

Agronomy

Nguyen van Nguu. Vietnam. The effects of cultural practices to increase fertilizer nitrogen efficiency in wetland rice.

Irrigation and water management

Virendra Pal Singh. India. Nitrogen movement in water draining from irrigated riceland.

Plant pathology

San Won Ahn. Korea. (a) Timing of fungicide application to control blast epidemics. (b) Components affecting blast disease development. (c) Reaction of Japanese field resistant varieties and differentials to Philippine isolates.

S.A. Miah. Bangladesh. (a) Studies on effect of temperature on the movement of virus-free *N. virescens* on healthy TN1 plants. (b) Studies on the possible development of different *N. virescens* biotypes of tungro-susceptible (TN1) and tungro-resistant rice plants (IR34) and subsequent transmission pattern of these biotypes. (c) Effect of interruption of feeding during inoculation feeding of *N. virescens* on the transmission of tungro virus. (d) Effect of temperature and light intensity on the development of symptoms on tungro-inoculated plants. (e) Studies on the translocation rate of tungro virus in inoculated susceptible plants.

Plant physiology

Jong Hoon Lee. Korea. The influence of environmental and nutritional conditions on the new variety Yushin.

Soil chemistry

M.S. Bajwa. India. Sodium tolerance in rice varieties.

K.L. Sahrawat. India. Nitrogen transformations in flooded soils.

Nico van Breemen. The Netherlands. Landscape hydrology and chemical aspects of some problem soils in the Philippines and Sri Lanka.

Soil microbiology

Kuk-Ki Lee. Japan. Gas transport through rice plant.

R. Siddaramappa. India. Decomposition and fate of carbofuran in rice-soil system.

OTHERS

Agricultural economics

K.V.N. Weeralugolla. Sri Lanka. Trainee, Economics cropping systems.

Agronomy

Herman Van Brandt. Senegal. One-month training in rice fertilization.

Entomology

Stephen Roy Pickin. England. Evaluation of ULV (ultra low volume) spray on lowland rice.

Experimental farm

D. Dissanayake. Sri Lanka. Management of farm and experimental station.

Yusuf Pontoh. Indonesia. Farm and experimental station management.

R. Suwika. Indonesia. Farm and experimental station management.

Multiple cropping

Wayan Sabe Ardjasa. Indonesia. Evaluation of alternative cropping patterns tested in

rainfed bunded areas.

Djadja Gozallie. Indonesia. Rice establishment method.

Attachai Jintrawet. Thailand. Agronomic performance and economic evaluation of upland crops.

Pataranaee Jootanon. Thailand. Preparation of the agroclimatic classification of Thailand.

Suwasik Karsono. Indonesia. Variety trial of soybean at zero and high tillage levels after rainfed lowland rice.

Md. Pandang Saleh. Indonesia. Cropping systems outreach sites training.

Tairan Sarimin. Indonesia. The IRRI-BPI cropping systems research site in rainfed and partially irrigated rice growing areas of Pangasinan Province, Philippines.

Zulkiply Mohd. Shah. Malaysia. Alternative cropping systems research site in rainfed and partially irrigated rice growing areas of Pangasinan Province, Philippines.

Deson Sianturi. Indonesia. A study on crop performance as influenced by puddling and paddy hydrology.

Muchiadansjah Sino. Indonesia. A study on varying row spacing in sorghum intercrop with peanuts after rice.

Chavaree Varasia. Thailand. Preparation of agroclimatic classification of Thailand.

Plant breeding

Allidawati. Indonesia. Training in rice quality laboratory.

A. K. Elemo. Nigeria. Training in general plant breeding techniques and procedures.

Plant pathology

Sunetra Eamchit. Thailand. Variation in virulence and bacteriophage typing of *Xanthomonas oryzae*.

Plant physiology

Kiyoko Hitsuda. Japan. Yield capacity of 16 varieties differing in grain size.

Kenichi Mijaji. Japan. Effect of plant types on conservation of moisture under upland conditions.

Soil chemistry

V.M. Palaniappan. Malaysia. Training on research in soil ecology and plant nutrients.

Soil microbiology

Karen Durbin. USA. N_2-fixing activity of sulfate reducer.

Makoto Kimura. Japan. N_2/Ar ratio technique to measure N_2 fixation.

SIX-MONTH RICE PRODUCTION TRAINING PROGRAM
27 March–15 September 1978

Md. Abdul Latif. Chief Superintendent, Bangladesh Agricultural Development Corporation, Madhupur Farm, Tangail, Bangladesh

Md. Abdur Rashid, Scientific Officer (Applied Research), Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Mohammad Mujibul Islam, Scientific Officer, Soil Chemistry Division, BRRI, Joydebpur, Dacca, Bangladesh

Md. Anwarul Kabir, Senior Scientific Officer (Breeding), BRRI, Joydebpur, Dacca, Bangladesh

Raihan Uddin Khan, Instructor, Staff Training Institute, Bangladesh Agricultural Development Corporation, Madhupur, Tangail, Bangladesh

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Sjrafi Daradjat Pulungan, Subject Ma

Specialist, Department of Agriculture, Bandung, West Java, Indonesia

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Karya Santana, Subject Matter Specialist, Department of Agriculture, West Java Province, Bandung, Indonesia

Djaendar Simanungkalit, Subject Matter Specialist, Department of Agriculture, Banjarbaru, South Kalimantan, Indonesia

Ubuy Yusuf Sobandi, Subject Matter Specialist, Department of Agriculture, West Java, Bandung, Indonesia

Surhaman Bursri, Subject Matter Specialist, Department of Agriculture, Palembang, South Sumatra, Indonesia

Adang Wangidiredja, Subject Matter Specialist, Department of Agriculture, Surabaya, East Java, Indonesia

Thomas Edward Cole, Plant Pathologist, WARDA, Monrovia, Liberia

Thein Fook Chung, Agronomist, Sabah Padi Board, Kota Kinabalu, Sabah, Malaysia

Rashdi Bin Khalid, Manager, FELCRA Seberang Perak, c/o JPT Teluk Sena, Parit, Perak, Malaysia

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Mohammad Ashraf Chaudhri, Extra Assistant Director of Agriculture, Burlwala Dist. Vehari, Government of Punjab, Pakistan

Mohammad Akram Chaudry, Extra Assistant Director of Agriculture, Attock, Government of Punjab, Pakistan

Barat Ali Choudhry, Extra Assistant Director of Agriculture, Agriculture Department, Gujrat, Pakistan

Abdus Sattar Javed, Agronomist, Rice Research Institute, Kala Shah Kaku, Pakistan

Ghulam Abbas Khuhro, Estate Officer, Rice Research Institute, Dokri, Sind, Pakistan

Rab Nawaz Lak, Extra Assistant, Director of Agriculture, Agriculture Department, Bahawal Nagar, Government of Punjab, Pakistan

Bashir Hussain Shahani, Assistant Agronomist (Rice), Agriculture Department, Agricultural Research Station, D.I. Khan, N.W.K.P., Pakistan

Abdul Jabbar Soomro, Research Assistant, Rice Research Institute, Dokri, Pakistan

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Alfredo V. Lamadrid, Sr., Farm Management Technologist, Bureau of Agricultural Extension, Legazpi City, Philippines

Josegil L. Parreñas, Farm Management Technician, Bureau of Agricultural Extension, Iloilo City, Philippines

Remedio D. Zaparilla, District Supervisor, Bureau of Agricultural Extension, Nueva Ecija, Philippines

Tilak de Silva Boralessa, Subject Matter Officer, District Agricultural Extension Office, Department of Agriculture, Kurunagala, Sri Lanka

Liyana Mudiyanselaga Somawardana, Agricultural Instructor, District Agricultural Office, Department of Agriculture, Colombo, Sri Lanka

SIX-MONTH MULTIPLE CROPPING TRAINING PROGRAM
25 September 1978–16 March 1979

Md. Abdul Ahad, Junior Research Officer, Bangladesh Jute Research Institute (BJRI), Bangladesh

Md. Rais Uddin Akanda, Scientific Officer, Rice Cropping Systems Division, Bangladesh Rice Research Institute (BRRI), Bangladesh

H.R.M. Mostafa Anwar, Assistant Director, ADE, Bangladesh Agricultural Development Corporation (BADC), Bangladesh

Md. Abdul Jabber, Scientific Officer, BRRI, Bangladesh

Md. A. Hossain Khan, Scientific Officer, BRRI, Bangladesh

Abdur Rahman Miah, Soil Scientist, FAO/UNDP Soil Survey Interpretation Project, Bangladesh

Golam Mostafa, Soil Scientist, FAO/UNDP Soil Survey Interpretation Project, Bangladesh

Mainur R. Siddiqui, Scientific Officer, BRRI, Bangladesh

Zaeny Dahlan, Subject Matter Specialist,

National Food Crops Extension Project (NFCEP), Indonesia
Joseph Handoko, Staff, Central Research Institute for Agriculture (CRIA), Indonesia
Sasa Johari, Technical Staff, CRIA, Indonesia
Muzani Mirza, Subject Matter Specialist, NFCEP, Indonesia
Rumansyah, Agroeconomist, CRIA, Indonesia
Mauliana Sibarani, Agronomist, CRIA, Indonesia
Ivan Dj Alagat Simbolon, Subject Matter Specialist, NFCEP, Indonesia
Wayan Sudana, Technical Staff, CRIA, Indonesia
Sunarsedyono, Staff, CRIA, Indonesia
Suprapto, Technical Staff, CRIA, Indonesia
Syafrida, Subject Matter Specialist, NFCEP, Indonesia
Nasintong Tambunan, Subject Matter Specialist, NFCEP, Indonesia
Abdul Salam Wahid, Staff, CRIA, Indonesia
Ananto Diasto Wijoyo, Subject Matter Specialist, NFCEP, Indonesia
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Ahmad bin Selamat, Research Officer, MARDI, Malaysia
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Bishnu Raj Kafle, Acting Agriculture Development Officer, Integrated Cereals Project, Nepal
B. H. Sharma, Assistant Agriculture Development Officer, Integrated Cereals Project, Nepal
Tito Arevalo, Regional Program Coordinator, National Multiple Cropping Program, NFAC, Philippines
Isagani Herrera, Supervising Soil Technologist, Bataan, Bureau of Soils, Philippines
Domingo Simbillo, Agronomist I, Pampanga, Bureau of Plant Industry, Philippines
Don K.W.G. Walter, Agricultural Experimental Officer, Regional Agricultural Research Station, Bandarawela, Sri Lanka
N. Kanaganayagam, Experimental Officer, Rice Research Station, Paranthan, Sri Lanka
Samer Jullavanich, Agronomist, Kalasin Research and Training Center, Kalasin, Thailand
Dedchao Kraisorakul, Agricultural Technician, Technical Division, Department of Agriculture, Thailand
Somporn Lewchalermvongs, Agricultural Officer, Division of Agricultural Economics, Department of Agriculture, Thailand
Sanong Quantharron, Agricultural Officer, Rice Division, Department of Agriculture, Thailand
Vinich Sereprasert, Research Assistant, Multiple Cropping Department, Kasetsart University, Thailand
Prissana Vachiraddanupap, Agricultural Officer, Rice Division, Department of Agriculture, Thailand

GEU TRAINING COURSE

Muhammad Badiul, Scientific Officer, Entomology Division, Bangladesh Rice Research Institute (BRRI), Joydebpur, Dacca, Bangladesh
Enamul Haque, Scientific Officer, BRRI, Dacca, Bangladesh
Quazi Azizul Haque, Scientific Officer, Breeding Division, Bangladesh Rice Research Institute, Bangladesh
Mahmuda Haroon, Scientific Officer (Physiology Division), BRRI, Dacca, Bangladesh
Md. Abul Hossain, Scientific Officer, Breeding Division, BRRI, Dacca, Bangladesh
Abdul Majid Miah, Scientific Officer, BRRI, Comilla Sub-Station, Bangladesh
Shamsur Rahman, Scientific Officer, BRRI, Habiganj Sub-Station, Sylhet, Bangladesh
Pranab Kumar Saha Ray, Scientific Officer, Breeding Division, Comilla Sub-Station, Comilla, Bangladesh
Francis Tien Liao, Rice Researcher and Advisor, Empresa Maranhense de Pesquisa Agropecuaria, Ave., Joao Pessoa, 268, Sao Luis, Maranhao, Brazil
U Muang Thwin, Farm Manager, Myaungmya Central Farm, Myaungmya, Burma

Daw Mya Mya, Additional Farm Manager (Research), Central Farm Mandalay Research Station, Burma

Daw Sein Sein, Assistant Farm Manager, Central Farm, Kyaukse, Burma

Cheng Yu-Yin, Agronomist/Assistant Teacher, South China Agricultural College, China

Lu Yung-Keng, Breeder/Lecturer, South China Agricultural College, China

Wu Jung-Tsung, Entomologist, South China Agricultural College, China

Chou Liang-Kao, Plant Pathologist/Associate Research Fellow, Kwangtung Academy of Agriculture, China

Ing. Andres Ginarte Lagart, Section Resistance Chief, Center Rice Station, Cuba

Ing. Jose Reire Lazo, Chief, Department of Chemistry, Estacion Central de Investigaciones de Arroz, Havana, Cuba

Yogendra Prasad, Assistant Pathologist (Rice), Rajendra Agricultural University, Bihar, Pusa District Samastipur, Bihar, India

Bikram K. Singh, Assistant Agronomist (Rice), Trihut College of Agriculture, Dholi, Bihar, India

Ramashrit Singh, Assistant Research Officer (Rice Entomology), Rajendra Agricultural University, Bihar Pusa, India

N. K. Mitra, Assistant Botanist (Germplasm), Rice Research Station, Chinsurah, Hooghly, West Bengal, India

Subrato De, Junior Soil Scientist, Rice Research Station, Chinsurah, Hooghly, West Bengal, India

D. Sarkar, Assistant Entomologist, Rice Research Station, Chinsurah, Hooghly, West Bengal, India

Anima Pal, Assistant Plant Pathologist, Rice Research Station, Chinsurah, Hooghly, West Bengal, India

Wafiah Salman Akib, Staff, Entomology Department, LPPM, Maros, Ujung Pandang, South Sulawesi, Indonesia

Subardho Ardjosentono, Researcher, Agronomy Department, Central Research Institute for Agriculture (CRIA), Bogor, Indonesia

Iwin Hadisyahban, Research Assistant, Plant Breeding Department, CRIA, Bogor, Indonesia

Arifin Kartohardjono, Assistant Entomologist, Entomology Department, CRIA, Bogor, Indonesia

Ea Anwar Kosman, Staff, Agronomy Department, CRIA, Bogor, Indonesia

Christine J. S. Momuat, Staff, Soils Department, LPPM, Maros, Ujung Pandang, Indonesia

Zainuddin A. Simanullang, Staff, Plant Breeding Department, CRIA, Bogor, Indonesia

Sumarmo, Physiology Department, CRIA, Bogor, Indonesia

Wasmo Wakman, Assistant Plant Pathologist, Maros Research Institute for Agriculture, LPPM, Ujung Pandang, Indonesia

Mohammad Bin Osman, Research Officer (Rice Breeding Section), MARDI, Kedah, Malaysia

Zulkiply bin Mohd Shah, Research Officer, MARDI, Jasin, Melaka, Malaysia

Benito Gamiao, Agronomist I, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines

Gnanambikai Jeyandran, Research Officer, Regional Agricultural Research Station, Bandarawela, Sri Lanka

Sangarapillai Ponnuthurai, Research Officer, Paddy Station, Paranthan, Sri Lanka

R. M. T. Rajapakse, Research Officer, Central Rice Breeding Station, Batalagoda, Sri Lanka

M. D. R. Geetha Gunashalinee Saparamadu, Agricultural Instructor, Agricultural Research Station, Maha-Illuppallama, Sri Lanka

Dalmie Lalantha Wickremasingha, Research Officer, Rice Research Station, Bombuwela, Sri Lanka

Amphon Assawasophonkul, Second Grade Officer, Rice Division, Department of Agriculture, Bangkhen, Bangkok 9, Thailand

Kalaya Kupkanchanakul, First Grade Officer, Rice Division, Department of Agriculture, Bangkhen, Bangkok 9, Thailand

Manat Potisurintara, Agriculturist, Sakolnakon Rice Experiment Station, Sakolnakon Province, Thailand

Apichat Thaotao, Plant Breeder, Rice Division, Department of Agriculture, Bangkok, Thailand

MECHANIZATION CONSEQUENCES TRAINING PROGRAM
31 July–29 September 1978

Dachlan Patong, Lecturer, Faculty of Agricultural Sciences, Hasanuddin University, Ujung, Pandang, Indonesia
Josuf Saefudin, Rural Dynamics Study (Staff), (Agro Economic Survey), Jl. Taman Malabar 7, Bogor, Indonesia
Masdjidin Siregar, Staff, Rural Dynamics Study, (Agro Economic Survey), Jl. Taman Malabar 7, Bogor, Indonesia
Maamun Yusuf, Acting Head, Socio-Economic Department, Maros Research Institute for Agriculture, Complex LPPM, Jalan Pertanian, Maros, Indonesia
Bhanupongse Nidhiprabha, Lecturer, Faculty of Economics, 298 Soi Prasawad, Banglumpoo, Bangkok, Thailand
Lavan Niyombit, Chief Survey Project, Statistics Section, Planning Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand
Arturo Maligaya, Agricultural Project Analyst, Central Bank of the Philippines, A. Mabini, Manila
Mininda Ocampo, Agricultural Credit Supervisor, Central Bank of the Philippines, A. Mabini, Manila

IRRIGATION AND WATER MANAGEMENT TRAINING COURSE
4 September–7 October 1978

D. K. Paul, Irrigation Research Engineer, Central Rice Research Institute, Cuttack 753 006, India
B.I.E. Basono, Assistant Operation and Maintenance, South Kedu Multipurpose Project Resources Development (DGWRD) Jalan Pattimura No. 20, Kebayoran Baru, Indonesia
Daud Berahmana, National Food Extension Project, Directorate General of Food Crops Agriculture (DGFCA), Selatan, Indonesia
Koewat Endik Hawanto, Staff, East Java Provincial Public Works Service, DGWRD, Indonesia
Md. Badawi Lambong, National Food Crop Extension Project, DGFCA, Indonesia
Masduki Mangkudisastra, National Food Crop Extension Project, DGFCA, Indonesia
M. Napitupulu, Staff, Directorate of Irrigation of Jatiluhur Project, DGWRD, Indonesia
M. S. Dudirdjo Sardjono, Deputy O and M Sub IDA Project Cirebon, DGWRD, Indonesia
Abdul Rahman bin Daud, Research Officer, Sistem Tanaman MARDI, Kuala Trengganu, Malaysia
Leodegario de la Cruz, Assistant Agricultural Engineer, National Irrigation Administration, Muñoz, Nueva Ecija, Philippines
Alfredo Pereyras, Zone Engineer, UPRIIS-NIA District II, Talavera, Nueva Ecija, Philippines
Teofilo Samatra, Hydrologist, UPRIIS-NIA, Cabanatuan City, Philippines
Rodolfo Solis, Engineer Trainee, NIA-OSP, Muñoz, Nueva Ecija, Philippines
Henry Gamage, Agricultural Officer (Wtr. Mgt.), In-Service Training Institute, Maha Illuppallama, Sri Lanka
K. Shanmuganathan, Chief Engineer (Irrigation Department), Northern Region, Sri Lanka
Mongkol Chotisasitorn, 5th Grade Engineer, Royal Irrigation Department (RID), Bangkok, Thailand
Charusak Champasri, Irrigation Engineer, RID, Thailand
Prasert Kanoksing, Irrigation Engineer, RID, Thailand
Pit Prumpalad, Irrigation Technician 2, RID, Thailand
Chuch Sarikabhuti, Project Engineer, RID, Thailand
Panumat Sudchookait. Irrigation Engineer 3, RID, Thailand.

TWO-WEEK AGRICULTURAL ENGINEERING TRAINING COURSE (1978)

Mirza Meshbahuddin, Production Manager, Essential Products, Ltd., Dacca, Bangladesh
U Aung Khin, Agricultural Mechanization Department, Ministry of Agriculture and Forest, Rangoon, Burma
Alejandro Reyes, Asistencia Tecnica a la Industria, Apartado Aereo 8053, Cali, Colombia

Evelio Cabrera, Instituto Superior de Agricultura, Apartado 166, Santiago, Dominican Republic

Surendra Nath Bhagi, A-38/II, Kailash Colony, New Delhi 110 048, India

Manohar Dhonddeo Jambhekar, Audyogik Tantra Shikshan Sanstha, C-II MIDC Chikcwad Pune 411 019, Maharashtra, India

C. L. Mahadevan, Greaves Cotton and Co. Ltd., 1 Forbes Street, P.B. No. 91, Bombay-1, India

P. A. Menon, Managing Director, Agro Engineering Products (Delhi) Pvt. Ltd., New Delhi, India

Hudson Peter, Assistant Engineer, Kerala Agro Machinery Corp., Ltd., Kerala

C.V.V Satyanarayanamurthy, Service Engineer, The National Engineering Co. (Madras) Pvt. Ltd., Madras, India

Kusen, Lecturer, Agricultural Engineering Department, Institut Pertanian Bogor (IPB), Bogor, Indonesia

Sjafriddin, Lecturer, Faculty of Agriculture, Andalas University, Air Tawar Padang, Indonesia

Hashim bin Halid, United Bando Sdn. Bhd., 37 Mezzanine Floor, Kuala Lumpur Hilton, Kuala Lumpur, Malaysia

Vijendra Singh, Balaju Yantra Shala (P.) Ltd., Post Box 209, Balaju, Kathmandu, Nepal

Mirza Mohammad Amin, 163-B, Model Town, Gujanwala, Pakistan

Iftekhar Ahmad Aziz, Senior Executive (Production), The Climax Engineering Co., Ltd., Gujranwala, Pakistan

Asghar Ali Ghazi, Ghazi Industries Ltd., G. T. Road, Mian Channu, Pakistan

Naveed Saeed Khan, Managing Partner, M/S Engineering Services, Peshawar, Pakistan

Miguel Gutay, Assistant Industrial Arts Supervisor, PRRM, Nieves, San Leonardo, Nueva Ecija, Philippines

Gustavo A. Neri, Muller and Phipps Industrial Corporation, Cor. Pioneer and Reliance Streets, Mandaluyong, Metro Manila, Philippines

John N. Coatman, Assistant Director, Eastern Technical Institute, Batticaloa, Sri Lanka

Balendra Subramanian, Radha Machine Company, 95 Hospital Road, Jaffna, Sri Lanka

Anan Balnalang, Technician, Kasetsart University, Bangkok, Thailand

Sayan Kavsaad, Agricultural Engineering Division, Ministry of Agriculture and Cooperatives, Bangkhen, Bangkok 9, Thailand

Montree Sakhonbanchoed, Limcheenseng Factory, Nakornsawan, Thailand

International activities

COOPERATIVE COUNTRY PROJECTS

IRRI international activity is the mechanism through which significant contribution to the efforts of different countries to produce more rice is ensured. A summary of the research in which IRRI scientists based in six countries participated follows.

Bangladesh. Six IRRI scientists assigned to the Bangladesh Rice Research Institute (BRRI) work in close cooperation with BRRI researchers.

- BRRI released two new varieties: BR8, from progeny line BR167-28-9 from the cross of IR272-4-1-2/31 and IR305-3-17-1-3, and BR9, from progeny line BR169-1-1 from the cross of IR272-4-1-2/31 and IR8. Both BR8 and BR9 are recommended for boro and transplanted aus. Of 417 other promising lines under evaluation, 227 are for aus, 150 for aman, and 40 for deep water. In 1978, 550 additional crosses were made but disease destroyed many lines in the F_2 nursery.
- After the observation that ammonium sulfate gave better yield than urea, it was found that the soils on the BRRI research farm were deficient in sulfur. Initial tests in farmers' fields indicated a similar deficiency. A workshop at BRRI on 18 December developed plans for a systematic evaluation of the sulfur status in farmers' fields.
- BRRI cropping systems research gained acceptance and recognition from agricultural policy makers, extension agencies, and agricultural development groups. Farmers have become interested in techniques for increasing cropping intensity and crop yields.
- Feasible practices for establishing deepwater rice in lower elevations subject to summer flooding were identified.
- Means for sharply reducing the turnaround time between aus and boro crops were successfully tested.
- A local manufacturer announced intent to construct 1,200 two-wheel tractors of IRRI design. The IRRI portable thresher was evaluated and appears adaptable at some locations.
- During 1978 three Ph D and four MS scholars completed training and returned to BRRI. Five Ph D and 12 MS scholars continued studies abroad.

Indonesia. Eleven IRRI scientists are assigned to work with the Central Research Institute for Agriculture (CRIA). Four scientists were at Bogor (rice breeder, cropping systems agronomist, economist, and liaison scientist); three at Maros (cropping systems agronomist, pathologist, and soils scientist); three at Sukamandi (entomologist, agricultural engineer, and pathologist); and one (agricultural engineer) at Pasarminggu.

- Cooperative activities in GEU, agronomy, entomology, pathology, soils, economics, and rice-based cropping systems were continued. A new project on the consequences of mechanization was initiated. Active involvement in the IRRI-coordinated international research network on cropping systems, International Rice Agro-Economic Network (IRAEN), International Rice Testing Program (IRTP), and International Network on Fertilizer Efficiency in Rice (INFER) continued.
- The Indonesian GEU program continued to provide new technology for the improvement of rice production. One of the most significant contributions was the release of four new rice varieties resistant to BPH biotype 1: IR2071-621-2-3, Brantas (from B1014-Pn-18-1-4), Citarum (from B2540-Pn-2-Mr-4), and Serayu (from B2360-6-7-1-4). Much of the germplasm involved in these varieties was initially provided through the International Rice Testing Program (IRTP).
- A gall midge-resistant line selected from the cross IR4744 performed well as a wetland irrigated crop and as a dry-seeded rainfed crop and may be released as a wetland variety. The cold-tolerant line IR2307-247-2-2-3 is resistant to BPH biotypes 1 and 2 and is being considered for use in high-elevation areas.
- A surveillance and monitoring program of BPH biotypes throughout Indonesia was developed by CRIA's Plant Protection Division. Screening for different BPH biotypes throughout the country was a major accom-

plishment and made it possible to determine the best varieties to plant in anticipated BPH *hot* spots.

- Significant progress in developing the large experimental center at Sukamandi was made by the farm development engineer and his colleagues. About 80 ha were leveled; 15 km of drains, 15 km of roads, and 1 km of irrigation canals were either improved or constructed.
- The fifth lowland rice crop of a long-term fertilizer trial at the Lanrang substation in South Sulawesi indicated that phosphorus was starting to become a limiting factor. A similar study at the Maros station indicated that by the third and fourth crops nitrogen was a limiting element. Sulfur studies in wetland rice continued in South Sulawesi, with more areas showing deficiency in that element. Multilocation trials are being used to pinpoint the deficient areas.

Malaysia. The Malaysian Agricultural Research and Development Institute (MARDI) has responsibility for rice research throughout peninsular Malaysia. It is actively involved in international research networks such as IRTP, INFER, and cropping systems.

Pakistan. Two IRRI scientists are assigned in Pakistan: an agricultural engineer and a production specialist. Important variables influencing rice yields were tested in 140 applied research trials in the rice-growing districts of Punjab and Sind provinces. Results indicated that incorporating nitrogen into dry soil before flooding resulted in a yield increase of about 1 t/ha over the current practice of applying nitrogen to paddy water.

- Plant population constitutes one of the major problems influencing Pakistan's rice yields. Farmers plant about 50% of the recommended population for IR6 and other medium- to high-tillering varieties. One solution to the problem is direct seeding. Studies showed that yields higher than 6 t/ha resulted from broadcasting 70 kg pregerminated seeds/ha on well-prepared, puddled, heavy clay soil with good water control.
- Testing, adaptation, and development of the two axial-flow threshers — a standard and a mini — continued to receive major attention. The two threshers were extensively tested and modifications were incorporated to improve their performance with wheat and rice. The minithresher was also tested for soybean and safflower. Several manufacturers who produced prototype units of the IRRI threshers were assisted in testing and improving the machines.

Philippines. The success of the Masagana 99 national rice production program, which began in May 1973, was highlighted in 1978 when the Philippines exported about 90,000 t of rice, in addition to maintaining its 3-month buffer stock. An IRRI rice production specialist continued technical collaboration with Masagana 99 agencies.

- The use of zinc oxide and zinc sulfate was emphasized during 1978; about 42,000 ha of irrigated rice lands were treated with zinc, which increased yields by about 0.6 t/ha.

To determine if an extra rice crop per year could be obtained, extension workers in Nueva Ecija province established 60 farm trials to harvest IR36 in 75 days by use of 40-day-old seedlings. The average yield of 57 trials harvested was 3.9 t/ha.

Sri Lanka. A production specialist, a plant breeder, and a cropping systems agronomist from IRRI worked with scientists of Sri Lanka's Department of Agriculture. The work plan for the rice varietal improvement program was completed with a GEU-type program as the central theme.

- Rice varieties with BPH resistance were yield-tested at Batalagoda; the sources of BPH resistance were PTB33, Suduru Samba, Sudu Heenati, and ARC6650.
- A severe gall midge infestation at Bombuwela emphasized the need for gall midge resistance; the sources utilized were OB677, OB678, PTB18, PTB21, MR1523, Meuy Nawng 62, Kulawati, IR36, Siam 29, and W1263.
- Screening for resistance to blast, bacterial blight, and sheath blight continued.
- Screening for tolerance for phosphorus deficiency and iron toxicity continued. The varieties used in the breeding program for tolerance for iron toxicity were IR1702, BG400-1, BG90-2, Mahsuri, PTB33, BW100, and IR2863-38-1.
- In studies on submergence tolerance, Koramana, Molligada, Sula, Niwdusamba, Mudali Wee, Sannayam, 75-L-16, BW85,

BG405-2, and BG380-2 performed best.

• Major emphasis was placed on grain quality in the breeding program. Milling tests, protein percentage, amylose, grain shape, and eating quality were determined for the 25 varieties entered in the coordinated full variety trial.

• Many early generation selections were selected at IRRI and grown in Sri Lanka. Most of the IRTP nurseries were likewise grown. KN361-1-8-6 was selected from the 1977 IRON and tested as a possible replacement for 62-355, a rainfed variety.

• In 1978 the cropping systems program researchers moved from Maha-Illuppallama to their final locations to initiate their own programs. Five cropping systems centers were added to the original two started in 1976. The program now includes seven research sites.

1. *Walamgambahuwa,* a small tank program in the northern dry zone;
2. *Katupota,* a rainfed area in the intermediate zone;
3. *Mahaweli,* a fully irrigated area surrounding Maha-Illuppallama;
4. *Paranthan,* a rainfed paddy area along the northern fringe of the mainland;
5. *Bandarawela,* an intensive upcountry area in which paddy is grown in sequence with vegetables, the most important of which is potato;
6. *Angunakolapallesa,* a major irrigation scheme in the dry zone;
7. *Manuar,* a minor effort in an isolated but important production area on the northern coast.

• A *Resource Capability Survey,* designed to develop a well-defined understanding of the different rice land units in Sri Lanka, made excellent progress. Field studies on the demarcation and characterization of the land system were completed for the Kandy district. Significant progress was made on the field studies in Kalurara, Kurunegala, and Matale districts. Work was initiated for the Colombo, Kegalla, and Badulla districts.

Thailand. Two IRRI scientists are assigned in Thailand.

• About 100 F_2 populations designed for the rainfed wetland regions of Asia were distributed to six rice stations in northeast Thailand for selection. Thai rice breeders were joined by an IRRI scientist who assisted in the selection process at flowering time.

• The Thai-IRRI cooperative deepwater rice program made satisfactory progress although unusual flooding caused serious damage at the Huntra station. There is a good possibility that two experimental deep water-tolerant semidwarf lines will be released to farmers in 1979. Thailand hosted an international group of scientists in August in connection with the deepwater rice monitoring tour and planning workshop.

• Improved methodology and identification of the variety FR13A from India boosted work in submergence and drought tolerance. FR13A is outstanding for both drought and submerged conditions.

• A new collaborative project initiated in July 1978 studies the consequences of farm mechanization. It is a joint effort of the Planning Division of the Department of Agriculture, Thammasat University Agricultural Engineering Division, and IRRI.

CONFERENCES

Ten international conferences, workshops, or symposia were sponsored or cosponsored during 1978. Their primary objectives were exchange of information and development of plans for collaborative research.

Workshop on the international cooperative project on national rice programs, 14–16 March. Twenty-five scientists from five countries reviewed work on the international cooperative project on national rice programs in Indonesia, Philippines, and Thailand. They discussed the structure of rice supply and demand and assessed the priority issues for policy research in each country.

International Rice Testing Program advisory group meeting, 21 April. The advisory group reviewed IRTP accomplishments for 1977 and developed plans for 1978. Eighteen advisers attended the meeting.

International rice research conference, 18-22 April. The 1978 rice research conference focused on rainfed wetland rice. In addition the collaborating scientists discussed and agreed upon plans for IRTP, INFER research, and

GEU collaborative projects. The conference was attended by 124 scientists from 28 countries.

Conference on farm-level rice yield constraints, 24-26 April. Sixty-two participants from 11 countries reviewed the findings of a 3-year research project on the constraints to high yields in farmers' fields in Asia.

Deepwater rice workshop, 17-19 August. The deepwater rice workshop was held in Calcutta, India, in cooperation with the Indian Council for Agricultural Research and the Government of West Bengal. Seventy-nine scientists from eight countries agreed upon an organized cooperative effort for improving rice yields in areas with deep and medium-deep water.

Workshop on the consequences of small rice-farm mechanization in Asia, 11-13 September. The farm-mechanization workshop reviewed and finalized work plans, budget, and communication procedures for the implementation of a project on the consequences of small rice-farm mechanization in Asia. Among the 27 participants from five countries were scientists from Indonesia and Thailand who will be actively involved in the project.

Rice cold tolerance workshop, 18 September. Scientists discussed the problems of rice grown in low-temperature areas in the workshop held at Suweon, Korea, in cooperation with the Office of Rural Development. Collaborative projects to find solutions to the problems were developed. Forty-nine scientists from nine countries participated.

Nitrogen and rice symposium, 18-21 September. Ninety-three scientists from 23 countries participated in the symposium to review and evaluate current nitrogen-fixing systems in rice culture, to identify research needs and opportunities, and to develop plans for international cooperation through a global research network.

Cropping systems working group meeting, 2-5 October. The cropping systems working group reviewed progress in the different national programs and discussed increased collaboration in the cropping systems research network.

Workshop on chemical aspects of grain quality, 23-25 October. The workshop reviewed the state of knowledge on the chemical basis of rice grain quality in rice breeding programs, obtained a consensus on priority problem areas on methodology of grain quality evaluation, and discussed areas of possible cooperative studies. Twenty-nine scientists from 11 countries participated.

Information resources, experimental farm, and service laboratories

LIBRARY AND DOCUMENTATION CENTER

Bibliographies. The *1977 Supplement* to the *International Bibliography of Rice Reseach* was published in 1978. It contains 5,238 references to scientific rice literature, most of which appeared in 1977 journals. An additional 26 serial titles were scanned and searched in the compilation. Coverage is worldwide and the items of reference are classified according to subject matter. As with previous supplements, an author index and a manually produced keyword index are provided. The supplement includes literature written in 24 languages. A list of 18 rice literature translations, mostly from Japanese to English, is included.

The year 1978 saw the publication of *Supplement 1976* to the *International Bibliography on Cropping Systems,* which embraces worldwide published and unpublished 1976 technical works dealing with all aspects of cropping systems involving food crops. The entries are classified according to subject, and within each subject category items are arranged alphabetically. An author index and a manually produced keyword index are provided.

Supplement 1978 to *Theses and Dissertations on Rice Available in the Library of the International Rice Research Institute* was produced during the year. The listing gives 97 titles of theses and dissertations, bringing the overall collection to 783.

The monthly *Library List of Acquisitions* was circulated to a wider audience.

The bibliography supplements are sent to agriculture libraries and documentation centers of the rice-producing regions for the use of rice research workers and those responsible for disseminating information on the crop. Essentially all citations included are available in the library.

Reference and circulation. Numerous requests for information and photocopying services were received during the year. As in previous years, requests for Japanese literature on genetics and breeding outranked requests for literature on all other aspects of rice culture. Requests for photocopies of literature on water management and irrigation were also received. Assistance in library organization and management and in the selection and acquisition of agricultural materials was also given. Requests for short specific-subject bibliographies increased. They came mostly from Bangladesh, India, Thailand, Indonesia, and Malaysia.

The number of books and journals and other library materials borrowed within the Institute during the year increased sharply.

Library holdings. With the addition of 2,641 monographs (books, pamphlets, and reprints), the overall monographic collection totaled 48,680. One hundred sixty-three serial titles were added during the year. They were received mostly through subscriptions and exchanges, but some were gifts and donations. Maps, translations, and microfilms were also added to the collection.

Other library activities. To keep the scientists informed of the latest publications on rice, routing of tables of contents of newly received journals was continued within the Institute and was extended to the Bangladesh Rice Research Institute; the Lembaga Penelitian Maros in Indonesia; the Central Research Institute for Agriculture, Sukamandi Branch, Indonesia; IRRI Sri Lanka; and the West Africa Rice Development Association in Liberia.

The library continued to purchase books and distribute them to Institute research scholars and trainees.

IRRI Tokyo office. The main activities of the Tokyo office were services for the IRRI Library and Documentation Center. Rice literature published in Japan was searched, selected, and indexed, and 1,387 items from 304 publications were sent to IRRI with English translation of titles. In addition, 400 items on multiple cropping were indexed. Number of items indexed during the year was 41% more than that in 1977.

OFFICE OF INFORMATION SERVICES

The Office of Information Services distributes scientific publications and educational and training materials to a worldwide audience of rice researchers, extension specialists, and policy makers. Ninety percent of the publications go to addressees in developing nations; 80% of the addresses are in Asia.

Series publications. *The IRRI Reporter*, a quarterly newsletter describing IRRI's activities and achievements, was distributed to more than 11,000 rice scientists, extension workers, and other rice workers.

The *International Rice Research Newsletter*, a bimonthly report of research on rice and rice-based cropping systems, went to more than 8,000 readers.

Eleven issues of the *IRRI Research Paper Series* were published and distributed globally in 1978:

IRPS #12—Scientific communication among rice breeders in 10 Asian nations

IRPS #13—Rice breeders in Asia: a 10-country survey of their backgrounds, attitudes, and use of genetic materials

IRPS #14—Drought and rice improvement in perspective

IRPS #15—Risk and uncertainty as factors in crop improvement research

IRPS #16—Rice ragged stunt disease in the Philippines

IRPS #17—Residues of carbofuran applied as a systemic insecticide in irrigated wetland rice: implication for insect control

IRPS #18—Diffusion and adoption of genetic materials among rice breeding programs in Asia

IRPS #19—Methods of screening rices for varietal resistance to Cercospora leaf spot

IRPS#20—Tropical climate and its influence on rice

IRPS #21—Sulfur nutrition of wetland rice

IRPS#22—Land preparation and crop establishment for rainfed lowland rice

Major publications. Major publications released in 1978 were:

- Annual Report for 1977
- Research Highlights for 1977
- Rice: Soil, Water, Land
- Soils and Rice
- Anatomy of a Peasant Economy
- A Handbook on the Methodology for an Integrated Experiment-Survey on Rice Yield Constraints
- Economic Consequences of the New Rice Technology
- Proceedings of the Workshop on the Genetic Conservation of Rice
- Interpretive Analysis of Selected Papers from Changes in Rice Farming in Selected Areas of Asia
- Proceedings of the International Agricultural Machinery Workshop
- Irrigation Policy and Management in Southeast Asia
- Rice Research and Production in China: an IRRI team's view

Research and training support. A project to prepare a series of slide-cassette tape self-instructional units for the Office of Rice Production, Training, and Research continued. Eighteen sets were completed.

EXPERIMENTAL FARM

The Experimental Farm Department continued to support the research departments by supplying all labor for land preparation, planting, weed and insect control, harvesting, and drying. During the year, 172 ha was prepared and planted for 14 research departments in the lowland area. In the upland area, 152 ha was prepared for planting by 7 research departments.

A total of 15.7 ha for seed multiplication was planted in 1978. The wet-season crop was on 12 ha, 10.7 ha of which was outside IRRI. The lines or selections multiplied were IR2058-78-1-3-23 on 3.5 ha, IR4432-52-6-4 on 2 ha, IR4570-83-3-3 on 2.4 ha, IR36 on 2.4 ha, and IR841 on 1.3 ha. The dry-season crop, planted mainly at IRRI, consisted of C22, C168, and IR841 on 3.7 ha.

Fertilizer consumption for 1978 was 143.2 t, a slight increase over 1977's 140.9 t.

Expenditures were US$65,157.11 for insecticides and stickers, $14,442.93 for herbicides,

and $97,671.60 for contract labor.

An income of US$12,217.76 was realized from the sale of farm products as rice seed, milled and unmilled rice, corn, cowpea, sweet potato, and rice bran.

Other accomplishments of the Department follow:

- Relocation of the main irrigation canal that passes through the lowland area was completed and the old canal was filled and converted into research plots. All plantable plots were assigned to research departments and planted during the wet season.
- Development of the rainfed area (series 900) was completed for planting by the Agronomy Deparment. Block H of the old lowland rice farm planted to dryland rice was converted into a wetland rice field. Block 3004 of the new dryland area and a portion of Block 3021 were leveled in preparation for planting.
- To minimize dry-season water shortages, a large reservoir was connected to four smaller reservoirs so that water could be drawn from the bigger reservoir during time of shortage. Measures to prevent misuse and waste of water, such as installing locks in the reservoir outlets and barbed wire fence around reservoirs in the new wetland and dryland areas, were taken. Provisions were made for power sprayers to get water directly from the deep wells.
- Drainage outlets were constructed around the farm building in the new area to prevent flooding during heavy rains.
- Rat control activities were undertaken during the year. Electric fences were installed, and baits and traps were used. Rats killed in 1978 numbered 17,387.

ANALYTICAL SERVICE LABORATORY AND PESTICIDE RESIDUE LABORATORY

Analytical Service Laboratory. The number of samples received by the Analytical Service Laboratory (ASL) doubled in its second year of operation (Table 1). The number excludes the germplasm bank samples analyzed in cooperation with the Chemistry Department in 1977. The head of the Tropical Soils Analysis Unit,

Table 1. Summary of analyses rendered by the IRRI Analytical Service Laboratory for 1977 and 1978.

Property analyzed	Determinations (no.) Plant	Soil
1977		
Number of samples	24,868[a]	4,542
Total nitrogen or crude protein	24,364[b]	3,857
Total element[c]		
Phosphorus	1,985	1,009
Potassium	1,840	584
Zinc	909	541
Iron	601	182
Manganese	115	172
Magnesium	523	149
Calcium	461	—
Copper	94	25
Sodium	—	—
pH	—	1,502
Electrical conductivity	—	333
Exchangeable cations:		
Sodium	—	375
Potassium	—	1,218
Magnesium	—	539
Calcium	—	636
Cation exchange capacity	—	1,186
Available phosphorus	—	1,716
Available zinc	—	23
Organic carbon	—	1,618
Particle size	—	506
Moisture	—	198
Amylose	11,729[d]	—
Total	42,601	16,169
Total	58,770	
1978		
Number of samples	28,242	7,304
Total nitrogen or crude protein	25,369	5,780
Total element[c]		
Phosphorus	7,643	1,439
Potassium	6,480	620
Zinc	2,841	768
Iron	1,330	503
Manganese	710	289
Magnesium	627	197
Calcium	487	—
Copper	296	242
Sodium	194	—
pH	—	2,545
Electrical conductivity	—	413
Exchangeable cations:		
Sodium	—	994
Potassium	—	2,897
Magnesium	—	1,030
Calcium	—	1,030
Cation exchange capacity	—	1,430
Available phosphorus	—	3,840
Available zinc	—	896
Organic carbon	—	2,938
Particle size	—	778
Moisture	179	23
Amylose	—	—
Total	46,156	28,642
Total	74,798	

[a]12,604 were world collection samples. [b]12,604 analyses for world collection samples. [c]Perchloric acid digestible for soil. [d]Part of world collection screening.

Table 2. Summary of analyses rendered by the Pesticide Residue Laboratory, 1974, 1975.

Constituent analysed	Determinations (no.)	
	Complete	GLC only
Carbofuran and 3-hydroxy carbofuran	395	91
Orthene	144	—
Others	—	477[a]
Total	539	568

[a] Leaf wax (Agronomy), pheromones (Entomology), and fatty acid methyl esters (Chemistry).

Land Resources Division, Ministry of Overseas Development, Reading, England, spent 3 weeks late this year reviewing the operations of the laboratory. His recommendations for increasing efficiency and minimizing unnecessary requests for analysis are timely because the ASL is approaching its peak capacity.

Pesticide Residue Laboratory. The Pesticide Residue Laboratory (PRL) strengthened its staff capability. Only the person in charge remains to be hired. The major pesticides analyzed were carbofuran and Orthene (Table 2). Plans are under way to transfer and consolidate the site of the PRL within the F. F. Hill Laboratory and to have a pesticide chemist consultant from the Tropical Products Institute, London, England, for 3 months.

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De Datta, S. K., K. A. Gomez, R. W. Herdt, and R. Barker. 1978. A handbook on the methodology for an integrated experiment-survey on rice yield constraints. International Rice Research Institute. Los Baños, Philippines. 60 p.

SEMINARS

The seminars held at IRRI during 1978 are grouped as Saturday seminars, general seminars, and special seminars. The Saturday seminars report ongoing IRRI researches. Unless otherwise stated the speakers were staff members.

Saturday Seminars

Component technology studies in Iloilo for crop year 1976–77, Mr. Marcelino Lumaban; Mr. Rafael Tasic, technician, Philippine Bureau of Plant Industry; and other members of the Interdisciplinary Cropping Systems Team.

Nitrogen transformations in rice soils, Dr. K. L. Sahrawat.

Some findings on field water use and productive efficiency of water in the dry zone of Sri Lanka, Mr. Kapila Goonasekere.

Hardness and stickiness of cooked rice as eating quality indicators, Mrs. C. M. Perez.

Some properties of undigested protein bodies of cooked rice, Ms. A. P. Resurreccion.

Development of methods to identify moderate levels of resistance to the brown planthopper, Mr. Md. Iman..

Factors causing resurgence of the brown planthopper in response to insecticide applications, Dr. S. Chelliah.

Sex pheromones in insect pest control, Mr. G. S. Arida.

Biochemical bases of insect resistance in crop plants, Dr. R. C. Saxena, visiting scientist, Entomology Department, IRRI.

The dynamics of water regimes in Iloilo and Pangasinan land systems, Dr. R. A. Morris.

Effect of dry soil mulch on moisture conservation in rainfed lowland and upland rice, Mr. M. P. Singh.

Quantitative evaluation of resistance to rice blast, Dr. S. W. Ahn.

Evaluation of alternative cropping patterns in Pangasinan, CY 1977–78, Mr. Herminigildo Gines.

Testing of rainfed lowland rice-based cropping patterns in Iloilo, crop year 1977–78, Mr. Rogelio Magbanua.

IRTP activities at IRRI, Mr. Toribio Ebron, Jr., Mr. Silvino Merca, and Dr. H. E. Kauffman.

Comparative performance of rice postproduction systems in the Philippines (farm level), Ms. Celerina Maranan.

Nitrogen movement in water draining from irrigated rice land, Dr. V. P. Singh.

Rice ragged stunt disease in the Philippines, Mr. E. R. Tiongco.

Cytogenetics of primary trisomics in rice and their usefulness in genetics and plant breeding, Dr. R. J. Singh and Dr. G. S. Khush.

Economic inefficiency as a constraint to high yields in Nueva Ecija, Philippines, Mr. A. Mandac.

The impact of new rice technology on rainfed rice farmers in Bulacan, Ms. Fe B. Gascon.

Time allocation among rice farm households in Central Luzon, Philippines, Mr. Ricardo Guino.

An economic analysis of a reserve stock program for rice in the Philippines, Ms. Amanda Te.

Agrarian adaptation to demographic and technological changes in two Central Luzon villages, Mr. Geronimo Dozina, Jr.

Rice farmers and landless rural workers: perspective from the household level, Fr. Antonio Ledesma.

Growing rainfed corn and soybean after puddled flooded rice: I. Soil physical conditions and management, Mr. Syarifuddin Karama.

Varietal resistance of rice to the green leafhopper *Nephotettix virescens*: sources, mechanism, and genetics of resistance, Mr. A. N. M. Rezaul Karim.

Growing rainfed corn and soybean after puddled flooded rice: II. Soil chemical conditions and management, Mr. Syarifuddin Karama.

An economic analysis of a pilot groundwater irrigation system in the Philippines, Ms. Linda M. Bantilan.

Reuse of drainage water in the Vaca Irrigation Project, Mr. Danilo Cablayan.

Management of irrigation water in a communal project in the Bicol region: a case study, Mr. Abel Sumayao.

Weeds in cropping systems as affected by hydrology and weeding regime, Mr. Nizamuddin Ahmed.

Genetic interrelationships of improved rice varieties, Dr. T. R. Hargrove.

A comparison of alternative rice milling systems in the Bicol Region, Mr. I. R. Camacho, Mr. P. M. Hidalgo, Mr. B. Duff, and Dr. E. P. Lozada, chairman and program leader, Department of Agricultural Process Engineering and Technology, University of the Philippines at Los Baños.

Development of the vertical batch dryer using value analysis, Messrs. Jose Arboleda, Herbert Manaligod, and Jose Policarpio.

Household and village storage practices in the Philippines, Dr. H. Takai and Ms. Leonarda Ebron.

Meeting the energy requirements of small rice farmers, Mr. Laurence Kiamco and Mr. John McMennamy.

Seeding and transplanting developments, Mr. Ignacio Manalili and Mr. Mamerto Aban.

The development of the IRRI plow-sole fertilizer applicator, Mr. Salvador Labro, Mr. Godofredo Salazar, Mr. Arsenio Resurreccion, and Mr. D. O. Kuether.

Continuous variation in virulence of *Xanthomonas oryzae*, the rice bacterial blight pathogen, Mr. M. Machmud and Dr. T. W. Mew.

The development of the plow-sole fertilizer applicator, Mr. Salvador Labro and Mr. Godofredo Salazar.

Biological constraints to high yields in selected farmers' fields in Nueva Ecija, Mr. Felipe Garcia, Mr. W. P. Abilay, Mr. J. M. Alcantara, and Dr. S. K. De Datta.

A field study on water use and duration of land preparation for lowland irrigated rice, Mr. Alfredo Valera.

Some aspects of research on the soil-plant-water relationships of rice, Dr. J. C. O'Toole.

Evapotranspiration from rice fields, Dr. V. S. Tomar.
A look at the traditional Filipino homeyard garden and its potential in agricultural development, Mr. Paul Sommers, crop specialist, University of the Philippines at Los Baños.
Approaches to control of sheath blight disease of rice, Mr. B. A. Estrada, Mr. F. L. Nuque, Ma. T. I. Verget de Dios, and Dr. S. H. Ou.

General Seminars

Individualized audio-tutorial instruction, Dr. Floyd H. Nordland, visiting communications specialist, Office of Information Services.
Survey of farmers' pest control practices in the Philippines, Dr. J. A. Litsinger.
The sociology of rice breeding in Asia, Dr. T. R. Hargrove.
Three F's of *Leucaena* (ipil-ipil), Mr. Mike Benge, agro-forestation officer, United States Agency for International Development (USAID), Manila, Philippines.
The natural (and unnatural) history of crop yield, Dr. Lloyd Evans, visiting scientist, Plant Physiology Department.
Kabaka – pilot extension project in Iloilo with rainfed rice, Mr. Romy Aquino, regional director, Bureau of Agricultural Extension, Iloilo, Philippines.
The fine structure of starch granules and protein bodies, Dr. B. O. Juliano.
Progress on biological control of rice insect pests, Dr. V. A. Dyck.
Controlling rice diseases, Dr. S. H. Ou.
Life beyond earth, Dr. Cyril Ponnamperuma, professor of chemistry, director, Laboratory of Chemical Evolution, University of Maryland, USA.
Is there a place for the potato in the tropics and subtropics, Dr. L. J. Harmsworth, regional representative for Southeast Asia and the Pacific, International Potato Center, c/o Philippine Council for Agriculture and Resources Research (PCARR), Los Baños, Laguna, Philippines.
Feeding physiology of the brown planthopper, Dr. K. Sogawa, visiting scientist, Entomology Department.
Implication of the International Rice Blast Nursery data for genetics of resistance — an approach to a complicated host-parasite relationship, Dr. H. Ikehashi.
Exploitation of biological nitrogen fixation for rice production, Dr. A. A. App, visiting scientist, IRRI.
The NIA (National Irrigation Administration) and communal irrigation implication of farmer involvement, Mr. Carlos Islas, Office of Special Program, NIA, and Dr. Frances Korten, Ford Foundation, Philippines.
Can small farmers cooperate? New approaches to the organization of water and pest management, Dr. Grace Goodell, visiting anthropologist, Agricultural Economics Department; Mr. Marcelino Lumaban; Mr. Wenceslao de la Viña; and Ms. Corazon Juliano, coordinator, Agency for Community Educational Services, Quezon City, Philippines.
Breeding for resistance to downy mildew of maize at UPLB, Dr. B. A. Aday, assistant professor, University of the Philippines at Los Baños, Laguna, Philippines.
Wheat and barley endosperm cell walls — development and composition, Dr. Bruce A. Stone, visiting scientist, Chemistry Department.
Water use, water stress, and crop productivity, Dr. T. C. Hsiao, visiting scientist, Agronomy Department.
Development of cropping systems programs in South and Southeast Asia, Dr. V. R. Carañgal.
Rices in saline and alkaline areas — observations and strategies for their improvement, Dr. H. Ikehashi.

Special Seminars

General host resistance on a single plant basis, Dr. Oscar Calvert, professor of mycology, Department of Plant Pathology, College of Agriculture, University of Missouri, Columbia, USA.
An analysis of government rice policy in the Ivory Coast, Dr. Charles Philip Humphreys, research associate, Political Economy of Rice in West Africa Project, Food Research Institute, Stanford University, California, USA.
Introduction of a new fertilization system to Southeast Asia, Dr. Jens Moller Nielsen, professor, Division of Agricultural and Food Engineering, Asian Institute of Technology, Bangkok, Thailand.
Landscape and hydrology of some problem soils for rice, Dr. Nico van Breemen.
Studies on a soil toposequence with differential zinc deficiencies, Dr. H. W. Scharpenseel, visiting scientist, IRRI.
Bacterial foot-rot, a new disease of rice, Dr. Masao Goto, plant pathologist, Shizuoka University, Japan.
Availability of soil water to plants, W. R. Gardner, professor of soil physics, Department of Soil Science, University of Wisconsin-Madison.
Towards resolving the energy and time constraints of small farmers in the humid tropics, Ray Wijewardene, head, Agricultural Engineering Department, Farming Systems Program, International Institute of Tropical Agriculture.
Soil sickness due to continuous cropping of rice, Dr. M. Nishio, soil microbiologist, Central Agricultural Experimental Station, Ministry of Agriculture for Fisheries, Saitama, Japan.
Nitrogen fixation in grass-bacteria association, Dr. J. Dobereiner, coordinator of the Program for Biological Nitrogen Fixation, Empresa Braseleira de Pesquisa Agropecuaria (EMBRAPA), Rio de Janeiro, Brazil.

Use of azolla as source of nitrogen fertilizer for rice culture, Dr. D. W. Raina, professor, Department of Agronomy, University of California, Davis, California, USA.

Agriculture in Tanzania, Dr. Harvey Philip Hermanson, soil scientist, Plant Science Department, North Carolina A & T University, Greensborough, North Carolina, USA.

Insecticide residues in soil, Dr. Harvey Philip Hermanson, soil scientist, Plant Science Department, North Carolina A & T State University, Greensborough, North Carolina, USA.

Carbon excretion in the rhizosphere, Dr. K. Martin, soil scientist, Commonwealth Scientific and Industrial Research Organization (CSIRO), Osmond, Australia.

Weed control in upland rice, Luis M. Lopez.

Utilization of stored water by crops, Dr. S. S. Prihar, head, Department of Soil Science, Punjab Agricultural University, India.

Adaptive drought tolerance in rice, Dr. Peter L. Steponkus, associate professor, Department of Agronomy, Cornell University, Ithaca, New York, USA.

FAO farm management data collection and analysis system, Mr. Heinrich-Georg Groetecke, farm management economist, FAO Regional Office, Bangkok, Thailand.

Alternative approach to risk in aggregate programming: an evaluation, Dr. John Wicks, research fellow, Department of Agricultural Economics and Business Management, University of New England, Armidale, Australia.

Slide show on recent breakthrough in rice production in Korea, Dr. H. M. Beachell, plant breeder, Cooperative CRIA-IRRI Program, Indonesia.

Finances

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

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

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

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

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

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

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

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

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

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

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

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

- $380 as the final release on a 2-year grant for research in Indonesia in cooperation with the Central Research Institute for Agriculture, and to develop cropping patterns for rainfed and partially irrigated rice areas and to adapt them through trials in farmers' fields;
- $50,130 as part of a 4-year grant to enable the University of the Philippines at Los Baños to conduct, in support of IRRI's multiple cropping program, varietal screening for corn, sorghum, mung bean, eggplant, tomato, and sweet potato; and
- $30,430 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute.

The Japanese government gave $2,300,000 in 1978 for purchase of equipment for research

and training, for partial support of cropping systems research, for the direct and indirect expenses of the plant physiology and soil microbiology departments, and for partial support of the genetic evaluation and utilization program.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Staff changes

January

Dr. Grace Goodell joined the Institute as associate visiting scientist at the Agricultural Economics Department

Dr. Eric T. Craswell joined the Institute as soil scientist to work on an International Fertilizer Development Center (IFDC)/IRRI collaborative research.

March

Mr. Venkat R. Reddy joined the Institute as agricultural engineer in the outreach project in Indonesia.

Mr. Peter S. Barton resigned as associate agricultural engineer in the outreach project in Thailand.

April

Dr. J. Thomas Cope, Jr. of Auburn University, Auburn, Alabama, began a 1-year sabbatical leave as visiting scientist at the Agronomy Department.

Dr. Thomas H. Wickham resigned as agricultural engineer and head of the Irrigation and Water Management Department.

June

Dr. Robert W. Herdt, agricultural economist of the Institute, assumed the position of head of the Agricultural Economics Department.

Dr. Gilbert P. Waldbauer, entomologist from the University of Illinois, began a 1-year sabbatical leave as visiting scientist at the Entomology Department.

Dr. Pedro B. Escuro joined the Institute as plant breeder. He will work temporarily with the Plant Breeding Department and will later be assigned to the IRRI/Burma project of the Institute.

July

Dr. John Freney of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, arrived to work 2.5 months with Dr. E. T. Craswell on an IRRI/IFDC collaborative research.

Dr. J. Pat Crill joined the Institute as plant pathologist and head of the Plant Pathology Department.

Dr. Theodore C. Hsiao of the University of California, Davis, began a 1-year sabbatical leave as visiting scientist at the Agronomy Department to work on drought resistance.

Dr. Satoshi Wakimoto, professor at Kyushu University, arrived to work 3 months with Dr. T. W. Mew on bacterial leaf blight.

Dr. Robert N. Hurst of Purdue University began a 1-year sabbatical leave as visiting communications specialist at the Office of Information Services and at the Rice Production Training and Research Department.

Dr. James E. Wimberly rejoined the Institute as acting team leader at the IRRI/Government of Sri Lanka project in Sri Lanka.

Mr. Everett Metcalf completed a 1-year sabbatical leave as visiting editor at the Office of Information Services.

Dr. Randolph Barker resigned as agricultural economist and head of the Agricultural Economics Department.

August

Mr. Alan M. Fletcher of Cornell University began a 1-year sabbatical leave as visiting editor at the Office of Information Services.

Dr. John C. Flinn joined the Institute as agricultural economist at the Agricultural Economics Department.

Dr. John Angus began a 9-month leave from the Division of Land Use, CSIRO, to work as associate visiting scientist at the Multiple Cropping Department.

Dr. Lyle Nelson of the Mississippi State University began a 1-year sabbatical leave as visiting scientist at the Soil Chemistry Department and as visiting professor at the University of the Philippines at Los Baños.

Dr. Floyd H. Nordland of Purdue University completed a 1-year sabbatical leave as visiting communications scientist at the Office of Information Services.

Mr. Keneth P. Haydock of the Division of Mathematics and Statistics, CSIRO, began a 1-year stay at IRRI to work with Dr. K. A.

Gomez of the Statistics Department.

Dr. John Lance began a 1-year leave from the University of Newcastle, England, to work as visiting associate statistician at the Statistics and Multiple Cropping Departments.

Mr. Marvin D. Davis resigned as crop production specialist at the Sri Lanka project.

October

Dr. Kaung Zan of Burma joined the Institute as liaison scientist for Africa, with station at the International Institute of Tropical Agriculture.

November

Dr. Bruce Stone arrived to work 6 months as visiting scientist at the Chemistry Department and at the University of the Philippines at Los Baños.

December

Dr. Joyce C. Torio resigned as communications specialist and head of the Office of Information Services.

Dr. Donald W. Puckridge of the University of Adelaide began a 10-month stay at IRRI to work with Dr. J. C. O'Toole on drought resistance.

Crop weather

Total 1978 rainfall at IRRI was 2,616 mm (the 1966–77 mean was 2,070 mm). All monthly weather data are presented in Table 1. Most of the rain was associated with 12 tropical cyclones that crossed the Philippines between August and October. During that period total rainfall was 1,744 mm; the 1966–77 mean was 777 mm.

The start of the 1978 monsoon rains was extremely late. June 1978 was the second driest month on record. The end of the rainfed rice-growing season was in late December on low-landscape positions, giving an overall rainfed rice-growing season of about 160 days.

Other weather elements reflected the rainfall pattern. Solar radiation and evaporation were above average in the early dry months of the year, about average in midyear, and below average during the typhoon-affected months (Table 1).

Table 1. Weather elements for 1978 and 1966–77 average, IRRI, 1978.

	Dry season					Wet season						
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Solar radiation (g cal/cm²)							
Totals for 1978	12,208	12,884	18,484	17,920	16,220	13,917	13,987	8,798	10,912	10,979	11,641	11,056
Mean 1966–77	11,092	12,464	16,009	17,627	15,768	13,756	12,621	11,752	11,601	11,674	10,173	9,315
					Sunshine duration (h)							
Totals for 1978	205.9	205.2	304.6	277.0	242.9	166.4	182.3	91.3	129.1	139.9	182.4	143.3
Mean 1966–77	180.0	197.9	249.5	283.1	246.6	183.3	161.0	151.6	143.0	166.5	160.3	148.8
					Evaporation (mm)							
Totals for 1978	121.3	127.2	197.3	194.8	190.7	130.2	133.3	78.3	99.5	166.5	109.7	111.8
Mean 1971–77	120.2	124.4	169.1	194.4	175.0	144.2	135.0	135.0	131.4	119.7	112.4	103.0
					Rainfall (mm)							
Totals for 1978	21.5	8.9	6.4	28.7	210.8	76.7	239.6	535.3	364.6	714.6	220.9	84.2
Mean 1966–77	52.0	15.4	31.4	28.9	193.5	236.3	260.9	247.3	223.3	222.0	294.2	234.3
					Water balance (mm)							
1978	−99.8	−118.3	−190.9	−166.1	+20.1	−53.5	+106.3	+457.0	+265.1	+598.1	+11.2	−27.6
					Max temperature (°C)							
Mean 1978	25.0	24.4	30.6	32.0	32.4	31.5	31.4	29.8	30.9	30.7	29.8	28.6
Mean 1966–77	27.8	28.6	29.9	31.8	32.3	32.1	31.4	30.2	30.7	30.0	29.2	28.2
					Min temperature (°C)							
Mean 1978	18.2	17.3	22.4	23.6	24.7	24.4	23.6	23.2	23.4	23.0	22.7	22.8
Mean 1966–77	22.6	22.6	23.2	24.5	24.7	24.6	25.0	24.4	24.7	24.4	24.2	23.5

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Irrigation & water management

Soil & crop management

Environment & its influence

Postproduction technology & management

Constraints on rice yields

Consequences of new technology

Cropping systems program

Machinery development & testing

Genetic evaluation and utilization (GEU) program

Drought resistance

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HYBRIDIZATION AND SELECTION

Plant Breeding Department

IRRI hybridization for drought resistance now includes crosses intended for dryland and rainfed wetland cultures. Forty-five single and 189 multiple crosses were made in 1978.

During the year 250 F_2 populations were grown in dryland fields at IRRI and in a farmer's field in Batangas province. Despite a September typhoon that caused lodging and crushing of plants, 2,971 F_2 plants were selected. Progenies selected from pedigree nurseries in dryland fields numbered 1,300.

For crosses intended mainly for drought resistance in rainfed wetland culture, 100 F_1 populations were grown. A fire destroyed all the F_2 seeds; the crosses will be repeated in 1979. A group of 17 F_2 populations, involving drought-resistant sources, was grown in the wet season.

VARIETAL SCREENING

Agronomy and Plant Breeding Departments

Dryland field (*Agronomy*). The 1978 dry-season field screening for drought resistance was at IRRI and in a farmer's field in Tanauan, Batangas province. The drought reaction at the vegetative stage of the entries, including drought-resistant checks IR442-2-58 and Salumpikit and drought-susceptible checks IR20 and IRAT 9, was recorded at 2, 5, and 10 bars soil moisture tension (SMT) at the 20-cm soil depth. Plots were sprinkler-irrigated after the 10-bar SMT scoring, and scored for drought recovery 15 days later.

IRRI. Among 4,757 entries, 18 varieties and 25 lines had drought scores of 1 to 3 (Table 1). The outstanding varieties originated in Thailand (5), India (4), Indonesia (4), Bangladesh (2), Liberia (1), Pakistan (1), and Sri Lanka (1). Only the line IR8103-120-3 had a drought score of 1 at all SMT levels. When scored for drought recovery 10 days after relief of moisture tension, all but two of the listed entries improved or retained a green appearance. Bakka Edjang and N22 suffered from sheath blight.

Batangas. Three varieties, but no IRRI lines, scored 3 at 10 bars SMT in the Batangas test of 2,403 entries (Table 2). The resistant check Salumpikit scored 4 as opposed to the 6 of IR442-2-58.

IRRI and Batangas results compared. Results for common entries were compared. The IRRI dryland area soil is heavy montmorillonitic clay, with a relatively shallow hardpan. The Batangas site's soil is silty with no hardpan to a 1.5-m depth. The subsoil was moist at 1-m depth and saturated at 1.5 to 2 m when SMT at 20 cm was 10 bars. That gave deep-rooted plants access to moisture.

The best entries at IRRI included known semidwarf, intermediate-statured, and tall varieties and lines; the best ones in Batangas were only the tall varieties. A possible explanation is that less moisture was available for root absorption at 20-cm depth and 10 bars SMT in the silty Batangas soil. The result was greater leaf desiccation in the Tanauan test. The drought-tolerant varieties in Batangas either had better resistance to lower moisture content or had roots that penetrated to the deep moist soil.

Screening dryland culture (*Plant Breeding*). During the 1978 dry season 5,719 traditional varieties and 2,216 breeding lines were screened for drought resistance. Because of the early showers (third week of April), drought resistance was scored only at the vegetative phase.

Among the accessions from the germplasm bank, 1,014 entries showed moderate to high levels of drought resistance at the early vegetative stage (Table 3). The largest proportion of drought-resistant entries came from the Assam Rice Collection of India, dryland varieties of Brazil, and varieties collected from Indonesia, Liberia, Sierra Leone, and Burma.

From the dryland breeding nurseries, progenies that have one drought-resistant parent or more in their pedigree produced a higher percentage of lines with good levels of drought resistance than did lines without a drought-resistant parent. Progenies of drought-resistant dryland parents also showed less stunted growth during the plant's moisture stress period. Some lines from the wetland breeding nurseries also showed a higher percentage of drought resistance at the early vegetative stage. Although the lines showed moderate signs of plant stress, i.e.

Table 1. Promising lines for field drought resistance in [illegible] plots seeded 30 January, [illegible] dry season.

Designation	Origin	Drought score[a]						
		First scoring 30 Mar., 2 bars		Second scoring 30 Mar., 5 bars		Third scoring 17 Apr., 10 bars		Recovery rating 3 May
		Growth stage	Drought resistance	Growth stage	Drought resistance	Growth stage	Drought resistance	
[illegible]	Indonesia	2	1	2	1	2	3	3
[illegible]	Indonesia	2	1	2	1	2	3	3
[illegible]	Indonesia	2	1	2	1	2	3	3
[illegible]	Indonesia	2	1	2	1	2	3	4
[illegible]	India	2	1	2	1	2	3	2
[illegible]	Thailand	2	1	2	2	2	3	3
[illegible]	Thailand	2	1	2	1	2	3	3
DV 85	Bangladesh	2	1	2	1	4	3	3
[illegible]	Thailand	2	1	2	1	2	3	1
[illegible]	Thailand	2	1	2	1	2	3	3
[illegible]	Thailand	2	1	2	1	2	3	3
CU 56	Thailand	2	1	2	1	2	3	1
Kalawahi	Sri Lanka	2	1	2	1	2	3	5
N22	India	2	1	2	1	2	3	3
Surjamhuhi	India	2	1	2	2	2	3	3
T1242	India	2	1	2	1	4	3	1
UCP 41	Bangladesh	2	1	2	1	2	3	3
9-D	Liberia	2	1	2	1	2	3	3
38A	Pakistan	2	1	2	1	2	3	3
IR[illegible]-22-1-3-2	IRRI	2	1	2	1	2	3	3
IR[illegible]-113-6	IRRI	2	1	2	1	2	3	3
IR[illegible]-3-1	IRRI	2	1	2	1	2	3	3
IR[illegible]-67-3	IRRI	2	1	2	1	2	3	3
IR[illegible]-110-2	IRRI	2	1	2	1	2	3	3
IR[illegible]-22-5-2	IRRI	2	1	2	2	2	3	2
IR[illegible]-139-1-3	IRRI	2	1	2	1	2	3	1
IR[illegible]-215-1-2	IRRI	2	1	2	1	2	3	2
IR[illegible]-69-2	IRRI	2	1	2	1	2	3	3
IR[illegible]-62-3-1-1	IRRI	2	1	2	1	2	3	3
IR[illegible]-110-5	IRRI	2	1	2	1	2	3	3
IR7777-7-1-1	IRRI	2	1	2	1	2	3	3
IR[illegible]-139-3	IRRI	2	1	2	1	2	1	1
IR[illegible]-33-2	IRRI	2	1	2	1	2	3	3
IR[illegible]-33-3	IRRI	2	1	2	1	2	3	3
IR[illegible]-65-1	IRRI	2	1	2	1	2	3	2
IR[illegible]-174-3	IRRI	2	1	2	2	2	3	2
IR[illegible]-49	IRRI	2	1	2	2	2	3	3
IR[illegible]-139	IRRI	2	1	2	1	2	3	3
IR[illegible]-194	IRRI	2	1	2	1	2	3	3
IR[illegible]-8-3	IRRI	2	1	2	1	2	3	3
IR[illegible]-13-1	IRRI	2	1	2	1	2	3	3
IR[illegible]-9-1	IRRI	2	1	2	1	2	3	3
IR[illegible]-46-2	IRRI	2	1	2	1	4	3	1
IR[illegible]-15	IRRI	2	1	2	1	2	3	3
IR442-3-58 (T-check)	IRRI	2	1	2	1	2	5	3
Sahumpilit (T-check)	Philippines	2	1	2	1	4	4	3
IR20 (S-check)	IRRI	2	2	2	5	2	8	5
IRAT 9 (S-check)	Ivory Coast	2	5	2	6	2	9	7

[a]Growth stage score, Standard Evaluation System for Rice (SES) scale 1–9:1 = seedling stage, 9 = maturity. Drought resistance score, SES scale 1–9:1 = no to negligible effect of moisture stress, 9 = all plants apparently dead. Recovery rating, SES scale 1–9:1 = all plants fully recovered; 9 = no plants recovered.

slight rolling and few dried lower leaves, plant growth was stunted and flowering was delayed.

Screening rainfed wetland culture (*Plant Breeding*). In a simulated rainfed wetland trial to screen for drought resistance in the dry season, about 500 varieties and lines were tested. Fifty days after seeding, the fields in 1 treatment were drained and allowed to dry for 3 weeks-1 month to simulate a prolonged drought. Fields in the other treatment were kept wet by frequent irrigation.

The susceptible entries started to show stress symptoms 10 days after the fields were drained. Stunting, accompanied by leaf rolling and drying of the lower leaves, occurred during the stress period. During the reproductive phase,

Table 2. Promising rices for drought resistance in plots seeded 9 February, Batangas, Philippines, 1978 dry season.

Designation	Origin	Drought score[a]						
		First scoring 3 Apr, 2 bars		Second scoring 13 Apr, 5 bars		Third scoring 16 May, 10 bars		Recovery rating 30 May
		Growth stage	Drought resistance	Growth stage	Drought resistance	Growth stage	Drought resistance	
ARC 10552	India	2	1	2	2	4	3	3
DNJ 148	Pakistan	2	2	2	2	4	3	3
Kumri	Bangladesh	2	1	2	1	2	3	3
IR442-2-58 (T-check)	IRRI	2	1	2	3	2	6	5
Salumpikit (T-check)	Philippines	2	1	2	2	4	4	3
IR20 (S-check)	IRRI	2	2	2	4	2	8	7
IRAT 9 (S-check)	Ivory Coast	2	1	2	3	2	8	8

[a]Growth stage: Standard Evaluation System for Rice (SES) scale 1–9:1 = seedling stage, 9 = maturity. Drought resistance score, SES scale 1–9:1 = no to negligible effect of moisture stress; 9 = all plants apparently dead. Recovery rating, SES scale 1–9:1 = all plants fully recovered; 9 = no plants recovered.

Table 3. Summary of field scores in drought resistance of 7,835 accessions and lines at the vegetative phase, IRRI, 1978 dry season.

	Entries tested (no.)	Entries (no.) with a score[a] of								
		1	2	3	4	5	6	7	8	9
Germplasm bank accessions	5,719	44	28	199	743	2,108	2,044	595		
Dryland breeding lines from other countries	69			2	3	36	23	3		
Entries from dryland replicated yield trial of IRRI	74			1	11	40	22			
Entri[illegible]m dryland observational yield trial of IRRI	1,652		3	75	373	785	406		10	
Rain[illegible]wetland varieties and breeding lines of IRRI	183			14	28	72	71		8	
Entr[illegible]s from hybridization block of IRRI	198		4	38	52	55	7			
GEU elite lines from wetland nurseries	72				3	16	52			1
Total	7,835									

[a]1 = highly resistant, 9 = highly susceptible.

susceptible plants showed uneven heading, delayed flowering, and high spikelet sterility (15–45%), despite early showers in the 3d week of April. Some of the lines, however, quickly recovered and produced well-filled grains after the rains came in early May.

The resistant entries, on the other hand, showed little reduction in height and tiller number. Heading dates were generally the same as those in the fully irrigated fields. Several traditional rainfed wetland varieties such as Vellai Illankali from Sri Lanka and Utri Rajapan from Indonesia showed vigorous growth, few dry leaves, and low spikelet sterility (Table 4).

The check variety BPI-76 (n.s.) had an average spikelet sterility of 12%. Plant height and tiller number were slightly lower than in the fully irrigated planting. Maturity was delayed by 25 days.

Bala, B76, IET 1444, and IET 5118 generally grew vigorously even during a long drought. Mahsuri showed good grain filling and 0.5% spikelet sterility, but its plants were 15 cm shorter and its heading date occurred 23 days later than in the fully irrigated plot. Mahsuri has good drought recovery, and early rains accounted for its high spikelet fertility.

Among 100 lines from the wetland breeding nurseries, 27 showed vigorous growth, little reduction in plant height and tiller number, and spikelet sterility of not more than 10%. Among them were IR9995-82-1, IR4712-38-1-2-3, IR5677-17-3-1, and IR11418-15-2. Several entries from among GEU elite lines also showed a high level of drought resistance and good recovery ability — IR2058-78-1-3 (IR46), IR3839-1, IR3880-10, and IR5853-162-1-2.

Table 4 shows a comparison of 11 entries grown with simulated moisture stress in rainfed wetland and fully irrigated plots.

Greenhouse screening (*Agronomy*). Screen-

Table 4. Agronomic traits of selected varieties and lines grown under simulated moisture stress in rainfed wetland (RW) and in fully irrigated (FI) wetland plots, 1978 dry season.

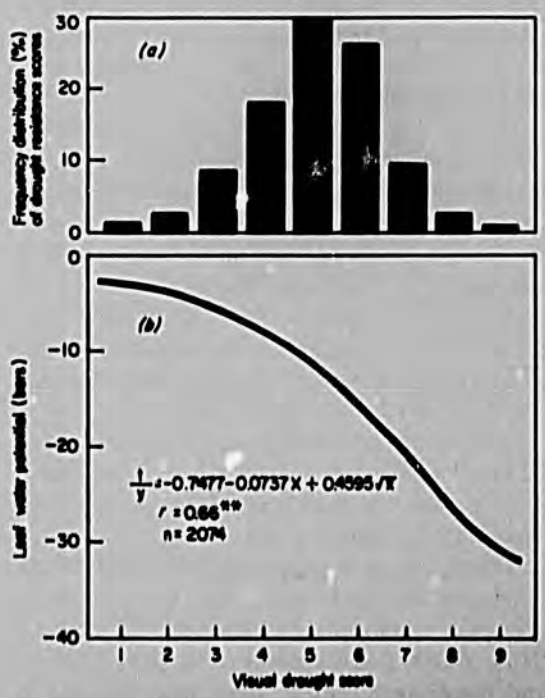
Variety or line	Origin	Plant ht (cm)		Tillers (no.)		Maturity (days)		Sterility (%)	Drought resistance* and other features
		RW	FI	RW	FI	RW	FI		
[illegible]	India	122.1	[illegible]	7	9	117	118	4.2	R
[illegible]	India	[illegible]	[illegible]	9	10	116	114	4.4	MR
[illegible]	Malaysia	[illegible]	123.4	13	12	160	147	6.5	MR-I
Uri Rajapan	Indonesia	[illegible]	[illegible]	8	13	139	149	7.1	MR
Vellai Manikal	Sri Lanka	126.4	133.6	10	12	131	126	7.8	MR and good plant type
IR[illegible]-78-1-3 (BR48)	IRRI	86.0	91.4	16	10	120	121	2.8	MR and good yield performance
IR[illegible]-136-1-3	IRRI	86.5	89.0	9	13	122	121	4.8	MR
IR[illegible]-1	IRRI	88.2	80.6	9	12	121	121	7.4	MR
IR4417-179-1-6-2	IRRI	88.2	89.6	8	11	146	136	16.14	S
IR[illegible]-136-2	IRRI	88.8	74.8	10	7	114	108	37.7	S
IR11418-15-2	IRRI	78.8	78.4	10	13	113	117	5.4	MR
BPI-76 n.a. (check)	Philippines	98.0	109.0	8	14	136	111	12.78	I

*R = resistant, MR = moderately resistant, I = intermediate, S = susceptible.

ing of rices for response to drought under simulated dryland field conditions continued throughout the 1978 wet season. Figure 1 illustrates the relationship between visual score and leaf water potential in 2,074 entries screened. Few entries showed both favorable visual score and high predawn leaf water potential. The relationship between those variables confirms that maintenance of plant water potential, a primary factor being studied at IRRI, is related to the performance of the rice plant (1977 Annual Report) as a rainfed dryland crop. The predawn leaf water potential measurement indicates a genotype's ability to rehydrate during the night, and indirectly provides information on the extent of the root system.

Most of the entries with a score of 1 or 2 in Figure 1 are from traditional, rainfed dryland areas; few are of rainfed wetland origins. Many entries with scores of 3 or 4 are hybrids whose pedigree includes the rainfed rices scored 1 or 2. Since 1976, parents such as Moroberekan, 63-83, E425, Nahng Mon S4, Nam Sagui, Pelita I, CR 94-13, and Colombia 1, have had a high frequency of progeny among the hybrids scoring 3 or 4. Many that show moderate levels of drought resistance had earlier shown good yield potential in a replicated yield trial (Table 5). Some elite entries for which information on yield potential was not available, but which had mean scores less than 4.0, were BR167-2B-3 (Bangladesh), C166-135, C22, IR5825-41-2-P2, IR3858-6 (Philippines), and TOS 2583 (Nigeria).

Dryland rice yield trial (*Agronomy*). The 1978 wet-season dryland rice yield trial was at



1. a) Frequency distribution of the visual drought resistance scores of 2,074 entries screened for drought resistance in the IRRI greenhouse. b) Relationship between visual drought score and predawn leaf water potential.

Table 5. Greenhouse drought screening scores and yields of some IURN 1977 replicated yield trial entries. IRRI, 1978.

Entry	Drought resistance score[a]	Yield (t/ha)
IR2070-414-3-6	3.2 ± 0.6	5.4
IR2071-[illegible]-2-6	3.0 ± 0.0	4.7
IR2081-64-3-2	3.5 ± 0.5	5.2
IR4617-179-1-5-2	3.0 ± 0.0	5.0
IR4422-6-2	3.2 ± 0.7	5.[illegible]
IR4432-[illegible]-5	2.7 ± 0.4	[illegible]
IR5853-118-5	2.3 ± 0.3	6.2
IR9669-165-1	3.5 ± 0.5	5.8
Pelita	3.0 ± 0.5	6.3

[a]1978 Standard Evaluation System for Rice scale: 1 = none to slight effects of drought, 9 = all plants apparently dead.

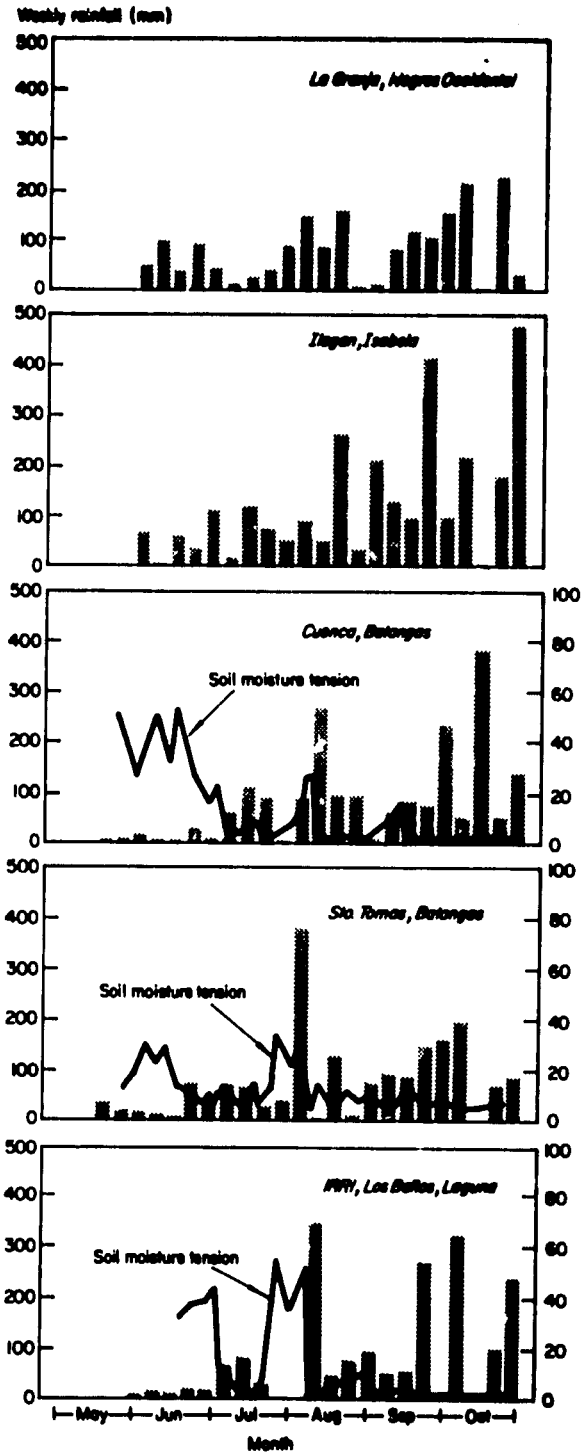
five sites: IRRI, two farmers' fields in Batangas province (Santo Tomas and Cuenca), and two Bureau of Plant Industry (BPI) experiment stations in Isabela (Ilagan) and in Negros Occidental (La Granja) provinces. There were 27 entries from the 1978 International Upland Rice Yield Nursery (IURYN), 21 from the 1977 International Upland Rice Observational Nursery (IURON), 17 from yield trials at 4 Philippines sites that included 1977 IURYN entries, and 16 from 1977 dry-season field drought screening. Two seedings about 1 month apart were made in the IRRI and Batangas trials; only 1 seeding was made at the BPI stations.

The weekly rainfall distribution and daily SMT for the test sites are plotted in Figure 2. Soil moisture was generally sufficient throughout the tests in all sites. There were short dry spells in late July at IRRI and Batangas, and in late August at La Granja. Moderate wilting and slight leaf tip drying were observed at IRRI and Santo Tomas. Typhoons in September and October caused shattering and lodging of many entries at IRRI and Santo Tomas.

Grain yield. The grain yields of 11 early- and 12 late-maturing rices selected at 5 sites, and those of M1-48 (early check) and C-22 (late check) are in Tables 6 and 7.

Among the early maturing rices IET 1444 outyielded M1-48 at most sites, but the difference was significant at only two. IR3839-1, IR36, IR2061-628-1-6-4-3, and IR8072-31-2 had significantly better yield than M1-48 at three sites.

IR9669 Sel., IR5853-118-5, and B733C-167-3-2 in the late-maturing group had sig-



2. Weekly rainfall and daily soil moisture tension in dryland rice yield tests at 5 Philippine sites, 1978 wet season.

Table 6. Grain yield of selected early-maturing rices in dryland yield tests at 5 Philippine sites, 1978 wet season.

Designation	Grain yield[a] (t/ha)						
	IRRI 31 May seeding	Santo Tomas 27 Jun seeding	Cuenca 5 May seeding	Cuenca 14 Jun seeding	Ilagan 6 Jun seeding	La Granja 31 May seeding	Mean
IET 1444	3.2*	2.6	4.0	3.8*	4.5	4.0	3.7
IR3839-1	2.8*	3.1*	3.4	3.9*	4.8	3.6	3.6
IR36	2.6*	2.3	3.4	3.7*	5.4*	3.5	3.5
IR2061-628-1-6-4-3	2.6*	3.3*	3.9	3.6*	4.4	2.9	3.5
BG 36-2	2.6*	2.6	3.4	3.4*	4.5	4.2	3.4
IR8072-31-2	2.6*	3.0*	3.8	3.4*	3.8	3.0	3.3
IET 4094	2.0	2.0	3.5	3.6*	4.2	4.5*	3.3
IR2061-522-6-9	2.3	2.6*	4.0	3.4*	3.6	3.1	3.2
IR8085-49-2	2.1	1.9	3.1	3.3*	4.7	4.3	3.2
Kn 361-1-8-6	2.8*	1.6	4.4	3.9*	2.8	3.0	3.1
IR3880-28	1.5	1.6	3.4	3.3*	4.1	4.0	3.0
M1-48 (early check)	1.5	2.0	3.6	2.5	3.7	3.5	2.8
C.V. (%)	20.3	20.1	11.0	13.6	15.3	17.3	

[a]A single asterisk (*) means grain yield significantly higher than that of M1-48 at the 5% level.

Table 7. Grain yield of selected late-maturing rices in dryland yield tests at 5 Philippine sites, 1978 wet season.

Designation	Grain yield[a] (t/ha)						
	IRRI 31 May seeding	Santo Tomas 27 June seeding	Cuenca 5 May seeding	Cuenca 15 June seeding	Ilagen 6 June seeding	La Granja 31 May seeding	Mean
IR9669 Sel.	2.6*	2.1	4.6	3.8*	5.2*	3.4	3.6
IR5853-118-5	2.0	3.0*	4.5	3.9*	4.8*	2.9	3.5
IR9575 Sel.	2.0	2.0	3.6	3.1	4.5*	4.9*	3.4
Gama 318	2.1	2.0	4.5	4.0*	3.6	4.2	3.4
IR1529-430-3	2.2	1.8	4.1	3.8*	5.5*	2.2[b]	3.3
B733C-167-3-2	3.5*	2.3*	4.5	3.5*	2.9	2.6	3.2
IR3880-10	2.1	2.0	4.0	3.4*	4.0	3.8	3.2
IR5643-128-1	1.6	2.1	4.5	3.5*	4.4*	2.8	3.2
IET 1785	2.3	1.5	4.1	3.8*	4.9*	2.4[b]	3.2
IR5853-213-1-1	1.7	1.8	4.4	3.4*	4.4*	2.7	3.1
BG 376-1	2.2	2.2	3.6	3.4*	4.4*	2.6	3.1
C46-15/IR24[b]	1.5	1.7	4.0	3.7*	4.5*	3.2	3.1
C22 (late check)	1.9	1.5	4.0	2.5	3.2	3.7	2.8
C.V. (%)	20.3	20.1	11.0	13.6	15.3	17.3	

[a]A single asterisk (*) means grain yield significantly higher than that of C22 at 5% level. [b]Grain yield significantly lower than that of C22 at 5% level.

nificantly better yield than the check C22 at three sites.

Other agronomic characteristics. The growth duration of the early group ranged from 107 to 117 days (Table 8). The shortest entry was IR36 and the tallest Kn 361-1-8-6. The latter, the only entry that lodged at maturity, was one of three (including IR2061-628-1-6-4-3 and IET 4094) that showed slight leaf tip drying during the dry spell at Santo Tomas, Batangas.

The late-maturing entries matured in 121–131 days (Table 9). Except for IR9575 Sel., B733C-167-3-2, and IR3880-10, the late high yielding entries were semidwarfs. IR5643-128-1 and IR5853-118-5, a line reported resistant to drought at IRRI, had slight leaf tip drying during the dry spell at Santo Tomas.

Leaf blast and sheath blight infected all the listed entries (Table 8, 9). Neck blast was also prevalent but spared some entries, such as IET 1444, IR36, IR9669 Sel., and IR1529-430-3. Kn 361-1-8-6 had the least disease infection.

IR5853-118-5 was recommended for inclu-

Table 8. Mean grain yield and other agronomic characteristics of selected early-maturing rices in dryland yield tests at 5 Philippine sites, 1978 wet season.

Designation[a]	Grain yield (t/ha)	Growth duration (days)	Plant ht (cm)	Lodging[a] at maturity	Drought score[b]	Panicles (no./m²)	Important diseases[c]
IET 1444	3.7	107	98	3	2.0	324	1349
IR3839-1	3.6	112	94	1	1.0	347	123469
IR29	3.5	112	73	1	1.3	314	134679
IR2061-628-1-6-4-3	3.5	114	98	1	2.7	312	12469
BG 35-2	3.4	116	87	1	1.3	305	12349
IR8072-31-2	3.3	112	83	1	2.0	340	123469
IET 4094	3.3	117	84	1	2.7	327	123469
IR2061-622-6-9	3.2	113	94	1	2.3	294	1234689
IR9202-49-2	3.2	116	90	3	1.3	297	12349
Kn 361-1-8-4	3.1	108	127	7	2.7	238	149
IR2809-39	3.0	110	101	1	1.7	271	1234689
M1-48 (early check)	2.8	119	122	3	2.0	186	1269

[a]Standard Evaluation System for Rice (SES) (1–9): 1 = no lodging; 9 = all plants flat (av of Cuenca, Ilagan, and La Granja). [b]SES scale 1–9: 1 = no to negligible effect of moisture stress, 9 = all plants apparently dead (Santo Tomas only after 15 days of fluctuating 15–42 cb soil moisture tension). [c]1 = leaf blast, 2 = neck blast, 3 = bacterial blight, 4 = bacterial leaf streak, 5 = false smut, 6 = leaf scald, 7 = leaf smut, 8 = narrow brown leaf spot, 9 = sheath blight.

Table 9. Mean grain yield and other agronomic characteristics of selected late-maturing rices in dryland yield tests at 5 Philippine sites, 1978 wet season.

Designation	Grain yield (t/ha)	Growth duration (days)	Plant ht (cm)	Lodging[a] at maturity	Drought score[b]	Panicles (no./m²)	Important diseases[c]
IR9669 Sel.	3.6	129	95	1	1.0	277	1346679
IR5853-118-5	3.5	122	90	3	2.7	289	1234689
IR9575 Sel.	3.4	122	105	3	2.3	239	123469
Gama 318	3.4	131	99	3	1.0	297	123469
IR1529-430-3	3.3	126	95	3	1.0	252	13469
B733C-187-3-2	3.2	121	107	5	2.0	282	124679
IR2880-10	3.2	122	108	3	1.7	262	1234569
IR5843-175-1	3.2	121	87	3	2.7	283	1234679
IET 1785	3.2	124	82	1	1.7	280	12349
IR5853-213-1-1	3.1	125	79	1	2.3	322	12346789
BG 375-1	3.1	126	93	1	1.0	256	1234689
C46-15/IR24[d]	3.1	121	90	5	1.3	265	12346789
C22 (late check)	2.8	124	122	3	2.7	244	123469

[a]Standard Evaluation System for Rice (SES) scale 1–9: 1 = no lodging, 9 = all plants flat (av of Cuenca, Ilagan, and La Granja). [b]SES for rice scale 1–9: 1 = no to negligible effect of moisture stress, 9 = all plants apparently dead (Santo Tomas only after 15 days of fluctuating 15–42 cb soil moisture tension. [c]Diseases: 1 = leaf blast, 2 = neck blast, 3 = bacterial blight, 4 = bacterial leaf streak, 5 = false smut, 6 = leaf scald, 7 = leaf smut, 8 = narrow brown leaf spot, 9 = sheath blight.

sion in the 1979 IURYN. The other outstanding entries were in 1978 IURYN.

Three-year yield data. Table 10 shows the 3-year grain yield of 9 promising dryland rices and 2 Philippine check varieties. The lines were in 1976, 1977, and 1978 yield trials at different sites.

Field evaluation of dryland breeding lines (*Plant Breeding*). Eighty entries were evaluated at three sites: fertile wet fields at IRRI, a well-drained soil of low fertility at IRRI, and a farmer's field in Batangas province. The entries were divided into three groups based on their maturity in the previous crop season. Rainfall was light from June to early August, and again in mid-September; the IRRI plantings had three mild stress periods, but no pronounced stress symptoms. Despite total precipitation of 1,756 mm during the crop season, yields at the wet, fertile IRRI site did not exceed 3.3 t/ha (Fig. 3).

Most entries planted at the wet, fertile IRRI site matured 5–10 days earlier than corresponding entries in the farmer's field at Batangas, and 7–10 days earlier than those at the IRRI dry site. Among the early-maturing lines (110–115 days), IR3839-1, IR7790-18-1-2, and IET 1444 had yields of 3.2–3.3 t/ha. In the late

Table 10. Grain yield and growth duration of selected rices in dryland yield trials in various locations for 1976, 1977, and 1978 wet season.

Designation	Mean growth duration (days)	Grain yield (t/ha)			
		1976[a]	1977[b]	1978[c]	Mean
Early-maturing					
IR36	110	3.8	3.6	3.5	3.6
IR3880-1	110	3.6	3.7	3.6	3.6
IET 1444	107	3.4	3.6	3.7	3.6
IR2061-522-6-9	111	3.4	3.4	3.2	3.3
Kn 381-1-8-6	107	3.2	3.4	3.1	3.2
M1-48 (early check)	118	2.5	2.2	2.8	2.2
Late-maturing					
IR9669 Sel.	130	3.1	3.5	3.6	3.4
IR1529-430-3	126	3.3	3.6	3.3	3.4
IR8575	124	2.7	3.6	3.4	3.2
C46-15/IR24[d]	124	3.0	3.2	3.1	3.1
C22 (late check)	126	2.8	3.4	2.8	3.0

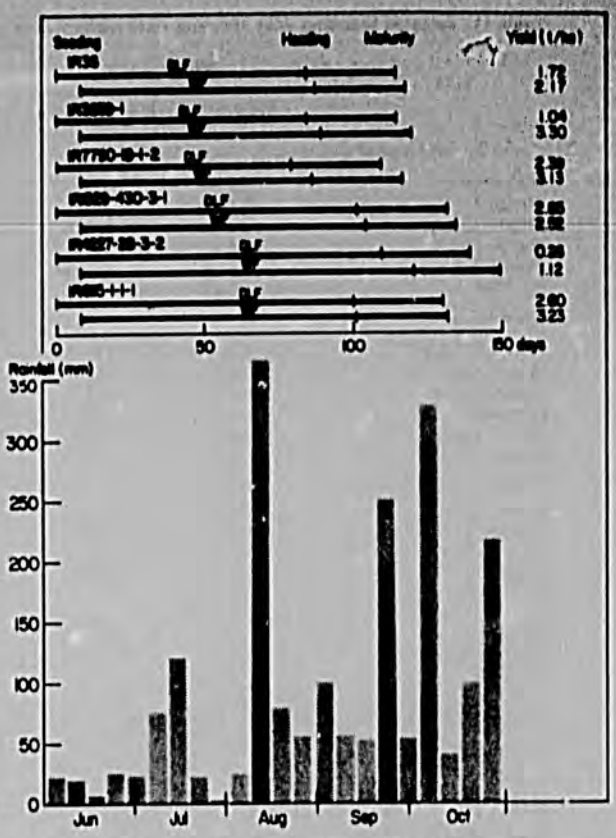
[a]Three sites (IRRI, Santo Tomas, and Cuenca). [b]Four sites (those of 1976 plus La Granja). [c]Five sites (those of 1977 plus Ilagan).

group, IR6115-1-1-1 yielded 3.2 t/ha and IR3880-17, 2.8 t/ha.

Early-maturing promising lines (selected from the dryland nurseries) IR5929-12-3 and IR7801-1-2-1 yielded 2.3–2.5 t/ha. Among the semidwarf lines, IR2061-522-6-9 yielded 2.3 t/ha and IR36 (check), 2.2 t/ha.

At the well-drained low-fertility IRRI site, the crop went through mild stress periods in the early vegetative growth and during the reproductive phase of the early and medium maturity groups. However, no pronounced stress symptoms were observed. The best performers among the early-maturing entries were IR5929-12-3 and IR5931-110-1, with 2.0–2.4 t/ha yields. Of the late-maturing group, IR9669 selection (from IR8*2/Carreon), which matured in 126 days, yielded 3.3 t/ha. IR9669 produces many tillers and has good drought recovery. Other lines, such as IR3880-10, IR3880-17, IR2035-242-1, IR1529-430-3-1, IR2043-178-1, C171-136, and IR6115-1-1-1 yielded 2.0–2.8 t/ha. The semidwarf lines IR2061-522-6-9 and IR36 yielded 1.3 and 1.7 t/ha.

The entries in a farmer's field in Batangas perfonned better than those at IRRI. The Batangas site also had mild drought stress at the early vegetative phase and again during the reproductive phase of the early-maturing



3. Rainfall distribution, growth duration, and yield performance of 6 selections grown at 2 dryland sites at IRRI, 1978 wet season. DLF = dry low-fertility site, WF = wet fertile site. site.

group. The highest yield, 4.1 t/ha, was from IR6115-1-1-1 which was harvested at 133 days after seeding. IR9669, IR2035-242-1, and IR1529-430-3 from the wetland breeding nurseries yielded 3.3–3.7 t/ha. They matured in 130–135 days. From the dryland breeding nurseries, IR7790-18-1-2 yielded 3.2 t/ha, and IR3839-1, which matured in 110–115 days, yielded 3.5 t/ha.

Table 11 shows the yield and growth duration of 21 selected lines and varieties from 3 maturity groups grown at the 3 sites. Among the promising dryland breeding lines, IR6115-1-1-1 gave the highest mean yield, 3.3 t/ha. IR6115-1-1-1, a cross between IR1529-680-3 and the African dryland variety Moroberekan, has intermediate height and moderate high tillering (40 tillers/50 cm), and matures in 130 days. Its spikelet sterility at the drier site was

Table 11. Selected breeding lines showing yield performance[a] and maturity at 3 dryland sites, IRRI, 1978 wet season.

Line	IRRI (dry site)		IRRI (wet, fertile site)		Batangas site	
	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)
Group A, early-maturing						
IR28 (check)	1.7 ab	115	2.2 b	110	2.1 bc	116
IR3839-1	1.0 b	115	3.3 a	112	3.5 a	116
IR3839-12-3	2.0 ab	116	2.3 b	116	2.5 bc	116
IR7790-18-1-2	2.4 a	110	3.1 a	109	3.2 a	112
IR7991-1-3-1	1.5 ab	112	2.5 b	112	2.0 c	117
IET 1444	1.8 ab	112	3.2 a	109	2.3 bc	113
Group B, medium-maturing						
IR3861-822-6-9	1.3 c	115	2.3 a	114	2.6 a	121
IR3946-6-3-1	1.8 abc	132	2.0 a	123	2.7 a	129
IR3946-13-2-2	1.2 c	129	2.2 a	126	2.6 a	132
IR3969-10	2.4 a	129	2.4 a	122	2.6 a	132
IR6083-118-6	1.6 abc	128	2.1 a	122	2.8 a	128
IR6831-110-1	2.2 ab	118	2.0 a	115	2.8 a	126
Group C, late-maturing						
IR1529-430-3-1	2.8 ab	131	2.5 bc	126	3.3 bc	134
IR2035-242-1	1.7 de	137	2.0 cdef	130	3.6 ab	134
IR2042-178-1	2.4 bcd	130	2.4 bcd	126	3.0 bcd	132
IR3880-17	2.0 cde	130	2.8 ab	123	2.5 de	126
IR4227-28-3-2	0.3 f	138	1.1 g	142	2.1 e	146
IR6115-1-1-1	2.6 bc	130	3.2 a	123	4.1 a	133
IR9669	3.3 a	126	2.5 bcd	127	3.7 ab	137
C22 (check)	1.5 e	132	1.6 efg	126	2.2 de	130
C171-136	2.2 bcde	131	1.8 ef	126	2.5 de	131

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

14%, and its average 100-grain weight at 3 sites was 2.5 g.

Yields of IR7790-18-1-2 (IR790-28/63-83/IR2035-290-2) at the 3 sites averaged 2.9 t/ha. The line is early maturing and has intermediate height, dark green leaves, and good seedling vigor. The average 100-grain weight was 2.3 g. Although the leaves easily roll, even when the soil is still moist, little drying of basal leaves or tips occurred during mild drought. IR6115-1-1-1 and IR7790-18-1-2 could do well at dryland sites of varying moisture regimes.

IR3839-1, which yielded an average of 2.6 t/ha at 3 sites, is early maturing, high tillering, and intermediate in height. It is better suited to rather wet fields in dryland culture. In drier fields, the line tended to have a high percentage of dried leaves near the base and some yellowing and tip drying of the younger leaves; however, it had good drought recovery.

During the 1977 wet season, IR6115-1-1-1 and IR3839-1 also performed the best at three dryland sites.

From the wetland breeding nurseries, IR9669 gave a mean yield of 3.2 t/ha at 3 sites. IR9669 is a high tillering semidwarf that matures in 130 days. It has good drought recovery. It performs well in wet soil. Other semidwarf lines such as IR1529-430-3-1 (IR43), IR2035-242-1 (IR45), and IR2042-178-1 are best suited to dryland areas where rainfall is evenly distributed throughout the crop season, or to areas with a bimodal rainfall pattern.

EVALUATION OF DROUGHT RESISTANCE IN RAINFED WETLAND CULTURE

Plant Breeding and Irrigation and Water Management Departments

Yield performance of 14 rices in 3 water regimes in Central Luzon. Evaluation of differences in drought resistance among varieties in farmers' fields continued. Varieties and breeding lines known to react differently to moisture stress were compared for yield performance under three water regimes in Central Luzon. Test sites were the same as in 1977 (1977 Annual Report); however, one site in Gapan, Nueva Ecija province, was relocated because of zinc deficiency.

Table 12. Yield performance and maturity of 14 rices grown in 3 water regimes at Gapan, Nueva Ecija, Philippines, 1979 wet season.*

Designation	Rainfed wetland (Mahipon)		Rainfed wetland (Maburak)		Partially irrigated		Fully irrigated	
	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)
IR30	3.5 ab	119	2.9 cd	119	3.1 cde	119	3.0 cd	119
IR36	3.5 ab	119	3.5 bc	119	3.0 cde	119	3.4 bc	119
IR2058-13-10	2.8 bc	130	3.1 cd	123	2.8 de	130	2.5 de	130
IR5853-118-5	3.3 b	120	3.9 ab	120	4.0 ab	130	3.7 bc	130
BPI-76 (n.a.)	2.4 cd	140	2.7 d	130	2.8 de	137	2.4 de	137
IR2058-78-1-3 2-3	4.2 a	140	4.4 a	140	4.3 a	137	5.1 a	140
IR2058-0-3-1	2.9 bc	130	3.4 bcd	130	3.6 abcd	130	3.0 cd	140
IR4432-28-5	3.1 bc	130	3.2 bcd	130	3.4 bcd	130	3.4 bc	137
Intan	2.8 bc	160	1.3 e	160	2.4 ef	160	2.3 de	160
Mahsuri	3.6 ab	146	3.4 bcd	140	3.7 abc	143	3.9 b	142
KDML'65-G1-U-45	2.8 bc	146	1.7 e	146	2.5 ef	153	2.3 de	146
IR34	3.0 bc	146	1.9 e	146	2.4 ef	146	2.5 de	146
IR2484-126-1-3	2.8 bc	146	2.9 cd	146	3.3 bcde	146	3.3 bcd	146
IR4219-36-3-3	1.9 d	146	1.2 e	160	1.7 f	160	1.8 e	160

*In any column, any two means followed by the same letter are not significantly different at the 5% level.

The fully irrigated trial was continuously flooded from transplanting until the hard-dough stage. The partially irrigated trial was allowed to sustain up to a maximum of 10 stress days before 1 irrigation. (Stress days are defined as the number of days in excess of three when there is no standing water in the field.) The rainfed trial had no irrigation. Total rainfall from transplanting to harvest was 1,939 mm. A strong typhoon on 26 October caused severe shattering and lowered the yield of some of the varieties.

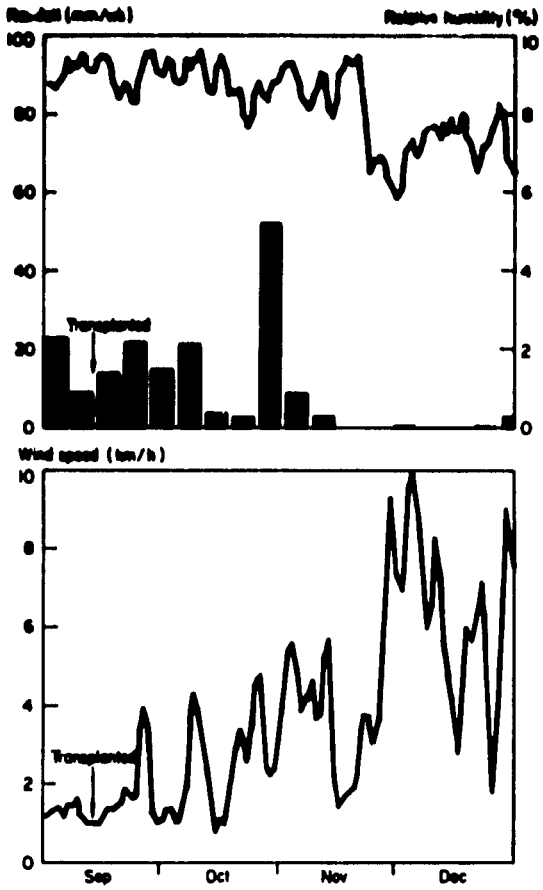
Table 12 shows the yield performance and maturity of 14 varieties and lines in 3 water regimes in Gapan. Statistical analysis shows that IR2058-78-1-3-2-3 performed significantly better than any named varieties in all treatments. This line normally matures in 130 days. The 10-day delay was attributed to delay in transplanting.

In all 3 treatments IR30 and IR36 consistently yielded an average of 3.1 and 3.3 t/ha. The yields of IR5853-118-5, a promising line reported as drought resistant in other tests, averaged 3.7 t/ha. KDML'65-G1-U-45 (RD15), a line from Thailand, did not yield well. In the Maburak rainfed site its yield was low (1.7 t/ha) because of lodging.

Only 13 lines were included in the experiment in Talavera. They were seeded 14 July and transplanted 8 August because the farmers planted late. With the decreasing day length of August, the late-maturing entries generally flowered 10 days earlier than those planted at Gapan. The October typhoon caused severe grain shattering that lowered the yields of early maturing and medium-maturity lines. The yields of the late-maturing entries were affected by lodging.

There was no pronounced plant moisture stress during the vegetative and early reproductive stages in the rainfed and partially irrigated treatments. Moisture stress started 4 November in the rainfed plots and affected the late-maturing entries at the late reproductive growth stage. The partially irrigated plots had 3- and 7-day stress periods before and after the October typhoon. Although rain totalled 4.1 mm for 4 days after the 7th stress day, there was no standing water in the field in both the rainfed and partially irrigated treatments throughout the reproductive phase of the medium- and late-maturing lines and varieties. The soil moisture content (dry basis) was 12.5% in the partially irrigated plots and 14.4% in the rainfed plots 1 week before harvest.

In the fully irrigated trial, the highest yielder was IR2058-78-1-3-2-3 with 5.1 t/ha. IR36 yielded 2.7 t/ha; Mahsuri and IR4432-28-5 each yielded 2.5 t/ha. In the partially irrigated plots, the highest yield did not exceed 2.3 t/ha. IR36, IR2058-78-1-3, IR4432-28-5, Mahsuri,



4. Weekly rainfall, 3-day moving av of mean daily wind speed, and relative humidity for evaluation of the International Rainfed Lowland Rice Observational Nursery at Guimba, Nueva Ecija province, Philippines, 1978.

and IR34 performed well with partial irrigation. They yielded between 2.1 and 2.3 t/ha.

In the rainfed trial, the typhoon affected yields. IR2058-78-1-3-2-3 and Mahsuri each yielded 2.8 t/ha. They performed well despite mild stresses at the vegetative and reproductive stages, during which the plots went through an intermittent period of moisture status between standing water and slightly below saturation. The other lines yielded 2.0 t/ha while the check variety BPI-78 yielded only 1.6 t/ha.

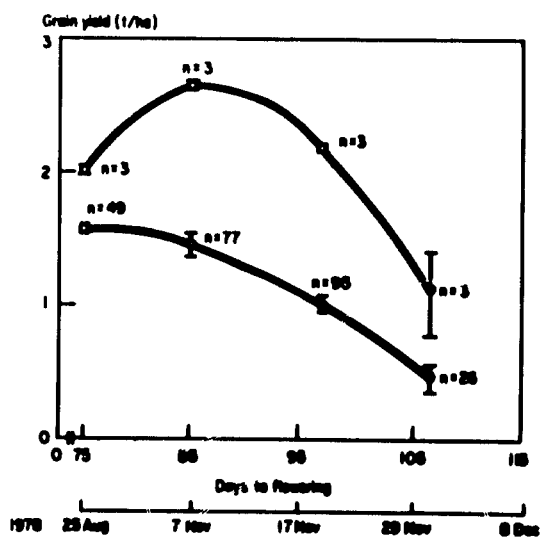
The 1978 results confirmed 1977 findings that varieties with higher drought resistance rating such as Mahsuri, are better suited to rainfed wetland areas where mild to prolonged drought periodically occurs. IR2058-78-1-3-2-3 also performed well in a 1978 dry-season, rainfed, wetland drought test (Table 4).

DROUGHT RESPONSE OF INTERNATIONAL RAINFED LOWLAND RICE OBSERVATIONAL NURSERY AT REPRODUCTIVE STAGE

Agronomy Department

The 261 entries of the International Rainfed Lowland Rice Observational Nursery (IRLRON) were planted in a farmer's field at Guimba, Nueva Ecija province. To simulate early withdrawal at the monsoon, the nursery was planted late (24 August).

Figure 4 illustrates the dramatic change in daily weather at the end of October. The lack of rain was accompanied by decreased relative humidity and increased wind speed. Those atmospheric events produced high evaporative demand and depletion of available soil moisture during the reproductive stage of many entries. Figure 5 illustrates the relationship between yield and maturity in the 247 entries. The mean of entries in each flowering period decreased steadily with time and continued dry weather.



5. Relationship between days to flowering and yield of the International Rainfed Lowland Rice Observational Nursery plots at Guimba, Nueva Ecija province, Philippines, 1978. The curves represent the mean of all entries and the 3 highest yielding in each maturity group.

The very early-maturing entries (≤75 days to flowering) illustrate the preference for this type of adaptation in rainfed rice. The other curve in Figure 5, however, shows that some entries (mean of highest three per flowering period) performed better than those in the earliest group and thus may represent drought-induced adaptations to rainfed wetland culture other than early maturity.

On 8 and 14 December, the entries' visual scores for drought response showed striking differences. Measurements of leaf water potential (both dawn and midday) agreed well with the visual scoring results. However, some entries with good visual score and relatively high leaf water potential, such as Pelita I-1, showed drying of panicles or the development of *whiteheads*, which were fully sterile in the severe case. The whiteheads are symptomatically similar to stem borer damage. There was some stem borer damage, but examination of the panicles showed that water stress caused most of the symptoms.

Some entries, such as Dinalaga and Palawan with the same relative level of dawn and midday leaf water potential, showed no development of sterile panicles. It appears that at the reproductive stages, there are some genotypic differences in drought response, especially panicle emergence, anthesis, and grain enlargement.

CLASSIFYING RAINFED RICE REGIONS

Agronomy Department

An initial step toward classification of rainfed rice environments on a regional scale was made with Thornthwaite's moisture index (I_m). I_m attempts to account for moisture surplus or deficit by predicting potential evapotranspiration and using the date to calculate the water balance by month. Although superior methods for predicting evapotranspiration are available, input data for many rainfed rice areas are not readily available for use. The data used here were from Thornthwaite's *Average Climatic Water Balance Data of the Continents* and include only the rice-growing months. Thirty-two sites where the 1976 IURON was grown were used as example. Figure 6 shows how the I_m values for the sites form a continuum of dry to wet sites and thus represent different levels of *water adequacy* for *rainfed* sites. Limited information about the rice crop's performance was available from the IURON records, but at all sites mean plant height, an indication of crop water adequacy, was positively correlated with I_m.

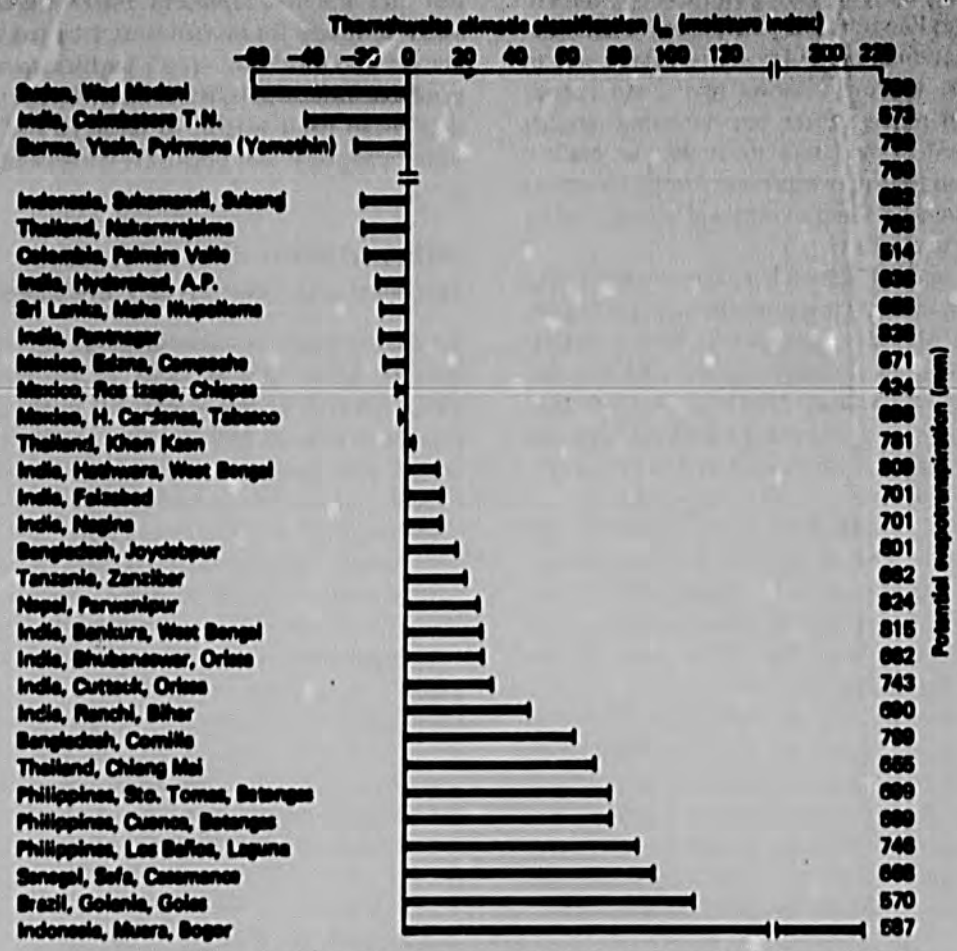
INTERNATIONAL COLLABORATION

Agronomy and Plant Breeding Departments

To aid scientists in national programs and to increase knowledge at IRRI of the requirements for crop improvement in drought-prone rainfed rice areas, collaborative research with scientists in strategic locations was increased. Figure 7 shows the locations of collaborative research projects in South and Southeast Asia. Less formal exchange of germplasm and observations with scientists in Brazil, Nigeria, and Ivory Coast also continued during the year.

Comparative evaluation of elite germplasm in rainfed wetland culture *(Plant Breeding). IRRI-Thailand.* Collaborative trials in northeast Thailand were at Khon Kaen and Chum Phae. Because of a flash flood during the early growth stage at Khon Kaen, only the Chum Phae trial produced obvious contrasts among varieties during the 1977 wet season. The trial had 40 varieties and lines from IRRI, Indonesia, India, Philippines, and Thailand that were known to react differently to moisture stress. A short drought occurred in late September and a prolonged drought lasted through most of October, when the early-maturing lines were starting to head and the late-maturing lines were at panicle initiation stage.

The 10 best entries at Chum Phae were KDML'65-G1-U-45 (RD15), BKN 6721-5-7-4 (RD8), KDML 105, IR3464-126-1-3, BKN6721-13-5-3, KDML'65-G2-U-68-254 (RD6), BKN6801-5-1, IR3646-9-2-1, IR1529-430-3, and BPI-76. The yields ranged from 2.3 t/ha (BPI-76 n.s.) to 3.2 t/ha (KDML'65-G1-U-45). There was no significant difference among the means of the 10 entries. The popular variety Nam Sagui 19 yielded 2.2 t/ha and the blast-resistant Mahsuri 2.1 t/ha. Their yields did not differ significantly from those of the top 10 entries, however. On the



6. Climatic classification of 32 sites where International Upland Rice Observational Nursery 1976 was grown. All values are for rice-growing months only. Calculations adapted from C. W. Thornthwaite Associates, Average climatic water balance data of the continents, 1963. Publications in Climatology, Vol. 16, no. 1, Centerto, New Jersey.

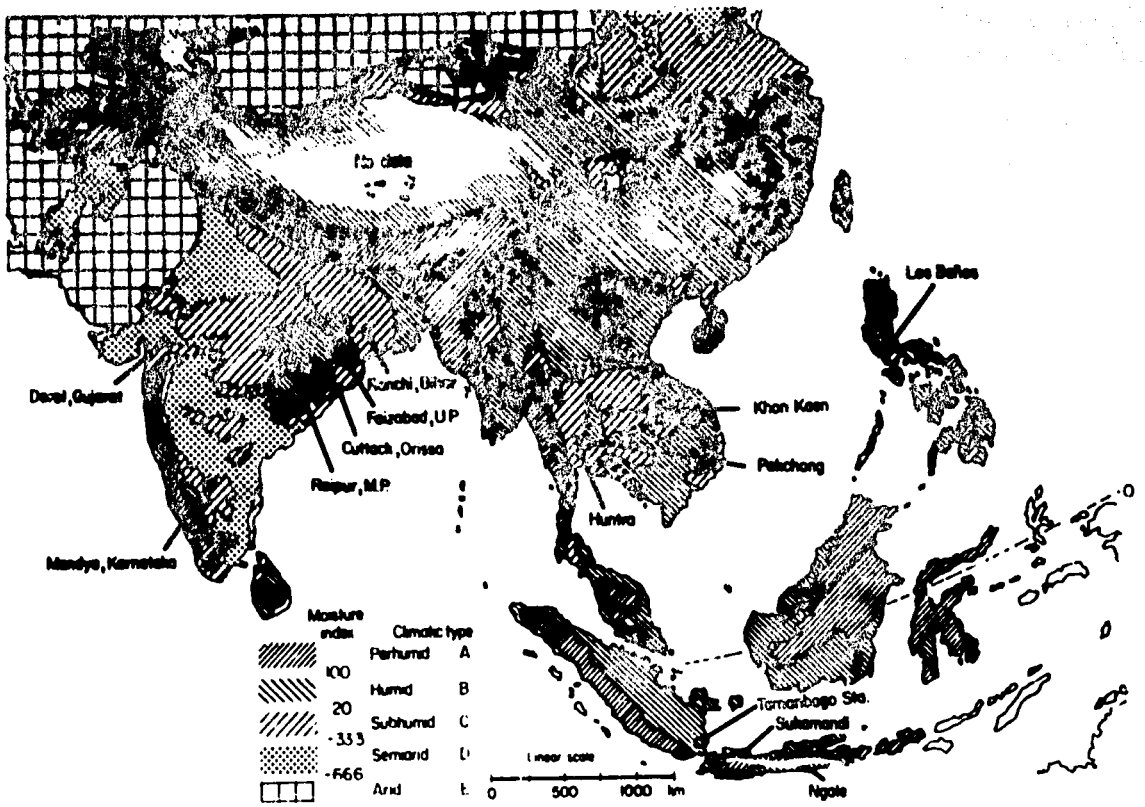
other hand, IR30 yielded 1.5 t/ha; IR36, 1.8 t/ha; and Intan, a check variety from Indonesia, 1.8 t/ha. The drought-susceptible IR4227-28-3-2 yielded only 1.0 t/ha.

In general, the yields correlated with the varying degrees of drought resistance in the different varieties tested earlier at IRRI.

IRRI-Indonesia. Eighteen varieties and two checks (Intan and BPI-76) with different reactions to moisture stress were included in a collaborative trial on drought resistance in rainfed wetland culture at Ngale, East Java, Indonesia. The crop was sown in January. Drought periods occurred during the vegetative stage in early March, in late March through early April, and again in late May, when the medium-maturity group was ripening and the late-maturing group was heading. The early-maturity group received little rain at heading time.

In late May uneven heading in IR4219-35-3-3 and aborted spikelets on Bengawan and Syntha indicated susceptibility to drought at an earlier period. The growth of IR36 and BPI-76 appeared poorer than in rainfed wetland culture at Los Baños or in Central Luzon, Philippines.

Of the 20 varieties and lines, the late-maturing IRRI lines, such as IR3464-75-1-1 and IR4219-35-3, recovered after the rains came during grain ripening, and yielded 2.0 t/ha. Mahsuri yielded 1.8 t/ha; C168, 1.7 t/ha;



7. Location of current (●) and proposed (○) collaborative research projects in Asia for improvement of the rice crop's capability to cope with drought. Map adapted from D. B. Carter and J. R. Mather. 1966. Climatic classification for environmental biology. Publications in Climatology, Vol. 19, no. 4. C. W. Thornthwaite Associates, Laboratory of climatology, New Jersey.

and IR3646-9-3-1, 1.6 t/ha. The Indonesian varieties Syntha and Remaja, which had aborted spikelets, yielded only 0.9 t/ha.

The yields in the fully irrigated plots at Ngale were generally low. Mahsuri had the highest yield of 2.4 t/ha; Syntha, 1.2 t/ha; and Bengawan, 1.4 t/ha.

The 20 entries were rated on the basis of tillering, uniformity in heading, panicle fertility, and difference in maturity in 2 treatments, and grouped into 3 classes according to their performance in the rainfed treatment:

- Good — IR3646-9-3-1, Mahsuri, Sigadis, Dewi Ratih, and IR34 (but infected with *Helminthosporium* and lightly with neck blast).
- Fair — IR480-5-9-3, IR3464-75-1-1, IR3464-126-1-3, IR4219-35-3-3, C168, Intan, Remaja, Jelita, and Nam Sagui 19.
- Poor — IR30, IR36, Bengawan, Syntha, IR3839-1, and BPI-76 (both infected with neck blast).

The significant difference in agronomic performance between varieties in the Philippines and in Ngale appeared related more to soil properties than to drought response. The collaborators at the Ngale Station will continue the experiment in 1978–79.

During the year scientists in four drought-prone states of India were contacted, and a drought nursery suitable to the problems of the specific area was planned.

Basic research on plant response to water deficit was also conducted collaboratively with scientists in developed countries. Scientists at Cornell University contributed to knowledge of how the rice plant osmotically adjusts or adapts to internal water stress. Contacts with scientists in the USA, Germany, England, and Australia

provided aid where specialized research facilities or techniques were required.

VERTICAL ROOT DISTRIBUTION

Plant Physiology Department

Crop species in dryland fields. Vertical root distributions of two rice varieties (wetland IR36 and dryland OS4) and four dryland crops were examined through core-sampling (1977 Annual Report). Plant spacing was 25 × 5 cm for IR36, 30 × 5 cm for OS4, 25 × 5 cm for wheat, 30 × 5 cm for soybean, 60 × 10 cm for sorghum, and 75 × 25 cm for corn. All the crops were sampled at flowering time, except OS4, which was sampled at the panicle differentiation stage.

Figure 8 shows vertical root distribution of the six crops. The four dryland crops and OS4 had similar root distribution patterns. Although IR36 had much shallower roots than the 5 other crops, it had only a negligible amount below the 50-cm depth. Figure 9 shows the root distribution in the soil. The rice varieties had much higher root density than the other crops. IR36's root density reached 30 cm/cm³ near the soil surface.

IR20 and OS4 at different growth stages. The vertical root distributions of IR20 and the dryland variety OS4 were analyzed at different growth stages from sowing to harvest in a dryland field. In IR20, heading occurred at about 90 days after seeding (DS); in OS4, at 79 DS. Figure 10 shows the distribution of root length at different soil depths on different DS. About 50% of the IR20 roots and 30% of OS4 roots were in the 5-cm deep layer below the soil surface.

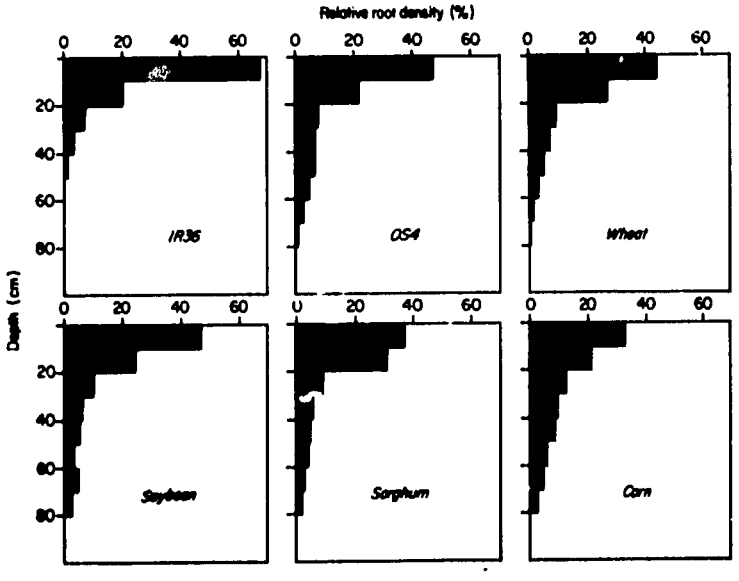
The trials suffered from a dry spell between 48 and 58 DS—at about the panicle differentiation stage. Throughout its growth IR20 did not change much in root distribution, even after the dry spell. On the other hand, the root length of OS4 decreased in the upper layers of soil and increased in the lower after the dry spell (Fig. 10).

Figure 11 shows root density at different soil depths before and after the dry spell. The root density of IR20 decreased at all depths, but that of OS4 increased with depth. This fact may be a reason for the drought tolerance of OS4.

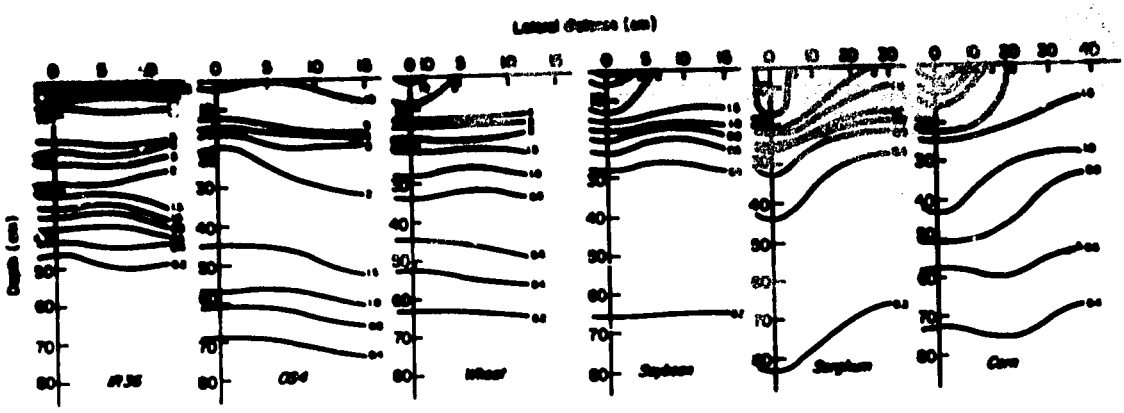
SOIL-PLANT-WATER RELATIONSHIPS IN RICE

Agronomy Department

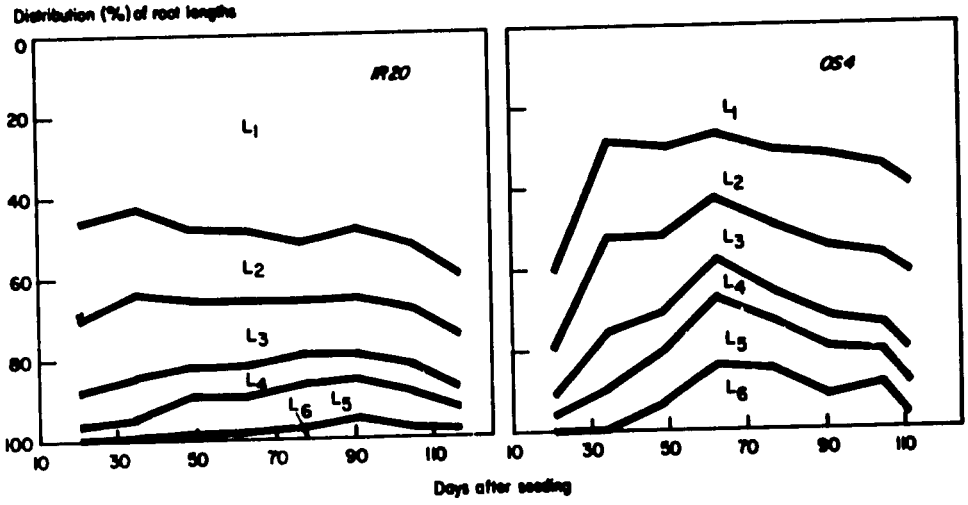
Drought tolerance under limited rooting depth. A methodology for screening rices for drought tolerance at shallow rooting depth (40 cm), use of which was begun in 1975, was slightly modified in the 1978 wet-season tests.



8. Vertical root distribution (%) of 2 rices and 4 dryland crops. IRRI, 1978 dry season.



9. Vertical root distribution of different crop species. Number at end of each curve is root density (cm/cm³). IRRI, 1978 dry season.

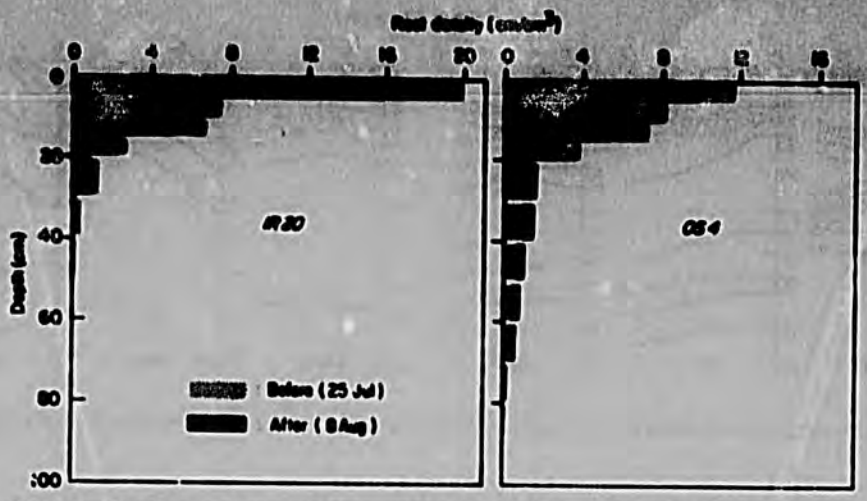


10. Percentage distributions of root lengths in different soil layers for IR20 and OS4. Depths (cm): L_1:0–5; L_2:5–10; L_3:10–15; L_4:15–20; L_5:20–40; L_6:40–90. IRRI, 1978.

A total of 105 entries (82 GEU elite lines and 23 selected varieties and lines) were evaluated for drought tolerance and the ability to recover from stress. Three entries, including the susceptible check Moroberekan, were planted in a steel drum. The drum was irrigated regularly with equal amounts of water until seedling establishment. After that the soil was allowed to dry naturally. When Moroberekan was apparently dead from moisture stress, the entries in the drum were scored for drought tolerance, the soil was sampled for moisture content, and the plants were rewatered. The recovery ability of rice was noted 2 weeks later.

The entries with relatively good recovery are listed in Table 13. Their relatively lower drought scores, compared with that of Moroberekan, indicate good drought tolerance. Based on a desorption curve, the average soil moisture tension just before rewatering was 25 bars.

The recovery from drought of IR3518-96-2-2-2 was outstanding. The deepwater rice line IR5825-44-3-P_1 also appeared promising. Lab



11. Vertical distribution of roots of IR20 and OS4 before (25 Jul) and after (8 Aug) a dry spell. IRRI, 1978.

Mue Nahng and Nam Sagui, which are parents of some promising lines, proved drought tolerant. They had performed well in previous tests.

Response of rice leaves to water stress. Stomatal closure is a commonly noted response to internal water deficits in crop species. It was measured in 2 rice varieties grown in 1-m-deep aerobic soil in the greenhouse. The soil was watered well before the water stress treatment. The degree of leaf rolling was also observed.

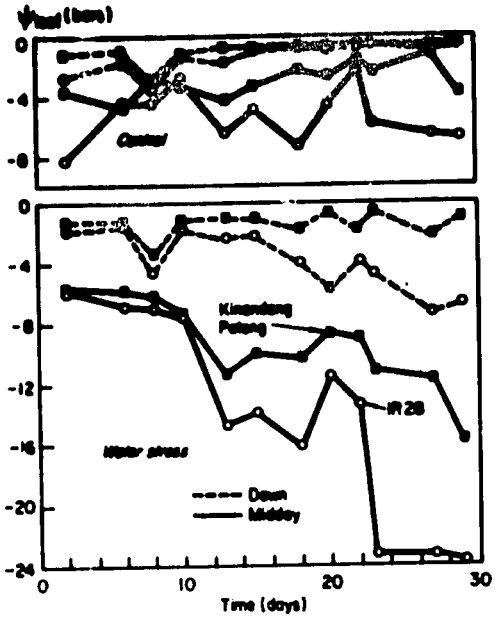
Table 12. Comparative drought tolerance ratings at vegetative stage of promising IRRI elite lines and some selected entries and their drought recovery scores after relief of stress. IRRI greenhouse, 1978 wet season.

Entry	Mean drought tolerance rating[a]	Mean drought recovery[b]
IR2518-86-2-2-2	7.5	3.5
IR6209-26-2	7.0	4.5
IR6209-262-3-6	7.5	4.5
IR7846-27-3-2	7.0	4.5
IR1529-430-3	7.5	5.0
IR2061-522-6-9	7.5	5.0
IR2035-13-7	7.5	5.0
IR4570-117-2-1-2	7.5	5.0
IR5960-181-3	7.5	5.0
IR5761-76-3	7.5	5.0
IR5769-19-2	7.5	5.0
IR5526-44-3-P_1	7.5	5.0
IR2369-P_{sr}-100	7.0	5.5
IR442-2-58	7.5	6.0
IR5553-119-5	8.0	5.5
C22-61	7.0	5.5
Lab Mue Nahng 111	7.5	4.0
Cauvery	7.5	4.5
Nam Sagui	7.5	5.0
Moroberekan	8.0	9.0

[a]1976 Standard Evaluation System for Rice (SES) scale 1–9: 1 = none to slight effects of stress, 9 = all plants apparently dead. [b]SES scale 1–9: 1 = 90%, 5 = 40 to 50%, 9 = no plants fully recovered.

Figure 12 illustrates the response of leaf water potential at dawn and midday for the 30 days after water was withheld. It is apparent that unlike IR28, the dryland-adapted variety Kinandang Patong did not experience a severe midday internal water deficit and recovered higher dawn leaf water potentials throughout the experiment. Its maintenance of relatively high leaf water potential indirectly indicates better absorption of soil moisture to meet evaporative demands or, alternatively, increased resistance to water diffusion from the leaves. Figure 13, however, shows that Kinandang Patong had a lower whole-leaf resistance to water loss, indicating that its root system is superior to that of IR28.

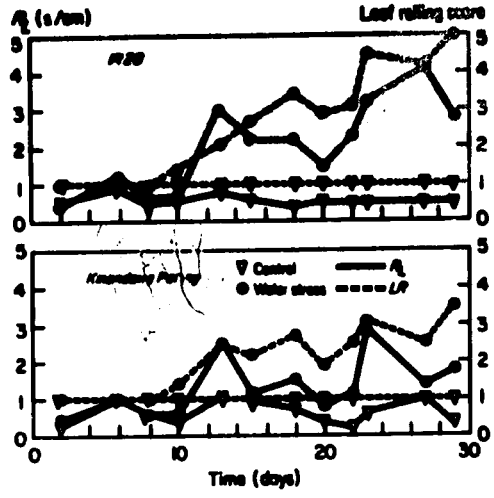
Figure 13 also illustrates how rice leaves roll in response to decreased leaf water potential. Stomatal closure and leaf rolling values both departed from those of control leaves at about the same time in the drying period (≈10 to 12 days) and at relatively high leaf water potentials (−9 to −10 bars). IR28 leaves reached low water potentials (−24 bars midday, −7 bars dawn) and still maintained relatively low whole-leaf diffusion resistance. Thus, the rice leaf stomata either were capable of adjusting to the decreasing water status or were less sensi-



12. Response of midday leaf water potential (ψ_{leaf}) of Kinandang Patong (rainfed dryland Philippine variety) and IR28 (irrigated wetland hybrid) to increased water deficit for 30 days after water was withheld. The crops were grown in large tanks with 1-m-deep soil in the IRRI greenhouse, 1977.

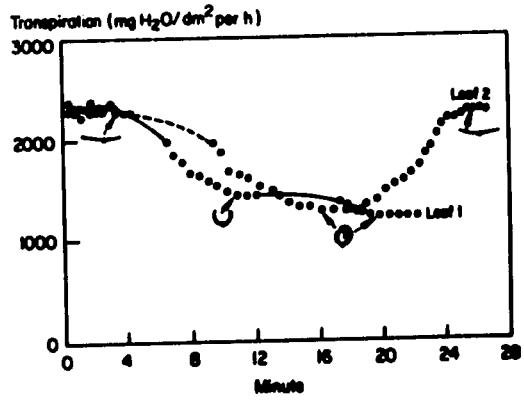
tive to leaf water deficits than the stomata of other cereals. Because stomatal closure and leaf rolling occurred simultaneously over a wide range of water potentials, it was not possible to evaluate their effects separately. However, leaf rolling decreases the radiant energy intercepted by the canopy and u. doubtedly increases the leaf boundary layer resistance, both of which may result in less water loss.

Leaf rolling and transpiration. The preceding experiment led to another in which the effect of leaf rolling or water loss from the rice leaf was investigated. Transpiration from single excised leaves mounted on a water source was measured at varying degrees of artificial leaf rolling. Figure 14 illustrates a typical response and shows the potential value of leaf rolling in decreasing water loss from rice leaves. It also shows how quickly leaf water loss responded to a change in leaf rolling. Changes in leaf rolling have been observed diurnally in dryland-adapted rices and the characteristic has become a component of the visual scoring system.

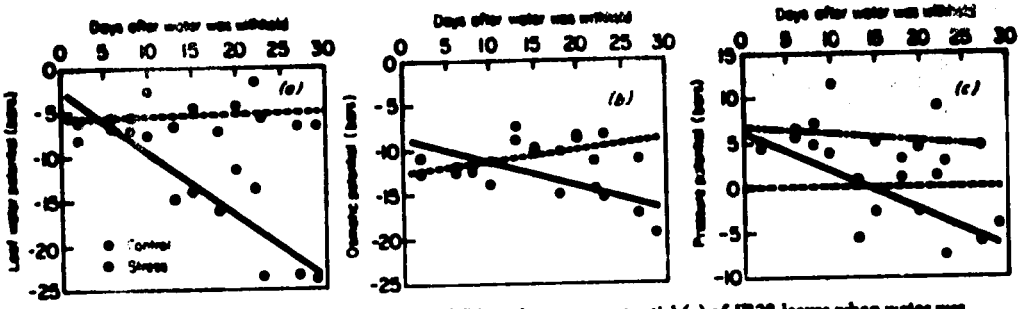


13. Response of whole-leaf diffusive resistance (R_L) and degree of leaf rolling (LR) in Kinandang Patong (rainfed dryland Philippine variety) and IR28 (irrigated wetland hybrid) to increased water deficit for 30 days after water was withheld. The crops were grown in large tanks with 1-m-deep soil in an IRRI greenhouse, 1977.

Components of water potential in water-stressed rice. Earlier research has shown that maintenance of relatively high water potential correlates well with evaluations of drought resistance in rice. The component adaptations involved in the rice plant's maintenance of high water potential have also been investigated. Being currently studied are the adaptive mechanisms present in the germplasm that may aid in the continuation of yield-determining



14. Response of leaf transpiration rate to artificial rolling of rice leaves. Dotted lines represent time required to change leaf shape. Leaf shapes are indicated under the curves. IRRI, 1978.



15. The leaf water potential (a), osmotic potential (b), and pressure potential (c) of IR28 leaves when water was withheld for 30 days. IRRI greenhouse, 1977 wet season.

physiological processes in the event that the plant no longer can maintain high water potential.

The principal components of plant water potential are pressure, or turgor potential, and osmotic potential. When osmotic potential is lower (becomes more negative), the tissue may maintain positive turgor or pressure potential at lower water potentials. This adaptation is referred to as maintenance of turgor or pressure potential by osmotic regulation.

Figure 15 illustrates the decline in total water potential of IR28 leaves and the corresponding decline in osmotic potential. The difference in leaf water potential and osmotic potential is an estimate of pressure potential (Fig. 15c). The data illustrate the decrease in osmotic potential in water-stressed rice compared with that in control leaves. The decrease of 5 to 7 bars was partially a function of concentration changes; thus further investigation of the mechanism is necessary to substantiate osmotic regulation and evaluate its significance as a drought resistance mechanism.

Water transport in rice plants. A primary objective of soil-plant-water relationship research has been to understand the behavior of water transport from soil through the plant into the atmosphere. An analogue of Ohm's law has been used to relate water potential in leaf (Ψ_{leaf}) and soil (Ψ_{soil}) to transpirational flux (q):

$$q = \frac{\Psi_{soil} - \Psi_{leaf}}{R_{soil} + R_{plant}} \qquad (1)$$

where R_{soil} and R_{plant} are resistances to water flow in soil and plant. R_{soil} and R_{plant} are conceived as dominantly liquid phase resistances, and R_{plant}, therefore, does not include stomatal resistance. In water transport models, both resistances have commonly been considered together because researchers have difficulty separating them. But flooded-soil rice culture offers a unique opportunity for studying the nature and extent of R_{plant} alone because R_{soil} and Ψ_{soil} can be considered as near zero. Thus, the liquid-phase resistance of the rice plant can be evaluated using the relationship:

$$R_{plant} = \frac{\Psi_{leaf}}{q} \qquad (2)$$

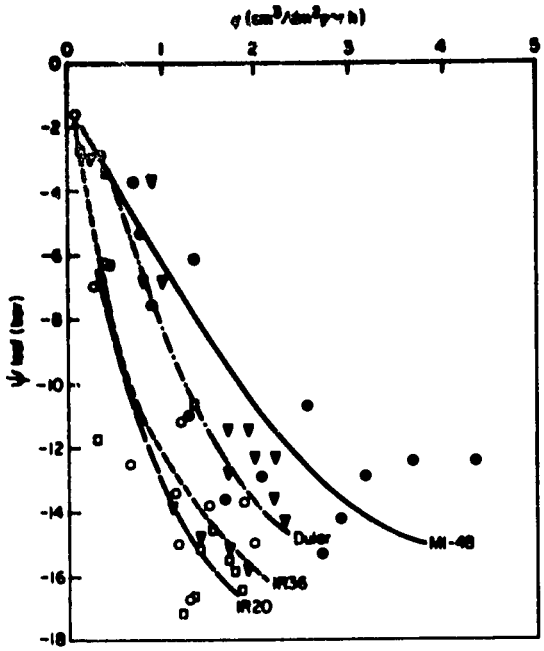
Resistance to water flux of the whole rice plant (R_{plant}) was calculated using values of transpirational flux of the whole plant (q, cm³/hour) and Ψ_{leaf} during that period. Values of R_{plant}, averaged over an active transpiration period (1200–1700 hours), are given in Table 14.

R_{plant} was higher in IR20. But the differences among other varieties were small, presumably because of the large variation in leaf area (Table 14).

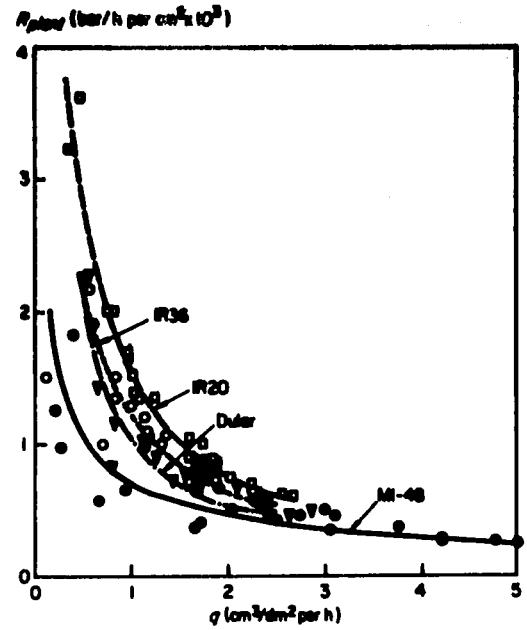
The relation between leaf water potential and transpiration rate (q, cm³/dm² per hour) is shown in Figure 16. Transpiration rate, in general, increased with the decrease in leaf water

Table 14. Resistance to water flow in rice plants (R_{plant}). IRRI, 1978.

Variety	Leaf area (cm²/plant)	R_{plant} (bars/h per cm³ × 10^{-5})
IR20	1934	58.1
Dular	1668	40.8
M1-48	1094	36.5
IR36	2712	32.6



16. Relationship between leaf water potential (ψ_{leaf}) and transpirational flux (q). IRRI, 1978.

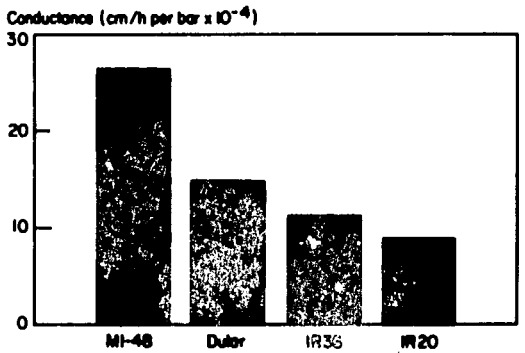


17. Relation between resistance to water flow (R_{plant}) and transpirational flux (q). IRRI, 1978.

potential for all varieties. One interesting observation was that the transpiration rate at any given leaf water potential was highest for M1-48, next highest for Dular and IR36, and lowest for IR20.

To clarify the nature and extent of resistance to water flow in different varieties, values of Ψ_{leaf} and q from Figure 16 were used to calculate plant resistance to water flow (R^1_{plant}, bars·hour per centimeter) using equation 2. The relation between R^1_{plant}, and q is given in Figure 17. IR20 maintained higher resistance to water flow at all transpiration rates, whereas M1-48 maintained the lowest resistance. In general, R^1_{plant} decreased with increasing transpiration rate and remained low in all varieties during periods of high transpiration rate. Differences in R^1_{plant} among all varieties were quite large, up to about 2 cm³/dm² per hour transpiration rate.

Figure 17 indicates that varieties differ in their water transport behavior. Because the R^1_{plant} values remain low during an active transpiration period, plant conductance to liquid-phase water flow was calculated for the period from 1200–1700 hours during the day. Average values of conductance over this period are presented in Figure 18. The conductance of M1-48 was three times that of IR20. The next highest conductance was that of Dular, followed by that of IR36. M1-48 is a Philippine dryland variety, Dular is a dual variety (dryland or wetland) from West Bengal, India, and IR36 and IR20 were bred and selected for irrigated wetland culture at IRRI. Higher plant conductance of water may be an adaptation associated with rainfed varieties as was the more extensive root system mentioned previously.



18. Liquid-phase conductance of rice varieties. IRRI, 1978.

Genetic evaluation and utilization (GEU) program

Adverse soils tolerance

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SCREENING

Soil Chemistry Department

Table 1 summarizes the 1978 results of screening for adverse-soils tolerance. Unless another scoring system is indicated, the scores cited are on a scale of 1 = almost normal plant, and 9 = almost all plants dying.

Salt tolerance. Of the 11,806 rices screened in the greenhouse in 1978, 1,386 scored as salt tolerant (Table 1). The latter included 978 from the salt tolerance hybridization program. Six Indonesian varieties, IR1529-677-2, and IR1820-210-2 were more salt tolerant than Pokkali. Six IR4573 lines, 11 IR4595 lines, 38 IR4630 lines, and 16 IR4763 lines equaled Pokkali in salt tolerance.

Among 1,460 progenies from the salt tolerance breeding program and other sources field tested, 113 were more salt tolerant than the tolerant check IR4630-22-2. Thirteen of the 33 cultures found salt tolerant in the greenhouse gave mean scores of <3.5.

A test of the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) at IRRI revealed salt tolerance in IR2058-78-1, IR4763-141-2-3, and 12 Indian cultures (CSSR 1, 2, and 3; Damodar, Nona Bokra, Nonasail, Getu; Cultures No. 29, 73, and 102; and Getu mutants 2735 and 2585).

Alkali tolerance. Among 1,433 rices screened for alkali tolerance in the greenhouse, the following scored 3 or less and were rated as tolerant: 15 Indian varieties, 4 Sri Lankan varieties, 1 Egyptian variety, IR2307-247-2, IR3941-97-1, IR4227-28-3, IR4417-179-1, IR4422-98-7, 20 IR4630-22 lines, 6 IR4763-141 lines, and IR5853-110-5.

Table 1. Summary of mass screening for adverse-soils tolerance. IRRI, 1978.

Soil problem	Rices (no.)	
	Screened	Tolerant
Salinity	11,806	1,386
Alkalinity	2,391	61
Iron toxicity	1,416	121
Peat soil problems	201	37
Phosphorus deficiency	1,382	87
Zinc deficiency	4,207	978
Total	21,403	2,670

In field screening of 950 lines from the alkali tolerance breeding program, 36 had scores of 3 or lower. Outstanding among them were IR8241-B-B-56, IR8241-B-B-71, IR8241-B-B-121, IR8236-B-B-357, and IR9232-213-B.

Forty lines found alkali tolerant in the greenhouse or in the field were grown in a replicated yield trial in an artificial alkali field at IRRI. A typhoon damaged the experiment, but IR8241-B-B-56 and IR8236-B-B-357, which scored 2.7 and 2.5 at 4 weeks after transplanting, gave the highest yield (2.3 and 1.9 t/ha). The resistant check Pokkali scored 6.5 and produced no grain.

In the IRSATON at IRRI eight overseas varieties, three IR2058 lines, IR2070-464-1, and IR4763-141-2 were alkali tolerant. Five of the overseas varieties and IR4763-141-2 were previously rated alkali tolerant in greenhouse tests.

Iron-toxicity tolerance. Greenhouse tests revealed that 56 of 371 rices screened had tolerance for iron toxicity. Of 400 rices mass screened in an iron-toxic field in the Philippines, 31 scored as tolerant. Among them were Mahsuri, Monkora, 4 IR2070 lines, 4 IR2071 lines, and 11 IR4630-22-2 lines. A similar screening of 245 rices in Sri Lanka showed that IR480-5-9-3, 6 IR2070 lines, 10 IR2071 lines, and 10 other IR lines were tolerant.

Peat-soil tolerance. Of 200 rices tested on peat soils (pH 5.5–5.8; O.M.: 32–50%) at 3 sites in the Philippines, 37 had scores of 2 or lower. The tolerant ones included three from the peat-soil areas of Indonesia. Of the 15 IR varieties in the test, IR20, IR32, and IR42 each had a mean score of 3.0 compared with IR8's 5.7.

Phosphorus-deficiency tolerance. In a greenhouse solution culture test of 672 rices, 42 had scores of 3 or lower. Among them were IR20, IR26, IR29, IR34, three IR3464 lines, three IR3880 lines, and three IR4427 lines.

Field scoring on a phosphorus-deficient soil in the Philippines revealed outstanding tolerance in 10 elite lines from the general breeding program: IR3464-8-1, IR3941-25-1, IR4422-46-3, IR4568-5-2, IR4613-54-5, IR4816-70-1, IR5254-3-5, IR5894-73-3, 75-5135, and 75-5072. In a similar test in Sri Lanka 53 out of 379

rices had scores of 3 or lower. The tolerant cultures included 6 IR2070 lines and 10 IR2071 lines. Outstanding among them were three IR2071-588-3 lines.

Zinc-deficiency tolerance. Of the 6,000 cultures screened in 1975–78 on a zinc-deficient soil, 374 scored 1. The best among the 2,476 cultures screened in 1978 were 2 Indian varieties (Batia Sira and Kamba), 3 Bangladesh varieties (Ctg-1122, DR-25, and DM22), and IR8192-31-2, IR9201-91-1, IR9209-259-2, and IR9805-99-2.

BREEDING

Plant Breeding Department

Salt tolerance. Massive pedigree selection for salt tolerance was continued in special pedigree nurseries. All selections were simultaneously tested for salt tolerance in the greenhouse. Emphasis in hybridization was shifted to the use of improved salt-tolerant rices, such as IR4630-22-2, IR4595-4-15, IR4573-4-3, and others, as donors to enhance the recovery of salt-tolerant lines with high yield potential.

In 1978, 22 of the advanced salt-tolerant breeding lines selected were tested in a replicated yield trial in a saline field with an electrical conductivity (EC) of 4.2–6.8 mmho/cm. IR9884-54-3 yielded 3.5 t/ha and IR4619-48-3 4.2 t/ha; tolerant Pokkali yielded 2.6 t/ha and IR26, 2.2 t/ha. IR42, IR2070-105-4-5, IR2863-35-3-3, IR4432-28-5, IR4570-83-3 — products of the general breeding program — have moderate salt tolerance (Table 2). Two years' performance tests of salt-tolerant rices confirmed that the yield can be increased by 1.0–1.5 t/ha with tolerant rices at the EC_e (electrical conductivity of the saturation extract) of 4.7–7.0 mmho/cm at 25°C.

To confirm the validity of selection for salt tolerance in the greenhouse, realized heritabilities were estimated to be 0.32–0.49 in 2 crosses. In another experiment some progeny from the crosses of the most tolerant rices were more tolerant than their parents at 3 levels of salinity (Table 3).

Alkali tolerance. Alkali-tolerant lines were among the progeny of the general breeding program. Thirty such lines were distributed among national breeding centers and through the International Rice Testing Program.

Table 2. Performance of salt-tolerant rices in a coastal saline area[a], Sabang, Camarines Sur, Philippines, 1978 wet season.

Variety or breeding line	Date of flowering	Plant ht (cm)	Yield[b] (t/ha)
IR9884-54-3	6–10 Oct	98.3	3.46 a
IR4619-48-3-3-6	18 Oct	110.5	3.16 ab
IR9884-3-3	9–10 Oct	97.1	2.93 abc
IR42	18 Oct	89.5	2.71 abcd
IR4595-4-1-15	19 Sep – 3 Oct	96.5	2.69 abcd
BPI-76	9–12 Oct	110.6	2.69 abcd
Pokkali	30 Sep – 1 Oct	150.7	2.63 abcd
IR2070-105-4-5	9–12 Oct	87.5	2.51 abcd
IR4573-4-3-7-14	14–18 Oct	93.5	2.50 abcd
C4-63 G	8–18 Oct	97.8	2.42 abcd
IR9858-45-5	28–30 Sep	90.4	2.42 bcd
IR4462-22A-2-17	29 Sep – 5 Oct	78.9	2.41 bcd
IR4432-28-5	1–11 Oct	88.8	2.41 bcd
IR4630-22-2-5-1	5–11 Oct	95.8	2.39 bcd
IR2863-35-3-3	3–12 Oct	77.1	2.39 bcd
IR9959-87-2	5–12 Oct	92.6	2.26 bcd
IR10199-108-1	27 Sep – 1 Oct	86.3	2.24 bcd
IR10206-29-2	23 Sep – 2 Oct	90.6	2.19 bcd
IR9849-74-1	28 Sep – 1 Oct	83.2	2.18 bcd
IR26	1–15 Oct	71.0	2.15 cd
IR10198-66-2	16–19 Sep	89.2	2.10 cd
IR4673-13-1-12	18 Oct	94.8	2.09 cd
IR9849-80-1	10–18 Oct	105.2	2.07 cd
IR10199-126-2	2– 3 Oct	85.9	1.91 d
IR10206-18-3	29 Sep – 4 Oct	121.1	1.81 d
IR5657-33-2-2	29 Sep – 3 Oct	80.3	1.81 d
IR9849-72-3	1–12 Oct	91.3	1.73 d
M1-48	28–29 Sep	89.4	0.73 e

[a]Data from IRRI-BPI (Philippine Bureau of Plant Industry) under EC_e (electrical conductivity of saturation extract) of 4.2-6.8 mmho/cm at 25°C. [b]Means followed by a common letter are not significantly different at 5% level.

Zinc deficiency is an inherent problem in alkali soils. Of 100 alkali-tolerant genotypes, 24 showed appreciable tolerance for zinc deficiency. Two genotypes with high tolerance for alkalinity were sensitive to zinc deficiency. That indicates independence of the two traits. IR4630-22-2, IR4763-141-2, IR4763-33-1, IR4570-15-1, IR9109-71-2, IR11418-15-2, IR11418-19-2, MR 359, and MR 363 showed tolerance for both alkali and zinc deficiency.

Acid-sulfate-soils tolerance. The main mineral stresses for rice in acid sulfate soils are aluminum toxicity, iron toxicity, and phosphorus deficiency.

Several F_2 hybrid populations were developed from iron-toxicity tolerant sources such as Gissi 27 and No. 2526 from West Africa, and Devareddi from Sri Lanka. Hybrid populations were also generated with varieties native to acid-sulfate-soil areas. Some such populations

Table 3. Salt tolerance rating and dry weight of selected F_3 lines of IR28/IR4629-22-3-5-1 and Nona Bokra/IR4629-22-3-5-1 crosses and their parents under 3 levels of salinity.

Parent or F_3 line	Salt tolerance rating[a] at			Mean difference[b]	Dry wt (g) at		
	16.5 mmho/cm	13.6 mmho/cm	10.2 mmho/cm		16.5 mmho/cm	13.6 mmho/cm	10.2 mmho/cm
IR28	9	9	9	8.0	0.8	0.3	0.1
IR4629-22-3-5-1	2	5	9	5.3*	5.9	2.0	0.1
13871-1	3	5	9	5.7*	5.1	2.1	0.1
13871-27	2	5	9	5.3*	5.8	3.4	0.1
13871-38	2	5	9	5.3*	5.8	2.4	0.2
13871-40	3	5	9	5.7*	5.0	1.6	0.2
13871-60	3	5	9	5.7*	4.3	2.0	0.3
13871-65	2	5	9	5.3*	6.5	1.6	0.2
13871-67	2	5	9	5.3*	6.0	2.3	0.4
13871-69	2	5	9	5.3*	5.2	1.9	0.1
13871-55	3	7	9	6.3*	4.5	1.4	0.1
13871-57	3	7	9	6.3*	4.0	0.8	0.1
Nona Bokra	3	9	9	7.0	5.4	0.6	0.2
IR4629-22-3-5-1	2	5	9	5.3*	5.9	2.0	0.1
13869-2	2	5	7	4.7*	7.5	2.8	0.9
13869-26	2	3	7	4.0*	8.6	5.3	1.5
13869-38	2	3	7	4.0*	7.3	3.0	0.9
13869-41	3	5	7	5.0*	7.5	3.1	1.2
13869-46	2	3	7	4.0*	6.3	3.0	1.2
13869-53	2	5	9	5.3*	8.9	4.2	1.2
13869-62	2	7	7	3.7*+	8.6	5.4	0.9
13869-63	2	3	7	4.0*	8.2	5.1	1.3
13869-64	2	3	9	4.7*	8.7	8.1	0.3
13869-69	2	5	7	4.7*	10.5	2.5	1.0
13869-78	2	5	7	4.7*	7.7	2.9	1.2
13869-87	2	3	7	4.0*	9.5	4.7	1.8
13869-88	2	3	7	4.0*	12.5	4.4	1.3
13869-82	2	5	7	4.7*	8.5	3.2	0.8
13869-84	2	3	7	4.0*	12.9	4.8	0.6

[a]1 = almost normal plants, 9 = almost all plants dying. [b]From the less tolerant parents IR28 and Nona Bokra. *Significantly different from both parents.

were sent to Africa, Thailand, and Vietnam for field testing.

Chemical mutation can change growth duration and plant height without affecting tolerance for adverse soils. To modify plant structure and growth duration, 10 photoperiod-sensitive varieties from problem-soil areas in Africa, India, and Indonesia were treated with ethyleneimine. The mutants will be distributed for testing.

Table 4. Genetic behavior of tolerance for zinc deficiency in 2 crosses. Screening was conducted on concrete beds. IRRI, 1978 wet season.

Generation[a]	Frequency of ratings on zinc deficiency tolerance[b]										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Cross (IR20/E425)											
P_1 IR20 (T)			1	8	2						
P_2 E425 (S)						1	3	5	1		1
F_1 (IR20/E425)					1	1					
F_1 (E425/IR20)					1	1					
F_2 progeny	2	5	21	20	32	19	3	5	2		
Cross (IR30/E425)											
P_1 IR30 (T)			1	3	6	1					
P_2 E425 (S)						1	6	1	2	1	
F_1 (IR30/E425)			1		1						
F_1 (E425/IR30)		1	1								
F_2 progeny	1	20	37	27	19	5	6			1	

[a]T = tolerant, S = sensitive. [b]Scale: 1 = most tolerant, 9 = most sensitive.

Zinc-deficiency tolerance. The genetics of tolerance for zinc deficiency was studied with two crosses (IR20/E425 and IR30/E425). The frequency distribution in F_3 of tolerant and sensitive genotypes, compared with that of their parents, indicated that zinc-deficiency tolerance is under polygenic influence (Table 4).

FIELD TESTING

Soil Chemistry Department

To ascertain the performance of rices found tolerant of adverse soils in tests at IRRI, replicated yield trials with good cultural practices were placed in Philippine rice fields where the problems occur.

Salt tolerance. Yield trials were planted in saline fields at six sites in the Philippines. Despite differences in climate, hydrology, salt concentration, salt dynamics, and soil characteristics among sites (*see* Soil and crop management, Table 1), IR4630-22-2 demonstrated salt tolerance at five sites and IR42, at three.

Three experiments on coastal saline soils in the Philippines illustrate the problems encountered in saline rice lands.

- At Lubao, Pampanga province, the experimental field was near a creek through which, at high tide in the dry season, saltwater flooded the land. The soil is a Tropaquent, with pH 6.9. At planting (1978 dry season) the EC was 6.1 mmho/cm in the soil and 2.8 mmho/cm in the surface water. Two weeks later mild salt injury was observed in all 11 cultures. One week later, saltwater entered the field, raising the EC of the surface water to 12 mmho/cm and that of the soil to 7–8 mmho/cm. Another week later, salt injury was severe in all varieties except IR4630-22-3 and IR5675-33-2, both of which scored 5.0. The only culture that yielded more than 1 t/ha was IR4630-22-3. In the wet season the field was submerged for 2 weeks by 1 m of floodwater, which destroyed the experiment. The soil is type 2, described in the section Soil characterization, in this report.

The site at Sinacaban, Misamis Occidental province, differed from the Lubao site in four ways. First, the area is a coastal saline swamp reclaimed by constructing dikes and flap gates; second, fresh river water and rain are abundant; third, the soil is a Typic Sulfaquent with a dry pH of 3.2 and a wet pH of nearly 7; and fourth, saltwater that enters by seepage or flooding at high tide is easily washed out.

At planting, EC was 4.5 mmho/cm in the soil and 3.5 mmho/cm in the surface water. Salt injury was mild and 1978 dry-season yields were 4.1–5.6 t/ha. IR42 and IR4630-22 were the top yielders, with 5.6 and 5.1 t/ha. In the 1978 wet season (when the EC was 2–8 mmho/cm), despite bad weather and mild iron toxicity, the salt-tolerant lines IR4430-22-5, IR4619-48-3, and IR2071-105-4 yielded more than 4 t/ha; the farmers' variety gave 2.1 t/ha (Table 5). Twice in 1978, yields higher than 4 t/ha were obtained with salt-tolerant rices on land that was idle coastal swamp in 1977.

- At Taal, Batangas province, the soil is an Andaquept with a pH of 7.8. Salinity is due to intrusion of brackish river water. The EC did not exceed 5 mmho/cm in both seasons. Zinc deficiency spoiled the dry-season experiment, and zinc was applied in the wet season. The wet-season EC was 1–2.9 mmho/cm. IR2071-105-4 with 2.5 t/ha and IR4630-22-2 with 2.4 t/ha were the top yielders.

Of the rices found tolerant in greenhouse tests, IR2071-105-4, IR2153-26-3, and IR4630-22-2 repeatedly demonstrated salt tolerance in field tests at IRRI and in farmers' fields.

Iron-toxicity tolerance. Fourteen rices with scores of 3 or lower in greenhouse tests were grown with a sensitive variety (IR26) on an iron-toxic soil at Malinao, Albay province. The soil is a Sulfaquept in an alluvial fan of volcanic

Table 5. Performance of 10 rices on a saline soil in a farmer's field, Sinacaban, Misamis Occidental province, Philippines, 1978 wet season.

Variety or line	Grain yield (t/ha)
IR2071-105-4	4.4 a
IR4430-22-5	4.1 ab
IR4619-48-3	4.1 ab
IR2053-35-3	3.6 b
IR4432-28-5	3.4 bc
IR4602-22A-2	3.4 bc
IR26	3.0 c
IR5675-33-2	3.0 cd
IR8241-8-8	2.5 de
Lumbang (farmer's variety)	2.1 de

Table 6. Performance of 16 rices on an iron-toxic soil, Malinao, Albay province, Philippines, 1978 wet season.

Variety or line	Grain yield (t/ha)
IR42	4.6 a
IR2058-78-1	4.3 ab
IR4432-52-6	4.3 ab
IR38	3.7 bc
IR2797-105-2	3.4 cd
IR2058-105-1	3.4 cd
IR4432-54-2	3.2 cde
IR4432-56-1	3.1 cde
IR20	3.0 de
IR2058-17	2.9 de
IR30	2.8 de
IR2058-38-1	2.7 de
IR5105-55-3	2.5 e
IR36	2.5 e
IR26	1.4 f

Table 7. Performance of 11 rices on a peat soil, Colorado, Agusan del Norte province, Philippines, 1978 dry season.

Variety or line	Grain yield (t/ha)
IR42	4.3 a
IR2307-247-2	4.0 a
IR3464-75-1	3.7 a
IR4613-54-5	3.2 bc
IR4422-6-2	3.1 bc
IR3518-86-2	2.9 cd
IR4616-70-1	2.8 cd
IR3880-10	2.7 cde
IR2071-137-5	2.6 ef
IR34	2.4 ef
E425	1.5 f

origin with pH 3.7, 2.1% organic matter, 2.2% active Fe, and 0.0001% active Mn.

IR42, IR4432-52-6, and IR2058-78-1 gave yields of 4.3–4.6 t/ha (Table 6).

Peat-soil tolerance. Eleven rices were grown in an abandoned field (pH 6.3; O.M.: 20%; available Zn: 0.05 ppm) at Colorado, Agusan del Norte province, with a basal dressing of 50 kg N, 25 kg P, 30 kg K, 10 kg Cu, 2 kg Mo, and 10 kg Zn/ha.

IR42 was the highest yielder with 4.3 t/ha; E425, the sensitive check, was the lowest with 1.5 t/ha (Table 7). Despite its tolerance for zinc deficiency, IR34 yielded only 2.4 t/ha.

Phosphorus-deficiency tolerance. Of 71 elite lines grown on a phosphorus-deficient soil at Pangil, Laguna province, in the 1978 wet season 13 rices, including IR20 and IR38, yielded more than 4 t/ha without phosphate fertilizer. With 25 kg P/ha, they gave a yield increase of less than 25%. IR4568-86-1 yielded 5.4 t/ha without phosphate and increased its yield only 12% with phosphate. In the same experiment, 24 rices, including IR32, gave yields of 1.3 to 2.8 t/ha and phosphate responses as high as 71%. Fertilizer phosphate hastened the maturity of the tolerant cultures by a mean of 12 days and that of the sensitive ones by a mean of 22 days.

Of 398 rices grown on the same site in the 1978 dry season, 56 were scored as tolerant on the basis of yield without fertilizer phosphate and the relative yield increase with phosphate. Outstanding among them were BR51-91-7, IR2786-113-4, IR3941-25-1, IR4422-98-3, IR4613-54-5, IR4723-217-3, IR5254-3-5, S45c-4, and 75-5135.

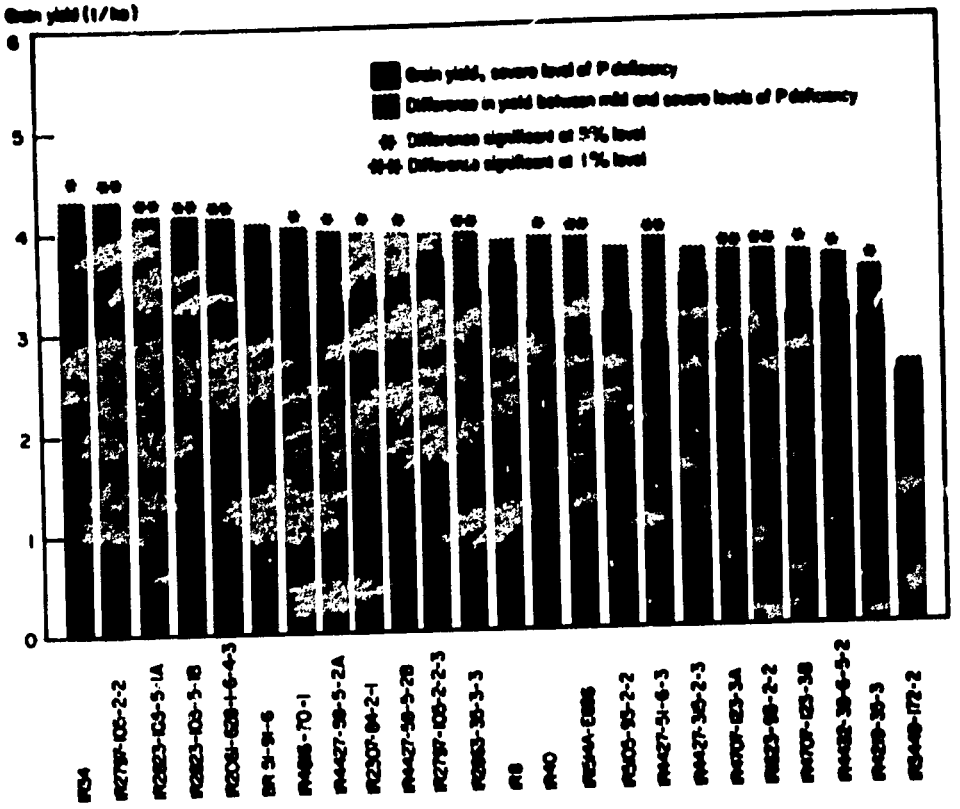
Adaptability of IR42 to adverse soils. In the greenhouse, IR42 had moderate tolerance for adverse soils. But in the field it outyielded tolerant rices (except IR20 on a phosphorus-deficient soil) on a variety of adverse soils (Table 8). IR42 appears to have traits that enable it to perform better than other IR varieties under field stresses.

IR42 may be the answer to the small farmer's prayer for a variety with stable yields in fields with adverse soil conditions.

Table 8. Performance of IR42 compared with that of other IR varieties on 6 problem soils, 1978 dry and wet seasons.

Variety	Rating[a]	Av grain yield (t/ha)
Salinity, Sinacaban, Misamis Occidental province		
IR42	MT	5.6
IR4630-22	T	5.1
Iron toxicity, Malinao, Albay province		
IR42	MT	4.6
IR36	T	2.2
Peat soils, Colorado, Agusan del Norte province		
IR42	MT	4.2
IR34	T	2.4
Nitrogen deficiency, IRRI		
IR42	—	4.6
IR34	—	1.2
Phosphorus deficiency, Pangil, Laguna province		
IR42	MT	3.9
IR20	T	4.2
Zinc deficiency,[b] General Santos, South Cotabato province		
IR42	MT	5.4
IR34	T	5.0

[a]MT = moderately tolerant, T = tolerant. [b]Partly corrected by zinc oxide dip.



1. Performance of 24 genotypes on phosphorus-deficient soil, Pangil, Laguna province, Philippines, 1978 dry season.

ROLE OF MINERAL STRESS TOLERANCE IN YIELD STABILIZATION

Plant Breeding and Soil Chemistry Departments

To ascertain the role of tolerance for mineral stresses in stabilizing yield in farmers' fields, tolerant and sensitive rices were grown on four problem soils at five sites in the Philippines.

Phosphorus deficiency. Twelve varieties tolerant of phosphorus deficiency and 12 sensitive to it were tested on a phosphorus-deficient soil (pH 4.7, Olsen P: 2 ppm) in the presence (P_1) and absence (P_0) of 25 kg P/ha in the 1978 dry and wet seasons.

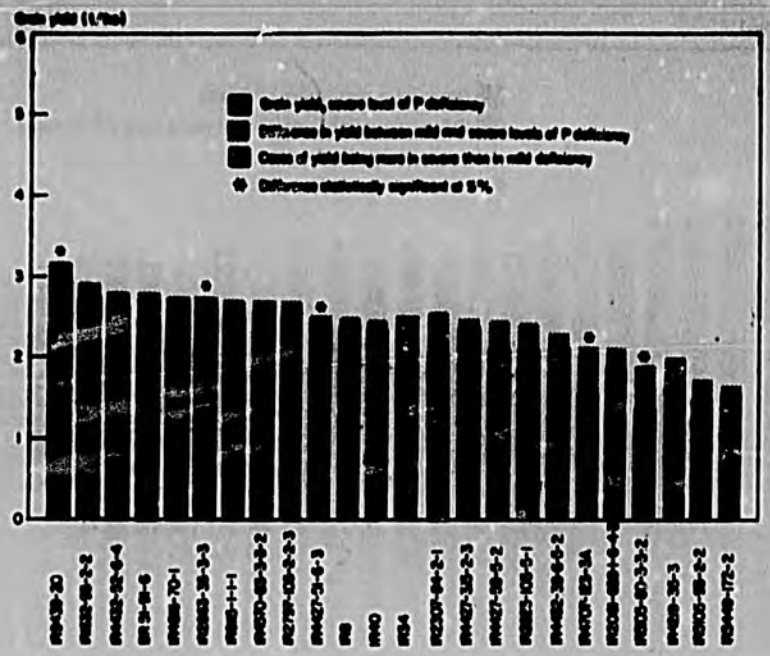
Differences in grain yield were significant at both P_0 and P_1 (Fig. 1, 2). The depression in grain yield due to the absence of phosphate fertilizer ranged from 4 to 27% with a mean of 15%. But six rices showed no significant depression in yield. BR51-91-6, IR34, and IR2823-103-5 were among the top yielders at both P_0 and P_1.

In the wet season, the yield depression due to the absence of phosphate fertilizer ranged from 0 to 28.4%. The responses on a phosphorus-deficient soil at Narra, Palawan province, were similar.

Growth retardation due to phosphorus deficiency varied with the variety; differences were most pronounced at tillering and least at flowering. Phosphorus deficiency delayed flowering by 2–9 days. Late-maturing rices had time to recover from phosphorus deficiency.

There were no significant varietal differences in the phosphorus content of the plant at maximum growth or in the straw and grain at harvest.

Zinc deficiency. In a replicated experiment in



2. Performance of 24 genotypes on phosphorus-deficient soil, Pangil, Laguna province, Philippines, 1978 wet season.

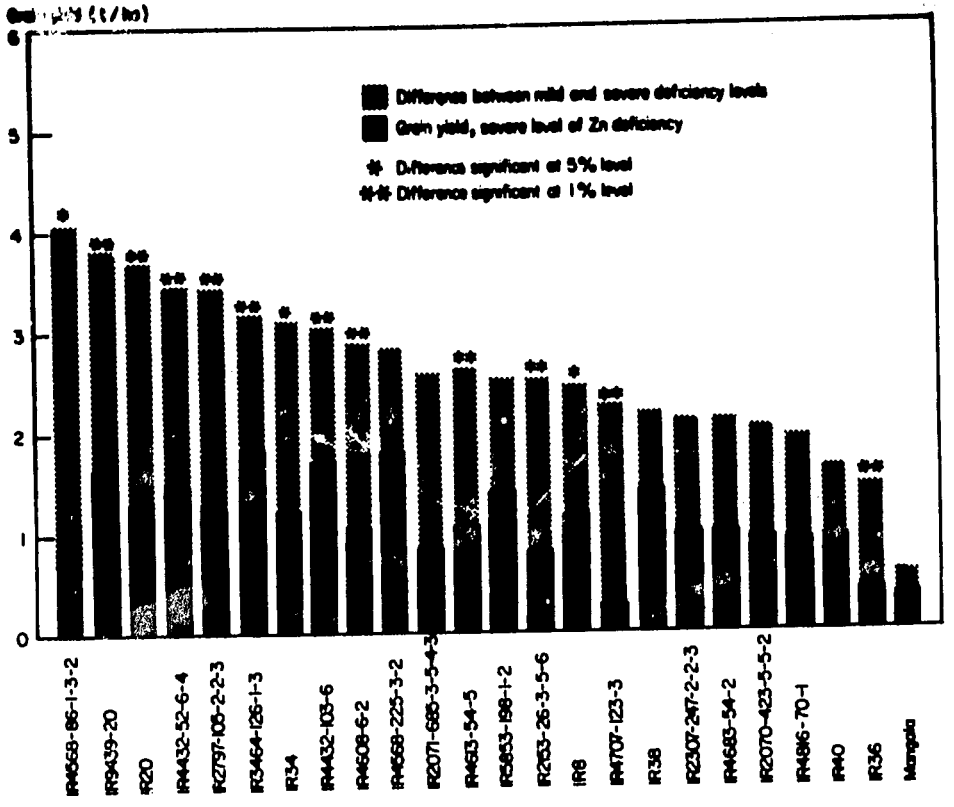
the wet season, 24 genotypes of varying tolerance for zinc deficiency were grown on a strongly zinc-deficient soil (pH 8.2; available zinc: 0.04 ppm) at severe (2% zinc oxide seedling dip) and at mild (4% zinc oxide seedling dip) levels of zinc deficiency.

The genotypes showed different reactions to the two deficiency levels (Fig. 3). The tolerant cultures generally produced more grain than the sensitive ones at the severe zinc deficiency level but there were varietal differences. The yield depression under severe zinc deficiency was 35% in the tolerant rices and 67–87% in the sensitive ones. IR8, IR2308-247-2, and IR5853-198-1 behaved like tolerant rices under mild deficiency but like sensitive ones under

Table 9. Analyses of variance for 4 experiments over 2 seasons.[a] IRRI, 1978.

Source	DF	SS	MS	F
Phosphorus-deficient soil,[b] Pangil, Laguna province				
Seasons, level	3	35.15	11.72	196.3**
Varieties	18	6.83	0.38	6.33**
Seasons × Varieties	54	3.27	0.06	
Zinc-deficient soil, Tiaong, Quezon province				
Seasons	2	16.19	8.09	33.71**
Varieties	14	8.42	0.60	2.50*
Seasons × Varieties	28	6.60	0.24	
Iron-deficient soil, IRRI				
Seasons	1	1.61	1.61	10.73**
Varieties	28	4.94	0.18	1.20ns
Seasons × Varieties	28	4.11	0.15	
Iron-toxic soil, Malinao, Albay province				
Seasons	1	0.22	0.22	1ns
Varieties	9	1.35	0.15	1ns
Seasons × Varieties	9	2.65	0.29	

[a]The analysis considered only the entries that were common to both dry and wet seasons. [b]Two levels of phosphorus deficiency and 2 seasons were treated as separate sets.



3. Performance of 24 genotypes at 2 levels of zinc deficiency. Tiaong, Quezon province, Philippines, 1978 wet season.

severe deficiency.

Iron deficiency. Thirty rices of varying tolerance for iron deficiency were grown as a dryland crop on Maahas clay (pH 5.8–6.2) and the same soil was limed to a pH of 7.0–7.5. Urea and zinc sulfate were applied to prevent nitrogen and zinc deficiencies. On the basis of their iron chlorosis scores and grain yields, the rices were classified as follows:

- Tolerant: IR22, IR24, IR36, IR661-1-170, IR1008-4-1, and IR7760-4-8
- Sensitive: IR5, IR34, IR38, IR712-23-2, IR2153-96-1, IR3646-9-3, IR9805-22-3, B9c-MD-3-3, and TOX 7-3-8-2-1

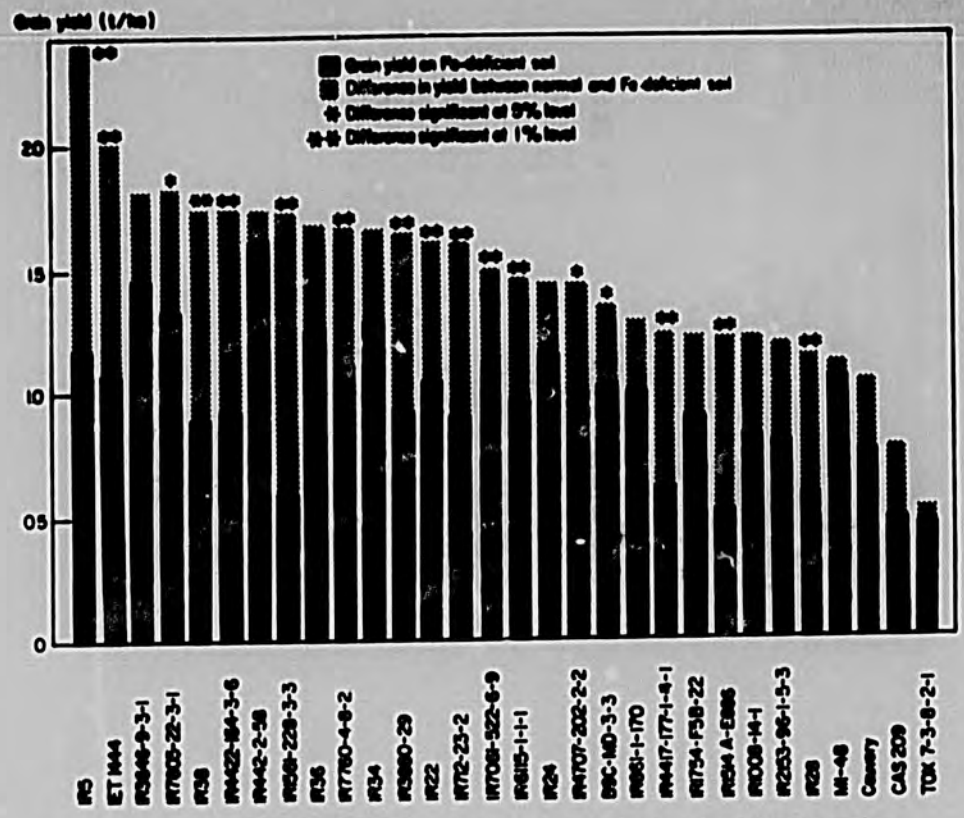
Yield depression due to iron chlorosis ranged from 0 to 65% and was significant for most of the sensitive rices (Fig. 4).

Iron toxicity. A field test at Malinao, Albay province, during the 1978 dry and wet seasons revealed that IR36, IR38, IR2797-105-2, IR3464-217-1, IR4227-28-3, IR4422-51-1, IR4707-123-3, IR5853-162-1, and IR9209-26-2 were tolerant of severe iron toxicity.

Yield stability over sites and seasons. The yield advantage realized with tolerant varieties has little practical significance at the farm level if their performance over sites and seasons is not reasonably consistent.

The experiments on phosphorus-deficient soil at Pangil, Laguna province, and on zinc-deficient soil at Tiaong, Quezon province, revealed a variety-season interaction (Table 9). But two varieties (IR34 and BR 51-91-6) tolerant of phosphorus deficiency were highly consistent in their performance. So were IR20, IR34, and IR4683-54-2 on the zinc-deficient soil.

In the iron-deficient soils, IR22, IR24, IR36, and IR1008-16-1 behaved consistently during



4. Performance of 30 genotypes on an iron-deficient soil, dryland culture, IRRI, 1978 wet season.

the two seasons. In the iron toxicity tests, tolerant IR36 and IR5853-162-1 behaved consistently in the wet and dry seasons. Tolerant IR2797-105-2 did better in the dry season, but tolerant IR4707-123-3 did better in the wet season.

Varietal tolerance contributes to yield stability on adverse soils. Table 10 shows that yield reduction due to severe mineral stresses is less in tolerant cultures than in sensitive ones.

IMPROVING SCREENING TECHNIQUES

Soil Chemistry Department

Salinity. Scores for salt injury in greenhouse screening are lower in the wet season than in the dry. Thus, many nontolerant lines are rated as moderately tolerant in the wet season, but some tolerant lines are scored as sensitive. This shortcoming hinders genetic studies of salt tolerance.

One objection to the present screening method (1974 Annual Report) is that the seedlings are subjected to a sudden and severe osmotic stress when they are transferred from normal

Table 10. Grain yields of some tolerant (T) and sensitive (S) rices at 2 levels of 3 nutritional deficiencies. IRRI, 1978.

Rice	Reaction	Yield (t/ha)		
		Mild	Severe	Difference
	Phosphorus deficiency			
IR24	T	4.3	4.0	0.3*
IR4427-51	S	3.9	2.9	1.0**
	Zinc deficiency			
IR24	T	3.2	1.3	1.9**
IR2797-105	S	3.5	0.8	2.7**
	Iron deficiency[a]			
IR36	T	1.7	1.2	0.4
IR26	S	1.7	0.6	1.1**

[a]Under dryland conditions.

culture solution to a saline soil with an EC of 8 mmho/cm. A test with eight rices of known salt tolerance revealed no significant difference between a sudden and a gradual stress.

The current screening method uses 3 varieties per tray in 3 rows of 15 plants each (1977 Annual Report). To save time, labor, and seeds, the number of seedlings was reduced to three.

Alkalinity. Adding calcium carbonate to the artificial sodic soil used in screening increased its pH from 8.5 to 8.6 and lowered the sodium adsorption ratio (SAR) from 40 to 36, rendering the soil more like a natural alkali soil.

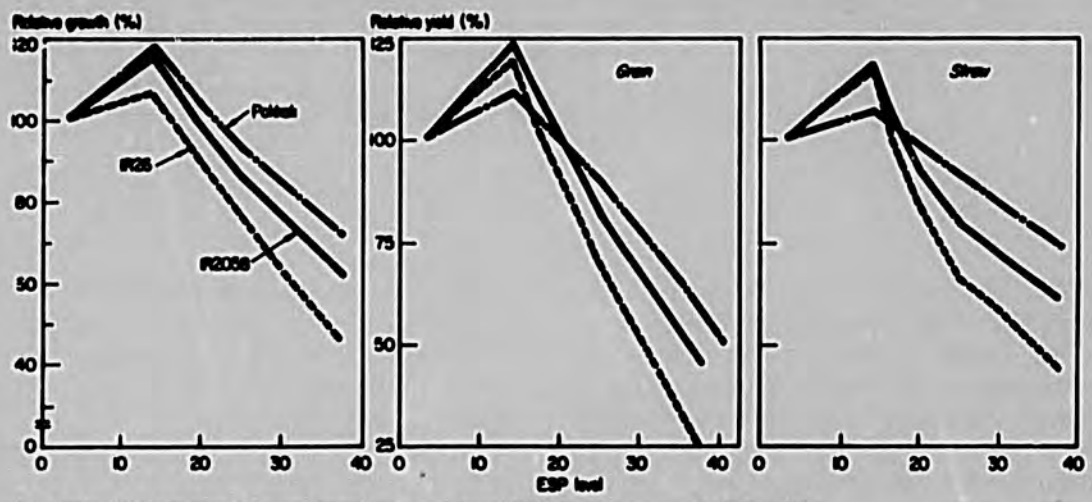
Iron toxicity. Greenhouse screening for iron toxicity is done in pots containing an acid soil from Taiwan. Because the amount of soil is limited, other media were explored.

Luisiana clay reduced by incubation for 2 weeks with sucrose solution, subsequently acidified, and then leached gave satisfactory scores, but the procedure was tedious. Sand and solution cultures containing 500 ppm Fe as ferrous sulfate with 50 ppm sucrose as an antioxidant gave reliable scores. Although the method permits scoring of large numbers, the use of nitrogen gas and changes of the culture solution render the methods unsuitable for routine screening.

PLANT CHARACTERISTICS AND MINERAL STRESSES TOLERANCE

Soil Chemistry Department

Plant characteristics and salt tolerance. Salt depresses the growth of rice and interferes with nutrient uptake. Table 11 shows that adverse

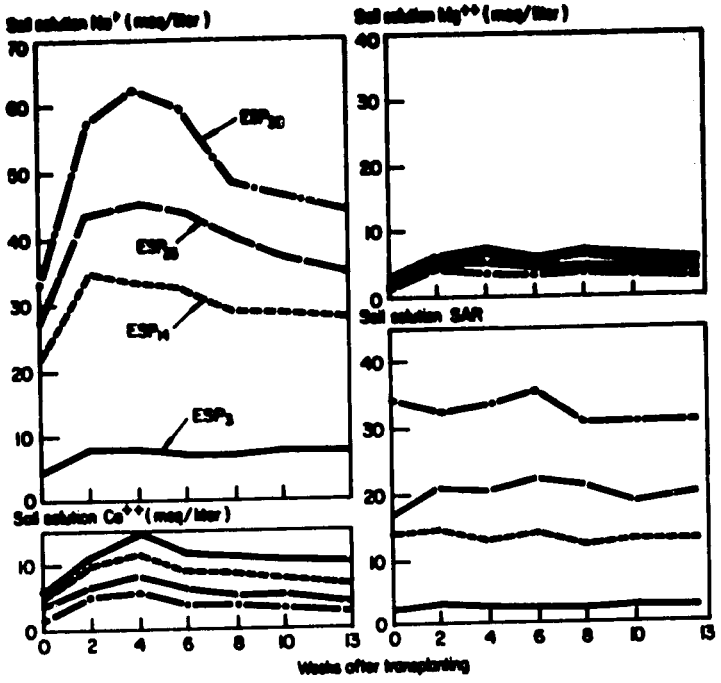


5. Relationship between exchangeable sodium percentage (ESP) and relative growth. IRRI, 1978.

Table 11. Effects of common salt on the growth and mineral composition of 2 rices on submerged Maahas clay in the greenhouse. IRRI, 1978.

Salt added (%)	Plant ht (cm)	Panicles (no./pot)	Straw (g/pot)	Grain (g/pot)	Potassium	Sodium	Calcium	Magnesium	Iron (ppm)	Score*
					(meq/100 g straw)					
					IR4630-22-2					
0	141	62	188	49	53	8	18	26	131	1.0
0.5	124	36	86	44	89	28	22	28	101	1.0
					IR26					
0	112	48	97	57	46	10	17	29	122	1.0
0.5	81	18	26	10	28	69	36	39	224	6.5

*1 = equal to resistant check, 7 = equal to susceptible check.



6. Kinetics of sodium, calcium, and magnesium in soil solution, IRRI, 1978. ESP = exchangeable sodium percentage, SAR = sodium adsorption ratio.

effects are less severe in the tolerant rice IR4630-22-2 than in the sensitive IR28.

The decrease in concentration of potassium in the shoot and the increase in concentration of sodium, calcium, and magnesium caused by salt were less in IR4630-22-2 than in IR28. Salt depressed the concentration of iron in IR4630 but increased it markedly in IR28.

Varietal reactions to exchangeable sodium percentage. Because there was no information on varietal reactions to increasing exchangeable sodium percentage (ESP), three cultures of varying alkali tolerance were grown in the greenhouse in a soil (pH 7.4; organic carbon, 1.7%) amended with sodium carbonate to give ESP values of 3, 14, 25, and 38.

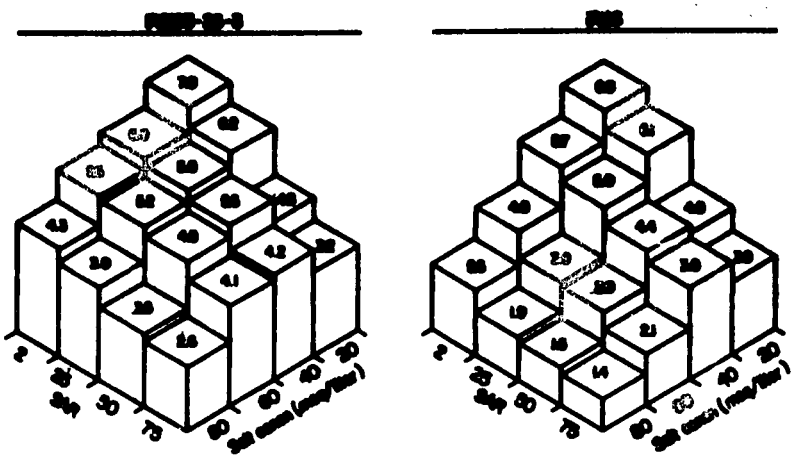
An ESP value of 14 stimulated growth in all varieties. Values beyond 14 depressed growth least in alkali-tolerant Pokkali and most in the sensitive IR26 (Fig. 5).

As ESP increased, the concentration of sodium in the soil solution increased whereas that of calcium and of magnesium decreased (Fig. 6). The sodium content of plant tops correlated positively, and the calcium and potassium contents negatively, with the sodium concentration in the soil solution.

Varietal reactions to sodium adsorption ratio. Growth retardation by salt is due to osmotic effects and to the influence of the ionic composition. Sodium adsorption ratio (SAR) is a measure of the ionic composition.

To ascertain the role of SAR in salt injury of rice, 4 varieties differing in salt and alkali tolerance were grown in 16 solutions representing the factorial combinations of 4 SAR (2, 25, 50, and 75 mmol/liter). The solutions were maintained at pH 5.5–6.0 and changed weekly. The water lost was replaced daily. The plants were harvested 35 days after planting and analyzed.

As SAR increased, the yield of dry matter decreased in all varieties at all concentrations of salt. But the relative yield depression was highest at the lowest salt concentration (20



7. Effect of sodium adsorption ratio (SAR) and salt concentration on dry matter yield of tops (g/plant) of IR2153-26-3 and IR26. IRRI, 1978.

meq/liter) and lowest at the highest salt concentration (80 meq/liter). It is remarkable that a SAR of 75, even in the absence of sodium carbonate, could reduce yield by more than 50% in all varieties (including the salt-tolerant ones) at so low a salt concentration as 20 meq/liter or an approximate EC of 2 mmho/cm (Fig. 7).

All varieties suffered a loss in yield as SAR or salt concentration, or both, increased. The salt- and alkali-sensitive IR26 suffered most from high SAR or high salt concentration, or both, but the salt-tolerant varieties accumulated less sodium and chloride than IR26.

The findings have practical implications:

1. salt injury in rice depends on both salt concentration and SAR;
2. salt injury is likely to be more severe in soils low in calcium and magnesium, such as acid sulfate soils and peat soils, than in calcareous soils; and
3. salt tolerance appears to be associated with tolerance for both high salt concentration and a high SAR.

Iron-manganese ratio and iron toxicity. An observation on iron toxicity in rice that has confounded researchers is the wide range (50–1,700 ppm) of water-soluble iron over which toxicity symptoms appear. One explanation is that rice becomes vulnerable to iron even at low concentrations when the available potassium, calcium, magnesium, and phosphate are low. The possible role of low manganese concentrations has been overlooked.

To ascertain the role of manganese, IR26 was grown in culture solutions containing the factorial combinations of 5 and 300 ppm Fe with 1.0 and 0.05 ppm Mn. To exclude oxygen, the solutions were continuously bubbled with nitrogen.

Table 12. Influence of iron and manganese concentrations in the culture solution on iron toxicity symptoms and iron and manganese uptake by IR26. IRRI, 1978.

Concn (ppm) in culture solution		Iron toxicity score[a]	Plant uptake (ppm)		Plant iron-manganese ratio
Iron	Manganese		Iron	Manganese	
5.0	1.0	1.0	218	626	0.35
5.0	0.05	1.7	224	97	2.8
300	1.0	8.0	1943	59	27
300	0.05	9.0	2380	61	39

[a]1 = no symptoms, 9 = plants dead or dying.

Table 12 shows that when the manganese concentration was 0.05 ppm, slight symptoms of iron toxicity were observed even when the iron concentration was 5 ppm. Plant analysis revealed an increase in the concentration of manganese, and a tenfold increase in the iron-manganese ratio in the plant. With iron at 300 ppm iron injury was severe with manganese at both 1.0 ppm and 0.05 ppm.

In a subsequent experiment, the role of manganese in the development of iron toxicity was confirmed. As the concentration of iron in the solution increased from 100 to 600 ppm, the severity of iron toxicity, the iron concentration in the plant, and the iron-manganese ratio increased at all 3 levels (0.1, 1.0, and 10 ppm) in the culture solution.

The concentration of manganese in the soil solution determines the iron concentration that produces symptoms of toxicity and should be considered in screening rice for iron toxicity.

Genetic evaluation and utilization (GEU) program

Deep water and flood tolerance

Plant Physiology, Agronomy, and Plant Breeding Departments and Thailand-IRRI Cooperative Deepwater Project and IRRI

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SCREENING FOR SUBMERGENCE TOLERANCE AND INTERNODE ELONGATION

Plant Physiology Department

In 1978 about 3,000 lines from the different pedigree nurseries were screened for submergence tolerance. An additional 700 varieties and lines from the germplasm collection, elite lines, International Rice Deep Water Observational Nursery (IRDWON), and International Rainfed Lowland Rice Observational Nursery (IRLRON) were also screened. FR13A remains the best variety for submergence tolerance. A total of 4,926 lines and varieties were screened for internode elongation ability. The best entries from the germplasm collection were Laki 146, Bhoro Diga, and Matia Gorol; all are from Bangladesh.

SCREENING FOR ELONGATION ABILITY AT EARLY GROWTH

Plant Physiology Department

Because most of the deepwater rice varieties, when submerged, need 6 weeks of growth before their internodes elongate, the IRRI germplasm collection was screened for internode elongation ability at 6 weeks old. Among 770 varieties screened, 71 had excellent and 177 had very good internode elongation. The available seeds of the good elongators were tested for their ability to elongate at 2 and 4 weeks after growth, instead of 6 weeks. Among 218 varieties, 20 showed excellent internode elongation at 4 weeks: Dholamon 51-1, Dholamon 64-3, Dholamon 658, Dholamon 664, Gowai 38-9, Gowai 38-13, Hansa, HBJ DW 8, Hybrid 10-1, Kalamon 36, Kalamon 113, Kalamon 243, Khama 49-2, Khama 49-8, Khama 55-22, Laki 550, Lalamon 245, Matiamon 70, Matiamon 73-23, and Sungail. With a water level of 100 cm, the total elongation of their internodes exceeded 60 cm 12 days after the water level was increased.

At 2 weeks old, 52 varieties showed internode elongation but the stems were generally thin and the plants looked as if they would rot if left in the field longer. Those plants had little strength for anchorage in case of strong winds and water current.

All the varieties except Dholamon 658 had a score of 1 in the new scoring system for measuring elongation (see next section).

STANDARD EVALUATION SYSTEM FOR MEASURING ELONGATION ABILITY

Plant Physiology Department

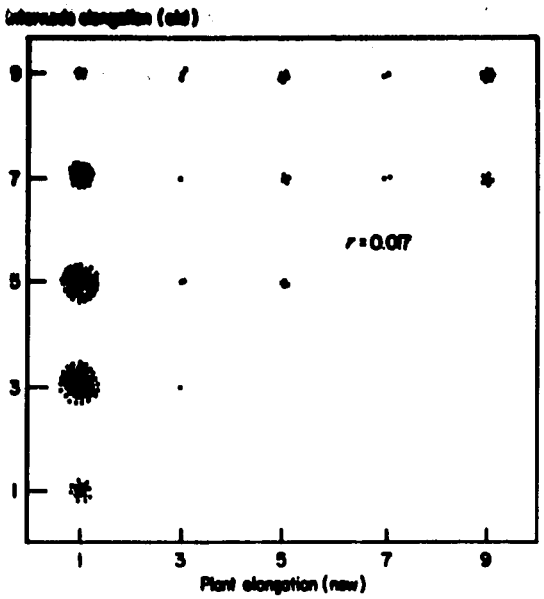
During the 1976 Deep-water Workshop in Bangkok, Thailand, the participants agreed upon a scoring system for measuring elongation ability. That scoring system differs from the system used in screening the IRRI germplasm collection (Table 1). The new system provides a faster method of scoring plants for elongation ability because the plants are scored visually instead of being measured individually. The new method provides data on total plant elongation — leaf sheath, leaf blade, and culm — and is not specific for internode or culm elongation.

The old and the new method were compared in a test using 218 deepwater rice varieties that were scored as 1 or 3 in the old system. The plants were treated at 4 weeks old instead of 6 weeks as in the old system and the water level was increased at 10 cm/day until it reached 100 cm. The plants were left at 100 cm for 3 days. Scores were recorded by both methods and plant and culm lengths were measured.

Although both methods supposedly measure elongation ability, there was a poor correlation between them (Fig. 1). The new method measures total elongation, the old measures total internode elongation only.

Table 1. New scoring system for measuring elongation ability of deepwater rice. IRRI, 1978.

Score	IRRI germplasm collection internode elongations	New scoring system agreed upon at 1976 deepwater rice workshop
0		No information
1	60 cm or more	Best elongation response (or better than that of best local floating variety)
3	40–59 cm	Response better than that of T442-57, not as good as that of the best local floating variety
5	20–39 cm	Response similar to that of T442-57
7	1–19 cm	Response better than that of the nonelongating semidwarf, not as good as that of T442-57
9	No elongation	Poorest elongation or none



1. Correlation between the old and the new methods for scoring elongation ability of 218 deepwater rices. IRRI, 1978.

Many varieties scored as 1 in the new system scored poorly in the old. Of the 174 varieties that were scored 1 in the new system, 11% were scored 1 in the old system; 38%, 3; 33%, 5; 15%, 7; and 3%, 9.

Figure 2 shows that many of the varieties scored as 1 in the new system had low internode elongation. They were scored as 1 because of their total increase in plant length. On the other hand, several varieties with good internode elongation received a poor score because of short total plant length. Figure 3 shows that many tall varieties had no or poor internode elongation even with submergence.

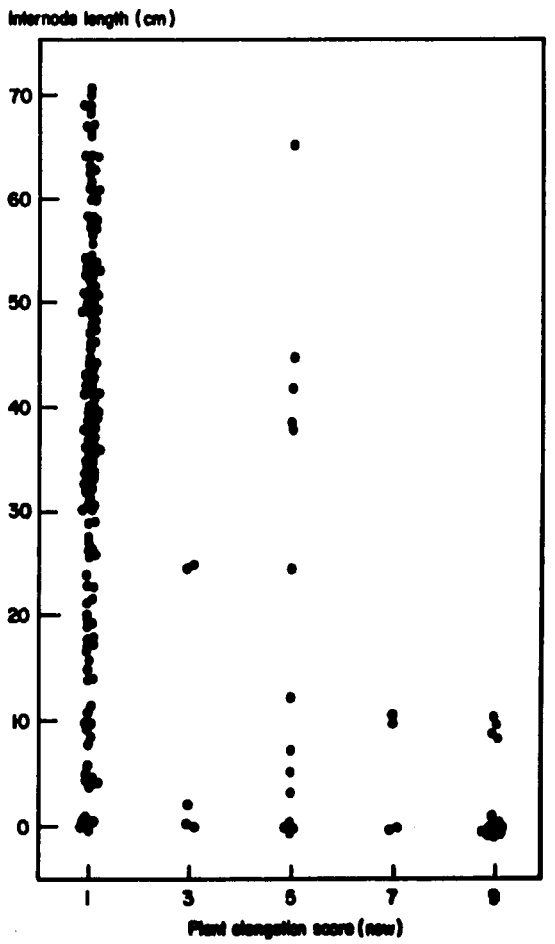
Although the varieties used supposedly had a score of 1 or 3 in the old system, the new method, which uses younger plants or submerges plants at a younger stage, identified several varieties with no internode elongation. Such varieties supposedly need a longer growing period (6 weeks) before they develop the ability to elongate internodes.

If internode elongation is the critical or desired character sought, users of the new scoring system for elongation should bear in mind that such method can give a score of 1 without any internode elongation. For the medium deepwater areas, the new system should pose no problem. But care should be taken in evaluating and using the data, or extrapolating the data from the medium-deepwater tests for the deepwater areas. Elongation tests for the deepwater areas should be conducted at higher water levels.

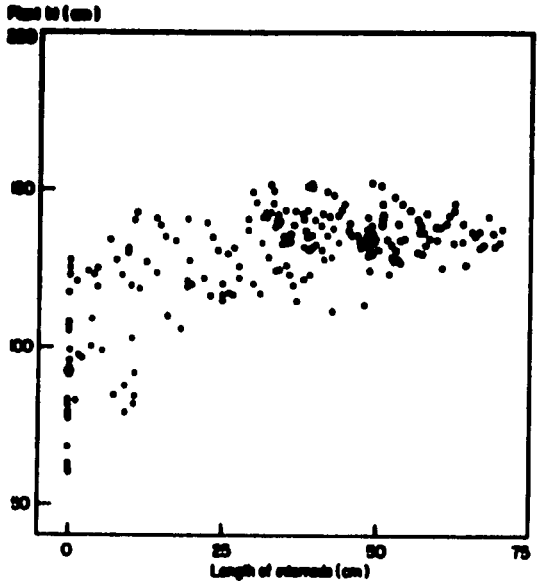
EFFECT OF PRESUBMERGENCE DROUGHT ON INTERNODE ELONGATION OF DEEPWATER RICE

Plant Physiology Department

In Thailand and Bangladesh the farmer's safest choice is to plant deepwater rice early, even at the risk of drought. Drought stress may affect the ability of deepwater rices to elongate with



2. Plant elongation score and internode length in tests of elongation ability of 218 deepwater rices. IRRI, 1978.



3. Plant height and internode length of 218 deepwater varieties submerged in 100 cm of water. IRRI, 1978.

rising water. Its effect on the subsequent ability of deepwater rice to elongate when submerged was studied.

Leb Mue Nahng 111 (LMN), a typical floating variety from Thailand, and IR442-2-58 (IR442), a drought-tolerant line with a limited ability to elongate, were used. IR442 is from the cross IR95/LMN. Seed was sown at the rate of 4/pot and the seedlings were thinned to 2/pot.

The field was kept flooded for 26 days after sowing, after which water was withheld according to the following schedule:

- 26 days after sowing (DS) — start of stress treatment T1
- 30 DS — start of stress treatment T2
- 34 DS — start of stress treatment T3
- 38 DS — rewatering of all stress treatments.

T1 had 12 days of no water, T2 had 8, and T3 had 4. Two days after they were rewatered, the plants were submerged in water that rose at 30 cm/day for 3 days. They were kept submerged for 5 days, then their rates of elongation were measured. The control plants — those not subjected to stress — were also submerged.

Drought stress reduced the rate at which both LMN and IR442 increased in plant height (Table 2). Although both varieties have some drought tolerance, withholding water for as little as 4 days reduced plant elongation. The plants subjected to stress hardly increased in plant height during the stress period. With 12 days of stress, plant height even decreased from that before submergence treatment because some of the leaves dried. Reduced rate of increase in plant parts is one of the first visual manifestations of drought stress.

Drought stress before submergence reduced both varieties' ability to elongate. Because IR442 is short, its leaves did not emerge above the water, even in the 4-day stress treatment. Neither variety elongated after 12 days of moisture stress. This decrease in elongation ability greatly affects the survival and yields of deepwater rices. Although IR442's ability to elongate was more reduced than that of LMN, the difference was small (Table 2).

Table 2. Internode length, plant height, and dry weight of Leb Mue Nahng 111 and IR442-2-58 subjected to moisture stress and then submerged in water, IRRI, 1977.

Stress days (no.)	Internode length			Plant ht (cm)			Total dry wt (g/plant) before submergence
	Before submergence (cm)	After submergence (cm)	Reduction (%)	Before stress	Before submergence	After submergence	
				Leb Mue Nahng 111			
0	0.6	30.0	—	—	101	186	3.36
4	0	24.0	20	86	87	143	2.47
8	0	3.6	87	72	72	114	1.23
12	0	0	100	69	65	69	0.69
				IR442-2-58			
0	0.16	11.9	—	—	69	93	2.81
4	0	7.3	41	69	65	69	1.69
8	0	1.0	91	56	58	64	1.38
12	0	0	100	69	52	49	0.52

Varietal differences were difficult to ascertain because the intensity of moisture stress differs with a variety's capacity to tolerate drought. When the same amount of water was withheld, however, the total dry weight was more reduced in LMN than in IR442. But the corresponding decrease in elongation ability was less in LMN.

In broadcast deepwater rice drought stress at the seedling stage affected the subsequent increase in height and internode elongation of plants subjected to a rising water level. Further tests should be conducted on varieties with similar capability for internode elongation to determine the least drought-affected among them.

MORPHOLOGY OF NODAL TILLERS IN DEEPWATER RICE

Plant Physiology Department

Deepwater rice scientists have recommended that nodal tillering ability be incorporated into new hybrids, but neither the importance of nodal tillers nor their origin and morphology have been assessed. A 1978 study sought such morphological data. Its main objectives were to determine the origin of the nodal tillers in terms of the main culm, the primary tillers, and the secondary tillers; and to determine their point of origin along the vertical axis of the basal tillers in relation to water depth. The development of the nodal tillers and their possible contribution to grain yield were also investigated.

Table 3. Tiller production in Leb Mue Nahng 111 and Kalar Harsall subjected to 85-cm water depth. IRRI, 1978.

Tiller type	Tillers (no.) at			
	6 wk*	10 wk	14 wk	Flowering
	Leb Mue Nahng 111			
Main	1	1	1	1
Primary	4.9	4.4	3.6	1.8
Secondary	8.3	5.8	2.4	0.7
Nodal	0	0	1.4	4.5
Total	14.2	11.2	8.4	8.0
	Kalar Harsall			
Main	1	1	1	1
Primary	5.7	5.8	4.0	3.7
Secondary	8.2	5.8	5.0	4.0
Nodal	0	0.2	8.4	1.7
Total	14.9	11.2	18.4	10.4

*Start of treatment.

The deepwater rice varieties LMN from Thailand and Kalar Harsall (KH) from India were tested in deepwater ponds of IRRI. Progerminated seeds were planted 1/pot, with 250 pots/variety. When the plants were 6 weeks old, the primary and secondary basal tillers were labeled. The plants were then subjected to increasing water levels. On the sixth day, the water reached 85 cm and remained at that level until harvest.

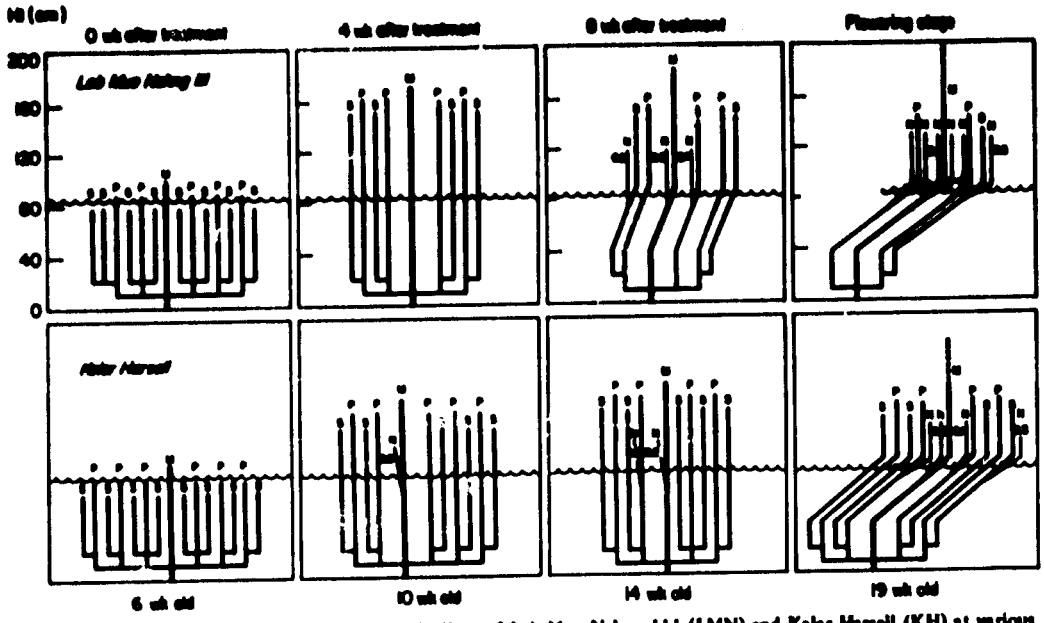
Tiller number. The total number of tillers generally decreased with growth in both LMN and KH (Table 3); the primary and secondary tillers decreased, but the secondary tillers decreased more. The effect of increase in water level was greatest on the survival of secondary tillers, but the production of nodal tillers partly offset the damage.

Nodal tillers increased as the plants grew older. LMN and KH differed in number of days of submergence before nodal tillers were formed. LMN produced nodal tillers 8 weeks after submergence; KH produced them at only 4 weeks. Although LMN produced nodal tillers late, it produced significantly more than KH. Early production and a high number of nodal tillers are two important plant characters that should be combined for a better rice plant type for some deepwater areas.

Tillering pattern. LMN and KH were barely above the water level at the start of the treatment (Fig. 4). Both varieties elongated rapidly during the first few days of submergence, but LMN elongated most, which could explain its delayed production of nodal tillers. Four weeks after treatment, nodal tillers were noted in KH but not in LMN. Generally the floating rice varieties do not produce nodal tillers while elongating. Branching or nodal tiller production occurs only after rapid elongation has ceased.

In KH the nodal tillers were first formed on the main culm, which is usually the tallest and thickest. The main culm produced only one nodal tiller. Succeeding nodal tillers were formed on the primary tillers at the rate of 1/tiller.

In LMN the nodal tillers came from the secondary tillers as well as from the primary tiller and the main culm. The main culm and the primary tillers produced more than one nodal



4. Plant height and number of basal and nodal tillers of Lab Mue Nahng 111 (LMN) and Kalar Harsall (KH) at various stages of growth. IRRI, 1978. Numbers indicate the average nodal tillers less than one.

tiller. In contrast, no nodal tillers were produced on the secondary tillers of KH. The culms of KH (15 mm) are thinner than those of LMN (20 mm). Further study is needed to determine if a thicker culm is associated with greater ability to produce nodal tillers.

At flowering, LMN had fewer primary tillers but more nodal tillers. But its increased nodal tiller production did not compensate for its lower primary and secondary tiller production; its total number of tillers was therefore lower than that of KH.

The nodal tillers originated from 10 to 25 cm below the water surface. No nodal tillers were formed from nodes more than 45 cm below it. At later growth the plants lodged and formed more nodal tillers below the water surface. No nodal tillers were formed from nodes above the water surface.

Internode elongation. The significant part of internode elongation occurred during the first 2 weeks after submergence; that was reflected in the length of the basal internodes (Table 4). LMN and KH each had five elongated basal internodes resulting from submergence but the basal internodes of LMN elongated more. That was also reflected in total plant length (Fig. 4). When the top leaves were above the water level, internode elongation slowed. Thus, internodes 4, 5, 6, 7, and 8 of LMN and internodes 6 to 7 of KH were shorter than the others.

The plant reactions in the field were similar. One can trace the rate of increase in water level by examining the length of the internodes. A

Table 4. Length of internodes of the main culms of Lab Mue Nahng 111 and Kalar Harsall at harvest, after the plants were subjected to 85-cm water depth. IRRI, 1978.

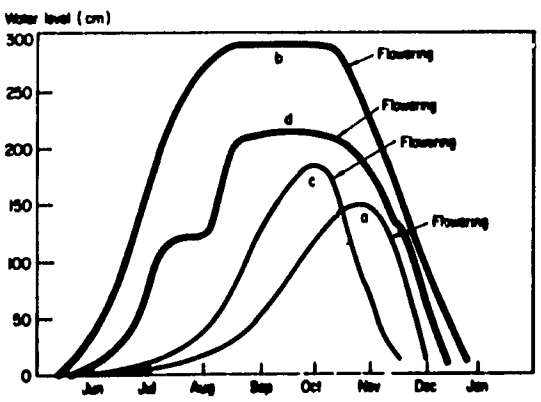
Internode no. (from top)	Lab Mue Nahng 111 Internode length (cm)		Lab Mue Nahng 111 Cumulative length	Kalar Harsall Internode length (cm)		Kalar Harsall Cumulative length
1	20		146	19		135
2	14		126	15		116
3	10		112	11		101
4	9		102	9		90
5	7		94	7	Full	82
6	6	Full	87	6	water	75
7	6	water	81	6	level	69
8	6	level	75	6		63
9	10		67	6		55
10	15		57	13	Zero	49
11	17	Zero	42	15	water	36
12	18	water	25	14	level	15
13	7	level	8	1		1
14	2		2			

decrease in internode length indicates a decrease in or stabilization of the water level.

In the improved semidwarf varieties, only the top three to four internodes usually elongated at flowering. In LMN and KH, an additional three to four internodes elongated even though the plant's growing parts were already above the water surface. Such extra elongated internodes may contribute to lodging even if the plants are supported by the water. Improved deepwater rice plants should not have extra elongating plant parts above the water.

Nodal tillering and water regime patterns. Nodal tillers occurred from 4 to 8 weeks after the plants were submerged in water whose level increased at 30 cm/day for the first 3 days until it reached about 85 cm. In the first week, the plants elongated to keep up with the rising water. The most active leaves were above the water level 1 week after submergence. Nodal tillers appeared only after rapid elongation decreased.

Figure 5 shows several water regimes in the deepwater rice areas. At Huntra, Thailand (or in areas with a similar water regime pattern), water may increase continuously from July to November, then decrease without stabilizing for 3 to 4 weeks. In such cases, plants will elongate but few or no nodal tillers will form because the water level increases and decreases rapidly and the plants flower. Elongation, tillering, and panicle development compete with one another. Because elongation and flowering are stronger physiological processes, nodal tiller production usually occurs only after elongation and before flowering.



5. Water level patterns for (a) Huntra Experiment Station, Thailand, 1969; (b) Bangladesh, 1970; (c) Illushi Rice Swamp Gauge, Illushi, Niger floodplain, 1964; and (d) a possible pattern in deepwater rice areas.

In some deepwater areas of Bangladesh, the water level increases around June and peaks in early August. It remains at that level for at least 10 weeks (Fig. 5, curve *b*). The plant has sufficient time to elongate and form tillers before flowering. In such a water level pattern, many nodal tillers form and contribute appreciably to the grain yield.

In the Niger floodplains, the water level increases steadily and peaks at about the flowering period (Fig. 5, curve *c*). Nodal tillers will not form because elongation precedes tillering. In that region, a high capacity for early tillering is important, but the ability to produce nodal tillers is of little use.

Another water-level pattern might be similar to that of curve *d* (Fig. 5). The secondary but relatively early leveling off of the water between July and August could result in the early production of nodal tillers, which could contribute significantly to yields.

This experiment and the analysis of some data on water regime patterns indicate that nodal tillering ability is not essential in some areas. Where water is more than 100 cm deep and where its level increases early, nodal tillers can be important, provided the water level is steady for 4 to 5 weeks before flowering.

Contribution of nodal tillers to yield. The contribution of nodal tillers to grain yields has been speculated on, but not measured. The morphology of the nodal tillers of mature plants was studied to determine their possible contribution to grain yield.

Most of the grain yield came from the primary tillers (Table 5). The nodal tillers produced only 1% of LMN's yield and 7% of KH's. Analysis of variance for grain yield among the main culm, primary tillers, secondary tillers, and nodal tillers of LMN and KH showed significant differences at the 1% level between basal tillers and nodal tillers.

Although LMN had 4.5 nodal tillers/plant, most of the tillers were ineffective, and panicle sterility was high. Thus, the grain yield of nodal tillers that matured was low — 0.18 g/plant

Table 5. Total grain yield and contributions to grain yield of the main, primary, secondary, and nodal tillers of Leb Mue Nahng 111 and Kalar Horsell submerged in 85 cm water. DRS, 1978.

Variety	Total yield (g)	Contribution (%) of tillers			
		Main	Primary	Secondary	Nodal
Leb Mue Nahng 111	8.31	38	52	9	1
Kalar Horsell	9.66	24	53	16	7

compared with 3.09 g for the main culms and 4.30 g for the primary tillers.

Similarly, the nodal tillers of KH had small panicles and low fertility. Thus, their grain yield was low — 0.65 g/plant compared with 2.33 g for the main culms and 5.10 g for the primary tillers.

SCREENING FOR ABILITY TO PRODUCE NODAL TILLERS

Plant Physiology Department

Eighty-two deepwater rices with good elongation ability were tested for differences in the ability to produce nodal tillers. The seeds were soaked in water for 24 hours, and incubated another 24 hours before seeding. Germinated seeds were planted 2/pot and then thinned to 1/pot 2 weeks after germination. Each pot contained 4 kg soil and 4 g ammonium sulfate, 2 g solophos, and 2 g muriate of potash. Six weeks after planting, five pots of each variety were placed in the deepwater pond. The water level was gradually increased to 85 cm within 6 days and nodal tillers were counted 8 weeks later.

Even though the varieties tested had similar elongation ability, they differed in the ability to produce nodal tillers.

Many plants in the test died. Some plants within a variety produced nodal tillers, others did not. There was wide variability on this trait within a variety. Whether it is caused by variety or by environment is not known.

The following produced the highest percentages of nodal tillers: Birain 392, Dholamon 2-4, Gowai 38-9, Gowai 476, Khama 49-2, Khama 49-8, Laki 550, Lalamon 245, and Maliabhangar. The main tiller usually did not produce more than two nodal tillers. Khama

6. Varietal difference in the production of nodal tillers in floating rice. Khama 49-8 (left) has many basal and nodal tillers, Gowai 38-9 (middle) has few basal but many nodal tillers, and Gowai 38-13 (right) has only basal tillers.

49-8 has excellent kneeing ability besides high nodal tiller production and good internode elongation ability.

Varieties differ widely in the ability to produce nodal tillers (Fig. 6). The present test can be used in screening varieties for this character. It is important, however, that the experiment be conducted when day length is long (March to July in the northern latitudes) so that flowering will not occur during the test and complicate the results.

SEEDLING AGE AND GRAIN YIELD

Plant Physiology Department

Most modern rice varieties cannot be grown in the medium-deepwater areas because the seedlings are short and they suffer from submergence at transplanting time. To overcome this problem, farmers use old seedlings that are tall or they do double transplanting.

Earlier studies on the effect of seedling age and grain yields showed conflicting results. An experiment was conducted to identify varieties that could withstand long duration in the seedbed without serious decrease in grain yields and to determine the growth characteristics responsible for such adaptation. Twenty- and 60-day-old seedlings of 9 varieties or lines of different growth duration were transplanted at the same time, 1/hill and spaced at 25 × 25 cm. The water level was maintained between 5 and 10 cm.

Seedling height. The 60-day-old seedlings of BKN6986-173-5 were 30 cm taller than the 20-day-old seedlings. Among the 60-day-old seedlings, BKN6986-173-5 was the tallest; it was followed by IR5825-41-2-P2. Seedling heights of 60 to 70 cm should be sufficient in areas with 30–50 cm water at transplanting.

Growth duration. Seeding-to-flowering data indicated that growth duration was prolonged by using older seedlings. However, the duration from transplanting to flowering differed little between the two seedling ages, although in all varieties the 60-day-old seedlings flowered earlier (Table 6). In the early maturing varieties (IR36, IR38, and C4-63), the early flowering of the 60-day-old seedlings was more marked.

Grain yield. Among the IR entries, the 60-day-old seedlings of IR5825-41-2-P2 gave the highest yields; those of IR5825-44-3-P2 and IR5825-41-2-P1 gave the next highest (Table 6). In all varieties with longer growth duration, grain yield was generally higher with the 60-day-old seedlings. For those with short growth duration (IR36, IR38, and C4-63) the 20-day-old seedlings gave yields similar to or better than those of the 60-day-old seedlings.

Thus, the use of older seedlings to obtain taller seedlings not only is practical but may increase grain yields for certain varieties with long growth duration. However, in varieties of short growth duration, increase in seedling age may be detrimental.

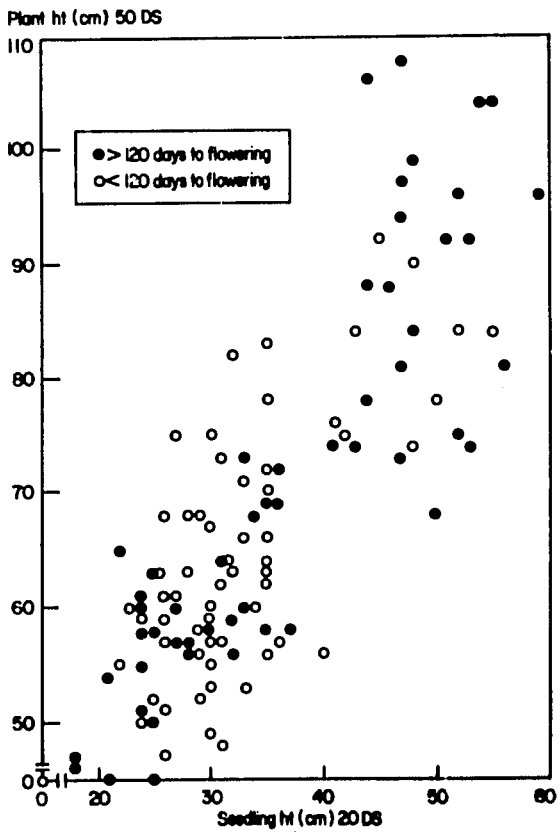
Table 6. Grain yield and growth duration of varieties using 20- and 60-day-old seedlings. IRRI, 1978.

Entry	Grain yield (t/ha) from		Transplanting to flowering (days) in	
	20-day seedlings	60-day seedlings	20-day seedlings	60-day seedlings
BKN6986-173-5	4.3	4.6	114	112
BKN6986-108-2	5.0	5.9	81	79
BKN6986-108-P	4.7	4.7	82	78
IR5825-41-2-P2	4.8	6.0	81	76
IR5825-44-3-P2	4.6	5.8	83	78
IR5825-41-2-P1	4.9	5.3	81	77
C4-63	4.8	3.8	79	67
IR36	4.1	4.3	76	54
IR38	4.8	4.7	54	46

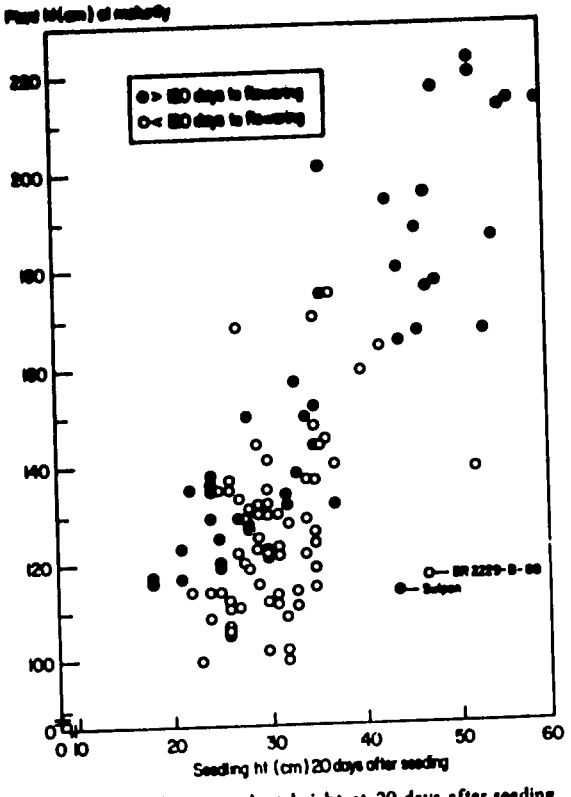
SEEDLING HEIGHT

Agronomy and Plant Physiology Departments

The possibility of obtaining tall seedlings that will have intermediate plant height at harvest was studied by measuring the plant height of the IRDWON, IRYN-M (International Rice Yield Nursery-Medium), and IRYN-L (International Rice Yield Nursery-Late) entries at transplanting, 30 days after transplanting or before the



7. Correlation between plant height 20 and 50 days after seeding (DS) of entries with different growth durations. IRRI, 1978 wet season.



8. Correlation between plant height at 20 days after seeding and at maturity of entries with different growth durations. IRRI, 1978 wet season.

water level was increased to 30–50 cm, and at harvest.

In medium deepwater rice areas where seedlings are transplanted in 10 to 30 cm water, tall seedlings are important. The modern varieties generally have short seedlings and are unsuitable to these areas even if old seedlings are used. In these areas tall native, long-growth-duration varieties, which generally have tall seedlings, are used. As an additional insurance, older seedlings, which are taller and stiffer, are used.

Seedlings that were tall at transplanting were also tall 30 days after transplanting; their height was an added advantage when water level was raised to 50 cm (Fig. 7). Seedling height at 30 days after transplanting was independent of the growth duration of the variety. The short-growth-duration plants were generally short at maturity and few had tall seedlings (Fig. 8). The late-maturing entries showed a positive correlation between plant length at maturity and seedling height. The data indicate that selection for tall seedlings may also result in selection for tall plant type instead of the desired intermediate plant length. However, two entries' seedlings were tall and their plants relatively short at maturity, even with 50 cm water.

THAILAND-IRRI COOPERATIVE DEEPWATER PROJECT

Breeding program. The main objective of the deepwater breeding program is to develop new rice varieties that will replace the traditional tall, photoperiod-sensitive cultivars now grown in stagnant water areas in the wet season. For the first time, lines with elongation ability combined with very early maturity (about 100 days) were evaluated in 1978. Four hundred lines at the 140-cm water depth were harvested.

About 10,000 lines were tested for elongation ability and 1,000 lines for submergence tolerance. Photoperiod-insensitive deepwater lines were planted in 900 shallow-water plots of 4 m^2 each; 1,000 other plots were planted to photoperiod-sensitive deepwater lines. From those plantings 220 submergence-tolerant lines were subsequently grown in a shallow-water field. All materials were routinely inoculated with bacterial blight, and 300 lines were tested for resistance to brown planthopper (BPH) biotype 1.

About 100 new F_2 populations — some from IRRI but most from Thai crosses — and new F_1s were planted. About 50 advanced lines were evaluated for performance in intrastation trials and regional yield tests in farmers' fields. Seventy lines were tested for drought resistance in Thailand and at IRRI. Weeds and uneven distribution of soil moisture partly affected the trials. The variety FR13A had excellent drought resistance and recovery, and several other lines were promising.

Promising lines. Several lines from 1969 crosses were promising for areas where floods do not exceed 1 m. The lines were included in on-station and farmers' field trials (Table 7). The line BKN6986-66-2 and BKN6986-147-2 were also planted in farmers' fields in the wet season.

Photoperiod-insensitive lines selected from a deepwater composite distributed by IRRI in

Table 7. Photoperiod-sensitive and -insensitive deepwater rice lines selected from the cross [illegible] in 4 International and farmers' field trials, Thailand, 1[illegible].

Line designation	Plant ht (cm)	Photoperiod sensitivity	Max water depth[a] (cm)	Yield range (t/ha)
[illegible]-65-2	105	Insensitive	100	2.5–4.0
[illegible]-109-3	119	Insensitive	100	3.8–4.5
[illegible]-91-6	105	Sensitive	100	2.1–2.4
[illegible]-147-2	145	Sensitive	100	2.5–3.2
[illegible]-161-3	127	Sensitive	100	2.7[b]

[a]Maximum water depth the line can withstand. [b]Only 1 test.

1975 have moderate elongation ability, 100–150 cm plant height, and resistance to bacterial blight and to BPH biotype 1 (Table 8).

Promising photoperiod-sensitive lines from the 1972 Thai cross SPR7233 (Leb Mue Nahng 111/C4-63) have elongation scores of ± 3 in 125 cm of water and a mature plant height of 120–140 cm in shallow water. They mature in late November or early December in Thailand. Some good, nonlodging plant types have slow semisenescence at the grain-filling stage.

Agronomy. Agronomy objectives in the Thai-IRRI Cooperative Deepwater Project are closely correlated with breeding objectives. The importance of fertilizer management, not only for higher yields but also for crop protection during exceptionally fast floods, was demonstrated in a fertilizer trial at Prajinburi, Thailand, where six deepwater varieties and lines were grown with four fertilizer treatments. A moderate flood at the seedling stage destroyed most of the no-fertilizer plot, but left the other three treatments largely intact (Table 9).

Table 8. Promising photoperiod-insensitive deepwater rice lines selected from a composite of crosses. Thai-IRRI Cooperative Deepwater Project, 1978.

Line designation	Maturity (days)	Scores[a] for Elongation[b]	BB	BPH 1
DWCT131-4-4	141	5	3	3
DWCT132-1-2	146	5	3	1
DWCT134-1-3	136	6	3	1
DWCT134-2-1	134	3	1	1
DWCT134-3-1	146	5	3	3
DWCT165-1-6	143	4	3	3

[a]Standard evaluation system for rice (SES) scale for scoring elongation: 1 = good elongation, 9 = no elongation. SES for seedling bacterial blight (BB): 1 = less than 1% hills affected, 9 = more than 50% hills affected. For brown planthopper biotype 1 (BPH1): 1 = little to no damage, 9 = plants dead. [b]Scored at water depth of 125 cm.

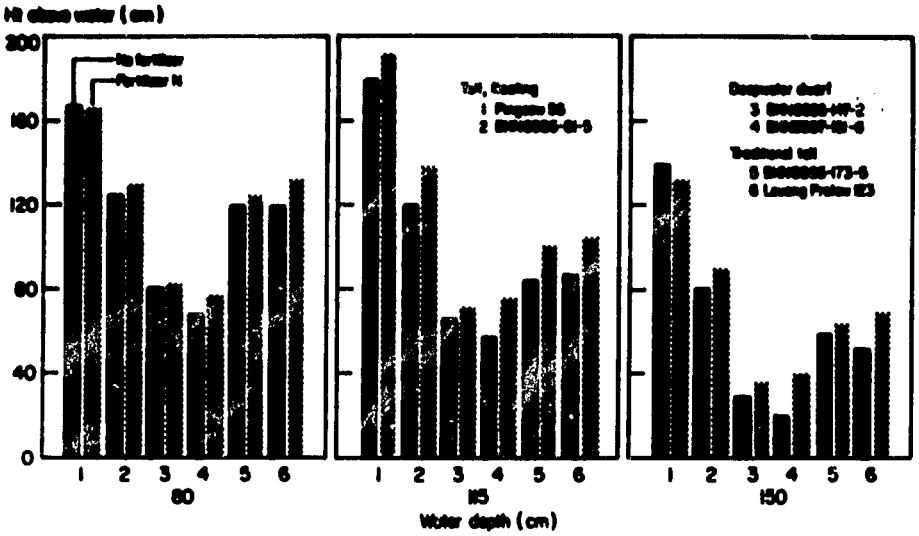
Fertilizer-water depth-variety trial. Response to fertilizer was measured in deepwater ponds at Huntra in an experiment with photoperiod-sensitive deepwater rices. The controls were photoperiod-sensitive floating rices and equally photoperiod-sensitive traditional tall rices. Water depths were 80, 115, and 150 cm. The following conclusions were drawn:

1. Response to 37 kg N/ha applied as basal was visible, especially at water depths of 115 cm and deeper (Fig. 9, 10, 11).
2. The fertilizer response of vegetative tiller number was substantially higher than that of yield in the 80-cm-depth treatment (Table 10). In deeper water, however, the response of the control was higher for yield and reproductive tiller number than for vegetative tillers. That suggests that a chain of events other than the response of the vegetative tillers causes fertilizer response in deepwater situations (Fig. 12).
3. At 80 cm water depth, the semidwarf lines with elongation ability had better average performance than either the floating or

Table 9. Grain yield of varieties and lines grown at different fertilizer levels and subjected to medium deepwater starting at seedling stage, Prajinburi Rice Station, Thailand, 1978 wet season.

Entry	Grain yield (t/ha) 0-0-0 (control)	0-37-0[a]	37-37-0[b]	75-37-0[c]
Nahng Khlow	0.92	3.57	4.72	5.00
Tapew Gaew	0.75	2.49	3.31	3.31
[illegible]-65-2	0.60	1.19	1.38	1.44
[illegible]-91-6	0.69	2.41	2.57	2.82
[illegible]-147-2	0.10	2.87	3.87	5.02
[illegible]-161-3	0.60	1.70	2.38	2.39

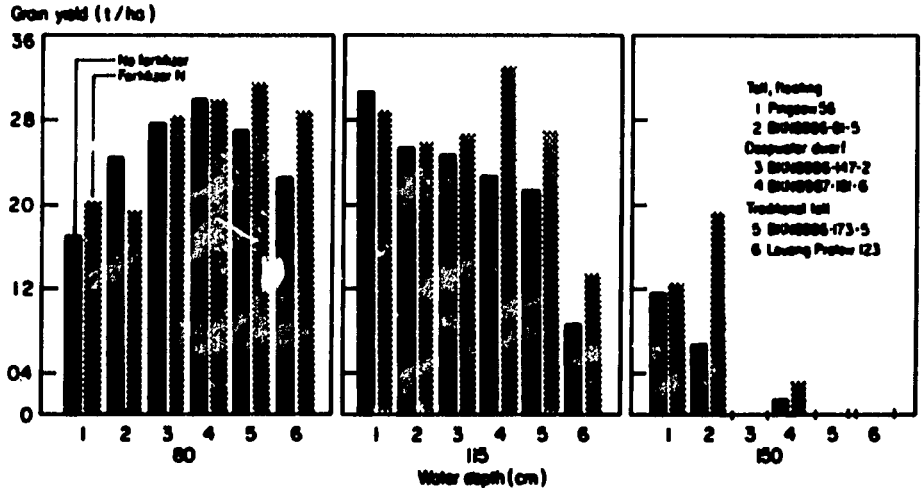
[a]Phosphate only (37 kg/ha). [b]Nitrogen (37 kg/ha) and phosphate (37 kg/ha). [c]Nitrogen (75 kg/ha) and phosphate (37 kg/ha).



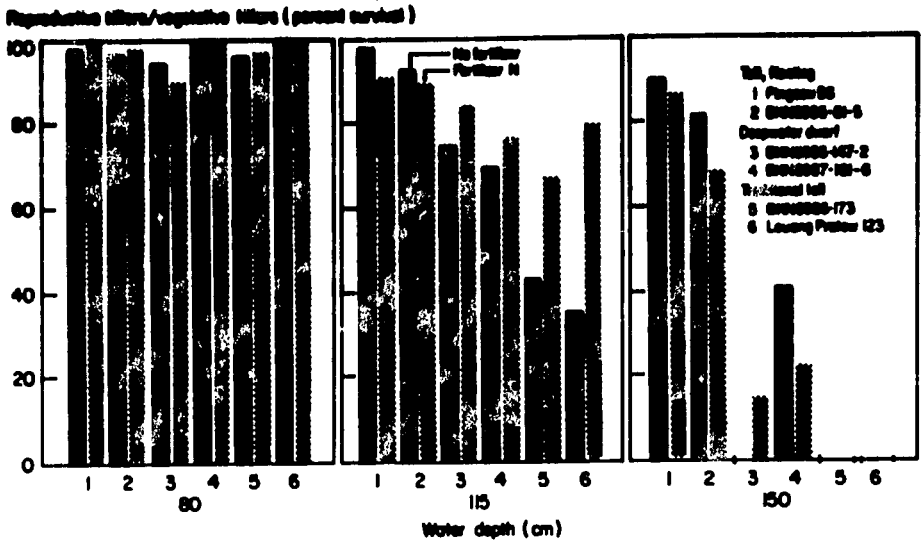
9. Effect of water depth (80, 115, 150 cm) and basal fertilizer on height of 6 rice varieties. Thai-IRRI Cooperative Deepwater Project, 1978.

the tall nonelongating rice entries. The results suggest that deepwater semidwarf varieties can be successfully introduced into areas where the maximum water levels vary across years but seldom surpass 1 m. In areas with less residual fertility than the Huntra Station ponds, fertilizer application may be a prerequisite, rather than merely a bonus, for the successful growth of such new lines.

Intercropping. Rices of different maturity are commonly grown mixed in countries such as Bangladesh. To duplicate the advantages of such a system, an alternate-row experiment was sown with a grain drill, intercropping the floating variety LMN with the photoperiod-sensitive semidwarf deepwater line BKN6986-141, in rows 25 cm apart. The experiment was planted in early June and BKN6986 flowered in late September. A transect of the field was sampled. A control plot of pure-stand drilled LMN had 142 tillers/m²; LMN in alternate rows yielded



10. Effect of water depth (80, 115, 150 cm) and basal fertilizer on grain yield of 6 varieties of rice. Thai-IRRI Cooperative Deepwater Project, 1978.



11. Effect of water depth (80, 115, 150 cm) and basal fertilizer on percentage of reproductive tillers from vegetative tillers. Thai-IRRI Cooperative Deepwater Project, 1978.

81 tillers/m² and BKN6986-141 had 92 tillers/m². Heavy and fast flooding in mid-October eliminated BKN6986. LMN survived, but yielded practically nothing because water hyacinth covered the plot.

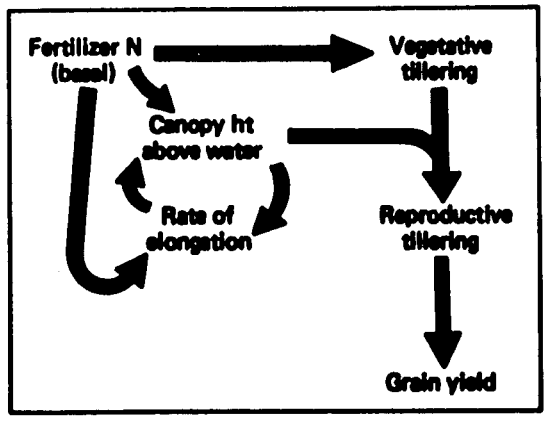
Several promising new lines for intercropping were identified in the deepwater ponds at Huntra. When seeded at the same date in the intercropping experiment (in some cases, 2 weeks later), the lines could be harvested in 120–140 cm water depths well before the onset of deeper flooding. To obtain shorter-growth-duration rices, 400 F_6 lines of 110 days maturity or less were selected from the deepwater ponds and planted at Bangkhen. The lines were obtained from the crosses IR11288 (IR36/LMN 111), IR11185 (IR40/LMN 111), IR7732 (Tarao Bao/IR2061-213-2-16), IR9288 (Tarao Bao/IR2061-213-2-16/ /IR34), IR7706 (Saran Kraham/IR28), and IR9274 (Saran Kraham/IR28/ /IR34). Several lines showed resistance to bacterial blight or to BPH biotype 1, or to both. The lines were from four cycles of rapid generation advance at IRRI.

Rapid generation advance. Rapid generation advance (RGA), a technique to speed the fixation of photoperiod-sensitive lines, uses close spacing under controlled day length in a

Table 10. Response to 37 kg N/ha[a] applied as a basal dose at 2 final water levels. Thai-IRRI Cooperative Deepwater Project, 1978.

	Response (%)	
	80 cm	115 cm
Vegetative tillers	23	22
Reproductive tillers	19	38
Grain yield	5	38

[a]Calculated on averages of 10 varieties.



12. Factors in fertilizer response after basal application in a rice crop at rising water levels. Thai-IRRI Cooperative Deepwater Project, 1978.

Table 11. Elongation performance of F_5 lines derived through rapid generation advance and subsequent selection for deepwater performance. Thai-IRRI Cooperative Deepwater Project, 1978.

Line	Lines (no.)	Lines (%) with elongation score[a] of			Lines (%) from which selections were made	
		1–3	4–6	7–9	Early	Late
IR11288	1381	34	34	42	9	14
IR11185	1411	34	22	43	1	32

[a]Standard evaluation system scale: 1–3 = best elongation, 4–6 = medium elongation, 7–9 = poor or no elongation.

Table 12. Effect of age of plant and of seeding on submergence tolerance in terms of survival percentage. Thai-IRRI Cooperative Deepwater Project, 1978.

Designation	Surviving stand (%) of plants submerged at indicated age			
	20 days[a]	50 days[a]	50 days[b]	70 days[b]
BKN6889-169-3	20	73	33	77
Nam Sagui 19	2	69	18	22
RD7	5	67	18	17

[a]Direct seeded. [b]Transplanted.

screenhouse (1977 Annual Report). A critical question regarding RGA is whether enough promising lines can be obtained from an unselected population of rapidly fixed lines to warrant the effort. In 1978, experience was gained with F_5 lines from two crosses: IR11288 (IR36/Leb Mue Nahng 111) and IR11185 (IR40/Leb Mue Nahng 111).

The lines were planted in a standard elongation test at the Huntra station in water reaching a 140-cm depth. Lines that elongated successfully but did not flower by 1 October were cloned and transferred to a shallow-water rice field at Bangkhen. Lines that were ripe at that date were harvested (Table 11).

Thus, more than half of the lines that had some degree of elongation ability and 20 to 30% of those with good elongation ability recovered. The proportion of late selections that were acceptable for transplanting is necessarily an overestimation of the proportion of late, sensitive, elongating segregants that can be recovered. The higher proportion of late segregants in IR11185 could be expected because its parent, IR40, flowers later than IR36, a parent of IR11288.

Elongation ability. Lines previously found marginal or poor in routine elongation tests were retested for elongation ability beginning at a 45-day seedling age (15 days later than normal tests). Each day the water level was raised by 2.5 cm, which is half the rate in normal tests.

The ability of some lines to keep up with the rising water increased significantly. Leuang Pratew 123, an ordinary tall, photoperiod-sensitive variety not known to have elongation ability, was still visible above the water at 205-cm depth but was destroyed at 140 cm in an adjacent test following normal methods. Thirty-two entries from the 1977 IRDWON that were destroyed at water depths from 85 to 100 cm in a normal test in 1977 survived at depths averaging 172 cm in 1978.

This result points to the need to specify test conditions in reports of elongation results.

Submergence tolerance. In a 4-level deepwater pond at Huntra, 10 lines were submerged for 7 days at water depths of 90, 104, 134, and 154 cm. All lines in the two deepest treatments were destroyed. Subsequent submergence tests at 115 cm seemed to distinguish lines best for submergence tolerance. Both transplanting and direct seeding were used. Submergence tolerance increased dramatically with age, or with direct seeding, or with both (Table 12). To provide scientists active in submergence testing with a common frame of reference, a set of 12 lines was agreed on at a 1978 International Deepwater Rice Workshop in Calcutta.

13. The excellent submergence tolerance of FR13A is clearly shown in a comparison with IR36 and SML Tunsola after submergence in 115 cm water for 10 days. Thai-IRRI Cooperative Deepwater Project, 1978.

Twenty-day-old seedlings of the 12 lines were submerged for 10 days at 115 cm at Klong Luang Station. FR13A from India was superior to the other entries, among them Nam Sagui 19 from Thailand (Fig. 13). In a similar screening test, and in previous submergence tests, several progeny lines from FR13A or FR43B were also superior to indigenous varieties in submergence tolerance. That suggests broad agreement with earlier IRRI tests using a laboratory screening technique. Late in 1978, crosses were initiated to incorporate submergence tolerance into future varieties.

BREEDING PROGRAM AT IRRI

Plant Breeding and Plant Physiology Departments

Efforts to develop improved germplasm for deep water by combining internode elongation ability and submergence tolerance with improved agronomic characteristics continued. In 1978, 454 single crosses were made using varieties from Bangladesh and improved breeding lines from Thailand as sources of internode elongation ability. Until 1977, SML Temerin and Nam Sagui 19 were extensively used as primary sources of submergence tolerance. To diversify the crossing program, FR13A, Goda Heenati, Kurkaruppan, Thavalu, Anlong Phnom, ARC 10661, from among 15 varieties identified as highly flood tolerant, were used as additional sources of submergence tolerance. Such crosses will generate improved germplasm for rainfed culture in medium deep as well as in deep water.

An experiment was conducted to identify donor parents with long basic vegetative phase (bvp). Because many Indonesian rice varieties seem to have long growth duration even under optimum photoperiod, the initial 75 varieties screened were from Indonesia. Plants were grown in pots and subjected to a 10-hour photoperiod from sowing to flowering.

Among the 75, 12 had bvp of more than 84 days. They were Brondol Puteh 277, Gendjah Benton 1101, Krang Serang 55, Banda 387, Banda 399, Baranda, Mandi, Bendek Kolon, Djalawara, Djalen, Karang Serang, and Leri. Each was used as a parent in the 45 crosses made. The longest recorded bvp in earlier IRRI tests for photoperiod response was 78 days.

INTERNATIONAL COOPERATION

Thai-IRRI Cooperative Deepwater Project and IRRI

The third International Deepwater Rice Workshop was sponsored by the Indian Council of Agricultural Research, the Government of West Bengal, and IRRI. The 60 participants agreed on collaborative programs to accelerate the development of varieties for deepwater areas:

- Screening for flood tolerance,
- Use of rapid generation advance,
- Screening deepwater rice for drought tolerance at the seedling and early vegetative stages,
- Trials on fertilizer efficiency in deepwater rice,
- Survey of stem borers in farmers' fields, and
- Accelerated collection of the rice germplasm from the deepwater areas.

Collaborative research on submergence tolerance. A collaborative project on submergence tolerance was initiated during the Deepwater Rice Workshop at Calcutta. Its purpose is to coordinate the different methods used for submergence screening and to find the relevance of the results from one set of conditions to those of another using the same set of varieties. Several cooperators agreed to conduct the submergence tolerance test involving a fixed set of varieties.

Postworkshop data from 7 cooperators showed that FR13A was the best in 6 different conditions — 4, 6, 8, and 10 days of submergence in the field, drought stress before submergence, and greenhouse screenings — out of 7. The data indicate that FR13A should be an excellent donor for submergence tolerance in different environments. It is a flood-resistant variety collected in India after a heavy flood. Kurkaruppan and Thavalu (15314) also gave a relatively high degree of tolerance.

The results also indicate that the varieties tolerant in one test are also tolerant in other tests; selections made by breeders at one site would more or less be tolerant at others.

Genetic evaluation and utilization (GEU) program

Temperature tolerance

Plant Breeding and Plant Physiology Departments and International Rice Testing Program

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LOW TEMPERATURE

Plant Breeding and Plant Physiology Departments and International Rice Testing Program

Breeding. Nearly 4,000 varieties and lines from the breeding program were screened for cold tolerance at the seedling stage. The extremely tolerant entries were advanced to cold tolerance testing at the panicle initiation stage.

Entries in the International Rice Cold Tolerance Nursery (IRCTN) were screened for tolerance at anthesis. AC 3828, B1581C-KN-55-1-7, CR 126-42-5, Dumsiah 81, Gujundo, IR2344-PLPB-3-1-3B, IR5090-PLP2-1-2B, IR5865-26-1, IR5865-26-1-2, IR5868-64-1-2-2, K143-2, and Madew (Acc. 36774) had 90–100% anthesis even at 21°C.

The crossing program for cold tolerance was expanded; 329 single crosses and 498 multiple crosses were made. Seeds of 174 F_2 populations were sent to breeders of 6 countries engaged in developing varieties with cold tolerance.

Field evaluation of breeding materials was continued at Banaue, Philippines, in collaboration with the scientists of the Philippine Bureau of Plant Industry.

At Banaue, progenies of 30 crosses were grown as F_2 bulk populations. Each cross combination had 2,000 to 3,000 plants. At maximum tillering stage all plants in F_2 populations were inoculated with the local strain of the bacterial leaf blight organism. When lesions appeared, susceptible plants were rogued. Vigorous plants with good panicle exsertion and high spikelet fertility were selected. In the wet season cloudy weather was prolonged and the flowering period coincided with heavy rainfall and a typhoon. Adverse weather conditions during anthesis caused a high degree of spikelet sterility. Only the plants of very early growth duration had good spikelet fertility. Such plants with good vigor were selected from each cross. A bulk harvest of healthy, vigorous plants from each cross was also made. Out of 30 F_2 populations, 1,040 single-plant selections were made, and 15 F_2 populations were harvested in bulk.

A total of 4,010 pedigree lines derived from 97 cross combinations were evaluated. The pedigree lines consisted of single-plant progeny in the F_3–F_6 generations. Approximately 1,277 single plants from the pedigree nursery were selected. Bulk seed of promising lines was harvested for distribution among the cooperators in other countries through the IRCTN.

One hundred fifty-six promising varieties and lines were evaluated in nonreplicated observational yield trials. The majority of the lines were selected from the pedigree nursery. Promising lines came from the crosses IR2061, IR3941, IR5865, IR5867, IR7167, IR7682, IR8460, IR8845, IR9202, and IR10222 (Table 1). The cold-tolerant donor parents involved in these crosses were Y6-100-9, Dughansali, Kunigan lines, Shensi, China 1039, Kuning Tinggi, and K17-BK-4-1.

In the hill stations and temperate areas where only one crop of rice a year is planted, the generation advance of the breeding lines has been slow, especially in areas without heated greenhouse facilities. The participants in the first International Rice Cold Tolerance Workshop recommended that rapid-generation advance (RGA) techniques be used to accelerate breeding materials.

Late this year F_2 lines of 5 crosses involving 4,881 plants were grown through RGA. The possibility of screening lines for cold tolerance at the seedling stage and selection for optimum growth duration when eventually grown in low-temperature areas are being studied.

Rice Cold Tolerance Workshop. The highlight of the cold tolerance program this year was the First International Workshop on Rice Cold Tolerance held in Suweon, Korea. The workshop was sponsored by the Korean Office of Rural Development and IRRI. Forty-eight scientists from seven countries reviewed the common problems limiting rice production in low-temperature areas and discussed research methodologies.

Several recommendations approved by the group have been implemented: the collaborative work on RGA, exchange of breeding materials, screening at a specific growth stage on a suitable site, and training.

Before the workshop, 12 scientists participated in various parts of the IRTP Cold Tolerance Monitoring Tour, which observed the IRCTN and rice improvement activities in low-temperature areas. A large number of entries

Table 1. Characteristics of selected cold-tolerant and bacterial blight-resistant breeding lines grown at Baguio, Region, Philippines, 1978 dry season.

Designation, cross	Ht (cm)	Maturity (days)	Yield (t)	Reaction[a] to blast	Grain quality[b]		
					Gel	Alkali	Amylose
IR9201-622-6-6-1, IR[illegible]-6-3-1-1/ / IR1561-148-1/IR1707	91	169	7.1	HR	9	1	7
IR[illegible]-10-1-2, YS-139-6/IR1514A-[illegible]	101	156	7.3	S	3	1	7
IR[illegible]-6-2, CR139-48-6/IR[illegible]-313	101	139	4.5	HR	5	3	1
IR[illegible]-48-3-3, IR[illegible]-6/Kn-1b-213-1-4-3/ / IR[illegible]-6/Kn-1b-361-1-6-6-10	97	155	6.5	HR	9	1	7
IR7167-16-1-3-1, China 1039/Kn-1b-361-6-6-10	113	139	4.5	HR	7	—	7
IR7167-39-3-4, China 1039/Kn-1b-361-6-6-10	112	155	6.6	HR	5	1	7
IR7[illegible]-135-3-3-2, Kuning Tinggi/IR26	103	134	4.9	HR	9	—	7
IR[illegible]-129-3-2, IR26/Shenai variety	76	162	7.9	HR	7	—	9
IR[illegible]-10-3-3, K17-6K-4-1/IR2053-621-1-1	107	149	5.2	HR	9	—	7
IR[illegible]-6-3-1, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	104	140	5.1	HR	3	—	9
IR[illegible]-6-1-2, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	107	137	4.6	HR	3	—	9
IR[illegible]-22-3-2, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	126	150	7.9	MR	5	—	9
IR[illegible]-23-1-2, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	116	140	5.2	HR	3	—	9
IR[illegible]-23-3-1, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	109	140	5.3	MR	5	—	9
IR[illegible]-26-1-3, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	120	154	6.7	HR	5	—	9
IR[illegible]-34-2-3, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	124	150	6.4	HR	1	—	7
IR[illegible]-36-3-2, IR2053-621-1-1/K116/ / Kn-1b-361-1-6-6-1	117	143	5.9	HR	3	—	7
IR10222-12-2, Kn-1b-214-1-4-3/N22/ / Kn-1b-214-1-4-3	139	154	7.5	HR	5	—	9
IR10222-24-2, Kn-1b-214-1-4-3/N22/ / Kn-1b-214-1-4-3	117	136	4.5	HR	3	—	7

[a]HR = highly resistant, R = resistant, MR = moderately resistant, S = susceptible. [b]Standard Evaluation System for Rice (1976) scales. For gel consistency: 1 = soft, 9 = hard. For alkali digestion: 1 = low, 3 = low/intermediate. For amylose content: 1 = very low, 9 = high.

selected from the 1978 nursery for inclusion in the fourth (1979) IRCTN show a great improvement in the quality of the individual entries and the nursery in general.

Korea-IRRI collaborative program. A collaborative cold tolerance program with Korea was initiated in late 1977. The first experiments were conducted in 1978 at the Chuncheon Branch Crop Experiment Station, Office of Rural Development.

Screening of cold tolerance nursery in a water gradient (17–27°C). A total of 750 entries from the IRCTN and early generation breeding lines from Korea, Indonesia, and IRRI were subjected to flowing cold water, from tillering to maturity. The treatment resulted in wide varietal response in terms of yellowing, plant height, tiller number, panicle exsertion, spikelet fertility, and growth duration. The best entries for each agronomic characteristic desired in low-temperature areas were selected.

Well-exserted panicle: Somewake, Oirase, Bandalbyeo, Thankote Marsi, IR5867-50-3-2-2-1, and IR9202-22-3-2.

Short growth duration: Matsumae, China 1039, K140-52-3, Fuji 269, and K39-96-1-1-1-2.

Intermediate plant height: Firooz, HP 46, Habiganj Boro II, IR2403-PLPB-7-2-1-3B, IR4997-PIP6-1B, IR4999-B-Jn2B, IR5086-PIP6-2B, IR5467-2-2-2, IR10222-12, Jaliya, MPR-1, Paro White, and Thankote Marsi.

Good phenotypic acceptability at maturity: IR5867-50-3-2-2-2, IR7167-33-1-2-3, IR7167-33-2-3-3, IR7167-33-2-4-1, IR7167-33-2-4-3, IR7167-33-2-5-1, and IR9202-22-3-2.

Evaluation of the extremely cold-tolerant varieties. To identify varieties or lines as sources of cold tolerance for use in the breeding program,

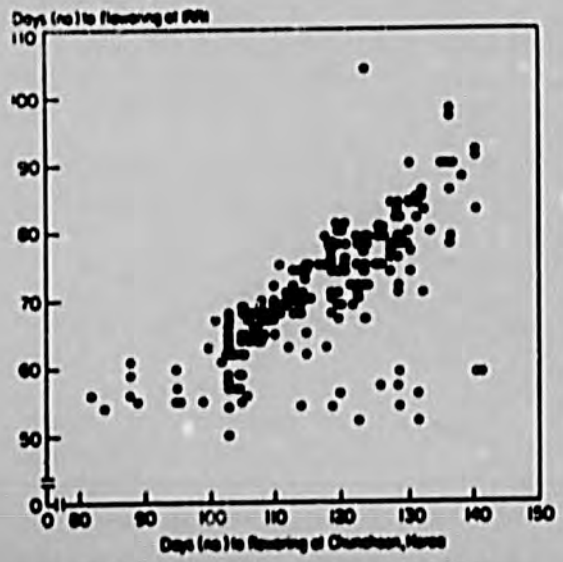
Table 2. Varieties excellent in at least 3 desired plant characteristics* in low-temperature areas, [illegible]

Characteristic	ARC [illegible]	Long Kwang	Stejo-ran 45	Oi Byoo	Ogoo Byoo	Shoa-Ga-Dau	Shoa-Nan-Tsan	HR 30
Good phenotypic acceptability	x	x	x	x			x	
Smoothly panicle exsertion	x	x		x				
Optimum culm length	x				x	x	x	x
Earliness (days)	111	119	114	126	126	127	113	130
Stable growth duration	x			x	x	x		x
Good tillering	x	x						
Long panicles						x	x	x
Large no. of spikelets per panicle					x			
Large no. of spikelets (per m²)	x	x	x				x	
High spikelet fertility	x	x	x	x			x	

*Excellent for the particular trait, even under low water temperature conditions.

the best selections from Korea and IRRI were subjected to 17°C water from tillering to maturity. Naengdo 13 had the longest panicle exsertion. Fuji 269 and ARC 6240 had the shortest growth duration. Silewah, Heug dae gu, and Pho Kha were the tallest at flowering. At harvest, Page Sampe Tuah had the most spikelets per panicle; ARC 6000, the most spikelets per square meter; Shoa-Nan Tsan and ARC 6000, the highest spikelet fertility.

Overall, the varieties listed in Table 2 are the best possible donors for improving rice for low-temperature areas.



1. Growth duration of 1978 International Rice Cold Tolerance Nursery entries grown in Korea and at IRRI. White circles represent entries that exhibited short growth duration at Los Baños but long growth at Chuncheon.

The test showed that many indicas are more cold tolerant than the well-known japonica varieties.

Development of an effective and rapid screening method for cold tolerance. Comparison of the different methods of screening varieties for cold tolerance shows that continuously flowing cold water creating a gradient from 17°C at one end to 27°C at the other provides the maximum number of plant responses that can be obtained from a single experiment. The reaction of the plant to low temperature, as shown by leaf discoloration, stunting, delay in growth duration, nonexsertion of the panicle, and high sterility, can be obtained by using this method.

Growth duration at Chuncheon and selected sites. Earliness is one of the major plant characteristics used in the selection of lines for low-temperature areas. The possibility of selecting early lines at Los Baños during the wet season, in spite of the high temperature, was tested by comparing the growth duration of the 1978 IRCTN entries planted at Los Baños and at Chuncheon.

In general, entries with long growth duration at Los Baños also had long growth duration at Chuncheon (Fig. 1). However, 12 of the 219 entries for both locations had short growth duration at Los Baños but relatively long growth duration in Chuncheon. The discrepancy probably resulted from the photoperiod sensitivity of the varieties and the long day lengths at Chuncheon.

Table 3. Grain yield of varieties treated with water at 17°C at different stages, compared with that of a control. IRRI, 1978.

Variety	Grain yield (t/ha)				
	Maximum tillering	Meiotic	Booting	Ripening	Control
Josaengtongil	3.62	3.64	4.81	5.52	6.27
Suweon 264	2.97	2.82	3.94	4.80	4.65
Long Kwang	3.60	3.43	3.85	3.85	3.67
Suweon 236	5.52	5.69	5.83	6.24	5.69
Nongbaek	4.02	4.06	5.81	5.35	5.68
Kn-1b-361	4.20	4.36	4.75	5.28	5.25
Towada	4.08	3.16	5.88	5.40	6.13

Preliminary selection for early maturity to fit the maturity requirement in low-temperature areas can be done at Los Baños. Entries with growth durations longer than 70 days at Los Baños can be removed.

Selecting for short growth duration. Long growth duration of rice is a major problem in low-temperature areas. Identification of possible donors with short growth duration is essential in breeding for cold tolerance.

Indica varieties in the IRRI germplasm collection with growth duration of 94 days or less at Los Baños were evaluated in Korea. Of the 240 varieties tested all but eight had early growth durations. The eight apparently are photoperiod sensitive and are therefore greatly delayed by the long day lengths in Korea.

Hungarian 1 and Tinpakhia were the earliest — 20 days earlier than the short-growth-duration Josaengtongil at 21.2°C water temperature.

Effect of low water temperature at different growth stages. To investigate varietal response to low temperature at different growth stages, 7 varieties were subjected to water temperature of 17°C at maximum tillering, meiotic, booting, and ripening stages. All were highly susceptible to low water temperature at the maximum tillering and meiotic stages (Table 3). Decrease in grain yield resulted mainly from reduced fertility and fewer spikelets per panicle.

HIGH TEMPERATURE

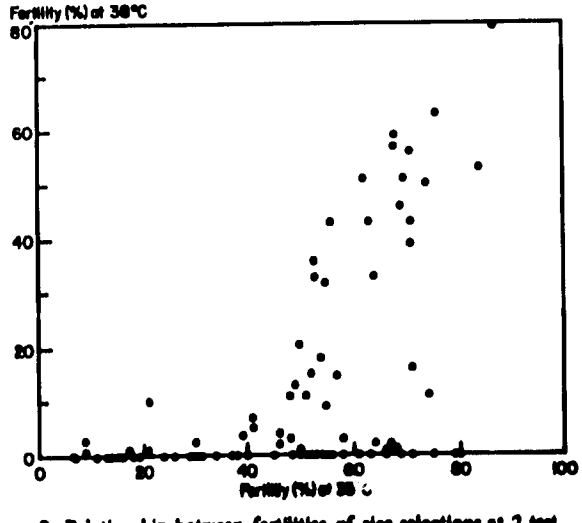
Plant Physiology Department

Flower fertility at two test temperatures. A simplified procedure in screening for tolerance for high temperature was developed. A screening temperature of 38°C was used first because IRRI data suggested that 35°C can determine susceptible varieties and 38°C tolerant varieties. But 38°C was found to be too high for many lines with good plant characteristics.

Eighty-four selections were subjected to both 35°C and 38°C treatments at flowering. Figure 2 shows the relationship between fertilities at these two temperatures. At 38°C about 75% of the selections had fertilities of less than 20%, and about half bore no fertile grains. Some selections with high fertility at 35°C were completely infertile at 38°C, while selections with high fertility at 38°C also showed high fertility at 35°C.

Apparently 35°C is better than 38°C in screening for high temperature tolerance.

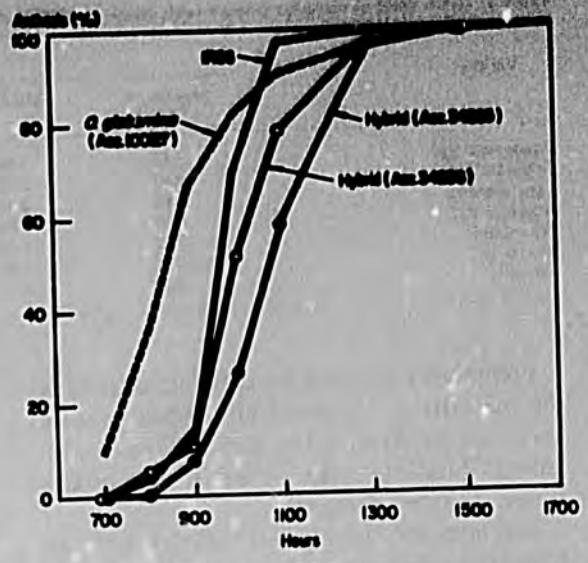
Donors of high-temperature tolerance with early maturity. If high-yielding varieties are to



2. Relationship between fertilities of rice selections at 2 test temperatures. IRRI, 1978.

Table 4. The best heat-tolerant early-maturing selections from 291 varieties tested at 35°C. IRRI, 1978.

Designation	Cross	Origin
DNJ 126		East Pakistan
IET 3684 (CR34-16)	TKM6/TN1	India
IET 3869 (CR53)	Cul. 349/Kanchi	India
IET 4084 (CR156-5621-307)	BU 1/CR115	India
IET 4165 (CR148-5662-215)	CR141/Pusa 2-21	India
IR9209-22-2-2	IR2061-427-1-17-7-5/ IR1552-63/ /IR30	Philippines
IR9209-36-2-2	IR2061-465-1-5-5/ IR2063-521-1/ / IR2070-625-1	Philippines
IR9209-69-1-1	IR2061-465-1-5-5/ IR2063-521-1/ / IR2070-625-1	Philippines
IR9209-181-3-5	IR2061-465-1-5-5/ IR2063-521-1/ / IR2070-625-1	Philippines
IR9403-3-1-1	CO21/IR26/ / IR2153-14-1-6	Philippines
IR9403-66-2-3	CO21/IR26/ / IR2153-14-1-6	Philippines
Sathra 278		Pakistan
Pusa 2-21		India



3. Time of flower opening of IR36, *O. glaberrima*, and their hybrids. IRRI, 1978.

be grown in high-temperature areas, high-temperature tolerance must be combined with early maturity. In all, 291 selections were screened at 35°C for these two qualities. Thirteen high-temperature-tolerant early maturing varieties are listed in Table 4, together with their ancestry and country of origin.

Time of anthesis in glaberrima-sativa crosses. High-temperature-induced sterility could be avoided if anthesis occurred in the morning before the temperature rose above the critical level. *Oryza glaberrima* has a unique early-flowering characteristic. It was postulated that incorporation of this characteristic into improved varieties could contribute to minimizing high-temperature sterility. Anthesis time in two crosses of *O. glaberrima* and *O. sativa* (IR36) was examined (Fig. 3).

Contrary to the expectation, the time of anthesis of these hybrids was neither near that of *O. glaberrima* nor between that of the parents. It was even later than that of IR36. The hybrids inherited the longer opening period of *O. glaberrima*.

Genetic evaluation and utilization (GEU) program

International rice testing program

International Rice Testing Program

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INTERNATIONAL NURSERIES

Results for 368 nurseries of 1977 were received from 34 different countries during 1978. They continued to reflect the improved quality and quantity of observations made on nursery entries (Table 1). Individual nursery reports and an overall summary were published.

In 1978 the IRTP sent 862 nursery sets to 52 countries (Table 2). One nursery was dispatched to 12 countries from Egypt and 123 nursery sets were dispatched from CIAT to 21 Latin American countries. Two new nurseries were initiated: a rainfed lowland observational nursery (IRLRON) for the rainfed areas of Asia and an observational nursery for the arid regions (IRARON) for irrigated areas in the dry region of the Middle East and West Asia.

Table 1. Promising entries from various 1977 nurseries of the International Rice Testing Program. IRRI, 1978.

Nursery	Promising entries
	Yield
International Rice Yield Nursery-Early (IRYN-E)	IR36, MCR603-303, IR661-228-3-3, BS41b-Pn-89-5-3-1, BR51-46-1-C1, B1014b-Pn-18-1-4, BPI RI-2
International Rice Yield Nursery-Medium (IRYN-M)	BR51-46-5, BS41b-Kn-22-7-2, BR4, BR52-87-1, IR4422-89-3-6-1, Taichung sen yu 195
International Rice Yield Nursery-Late (IRYN-L)	IET5666 (RP925-109-2), IR4625-132-1-2, CR1002, CR1016, CR1009, IET3257
International Upland Rice Yield Nursery (IURYN)	IET1444, IR36, C 22, C46-1[illegible]/IR34[illegible], IR1529-430-3, KN361-1-8-6, IR3839-1
	General observational
International Rice Observational Nursery (IRON)	Biptab, BR13-47-3, BR51-46-5, BR51-199-1, BR160-2B-6, BR167-2B-6, CNSP217 (157), CR261-7039-236, IET4662 (RP974-210-10-11), IET4663 (Ratnagiri 9-5-3-2), IET4700 (RP967-11-1-2), IET5666 (RP933-89-3-1-4), S39C-68, IR2058-78-1-3-2-3, IR4723-217-3 (based on wider phenotypic acceptability)
	Physicochemical stress
International Upland Rice Observational Nursery (IURON)	C22, KN361-1-8-6, IR2061-522-6-6, IR5575 Sel. IR2061-628-1-6-4-3, DV110, ARC10372, Surjamukhi, Duler, IR1750-PSB-5, IR3880-10, IR3880-13, BPI 76 (NS), Salumpikit, DJ29, MRC172-6 (based on wider phenotypic acceptability)
International Rice Deep Water Observational Nursery (IRDWON)	BKN7022-10-1-4, CNL539, CNL31, BKN6986-66-2, CN540 (phenotypically rated good under medium-deep condition)
International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON)	*Salinity-vegetative stage:* CSSR 1, CSSR 2, IR2058-78-1-3-2-3, None Saitra, IR4-11, Nonseeli (Sel.), Poldaii *Salinity-maturity stage:* CSSR 1, CSSR 2, IR2053-436-1-2, IR2058-78-1-3-2-3, IR2153-38-3-5-2, Nonseeli (Sel.), Cut. No. 102, Poldaii *Alkalinity-vegetative stage:* IR2053-436-1-2, IR2058-71-1, IET5233 (RP972-39-4), IR32, IR4-11, IR1154-343 *Alkalinity-maturity stage:* IR2053-436-1-2, IR2823-388-5-6, IR1529-430-3, IR1630-210-2
International Rice Cold Tolerance Nursery (IRCTN)	Kaohsiung 68, K39-13-Bk-1-3-1-1, K39-62-B-1, K31-163-3 (Khudwani), P33-C-19 (HPU67), P33-C-39 (HPU 71)
	Biological stress
International Rice Blast Nursery (IRBN)	Resistant in most locations: IR3289-PP5-169-1, IR3289-PP11-169-4, IR3289-PP11-169-6, IR[illegible]-89-1-12, IR[illegible]-PP[illegible]-1, IR[illegible]-89-3-1-1, IR[illegible]-[illegible]1-1, IR[illegible]-[illegible]-1, IR1416-1-42-2-3-5, IR1416-128-5-6, Ta-po-cho-z, Tetep
International Rice Sheath Blight Nursery (IRSHBN)	IR3576-122-2-3-5, ARC[illegible], Ram Tulasi (Sel.) Sudurwa, Tabend, Tadulan (ACRIP), Tiotiaohari

Continued on opposite page

Table 1 continued

Nursery	Promising entries
International Rice Tungro Nursery (IRTN)	AC4228 (Dhulia), Ambemohar 159, ARC5985, ARC10453, ARC11353, ARC11554, Gam Pai 39-12-15, Pib 18, Uri Marsh
International Rice Brown Planthopper Nursery (IRBPHN)	Resistant at most locations and to all 3 biotypes at IRRI: Pib 33, Balamawee, Gengala, Rathu Heenati, Sinna Sivappu, Sudu Hendaruwala, Pib 21, Suduru Sambe
International Rice Gall Midge Nursery (IRGMN)	Resistant in India, Indonesia, and Sri Lanka: CR95-JR-46-1, CR159-4, CR159-1, CR200-1, IR4744-128-1-3, OB677, 75-189, RPW6-17 Resistant in Thailand: Some of W1263 and RD9 derivatives (e.g. R7-2760, R35-2760, BKNBR1030-12-1, BKNBR1031-4-3, BKNBR1094-56-1
International Rice Stem Borer Nursery (IRSBN)	Resistant at vegetative stage: CR94-13, IET3945 (RPS-1989-25-4), IET3640 (F34-73-269) IR1514A-5969, IR4791-69, IR4791-89, IR3941-87-1, IR36, TKM6 Resistant at maturity stage: CNT7246-2-2-3, CNT7246-4-2-1, IR1529-52-2, IR2070-34-2-3-5, IR2839-30-1-1, IR3301-127-2, IR4227-39-3-2, Pajam II

MONITORING PROGRAM

In 1978 use of monitoring tours for planning increased. Four tours focused on regional rice research activities in southern India and Sri Lanka, the southern part of South America, West Africa, and the Indus River plains of Pakistan and India. Six tours focused on specific programs: rice improvement in rainfed and deepwater areas; breeding for cold tolerance, long growth duration, resistance to virus diseases; and collaborative breeding for drought resistance. Four tours coincided with workshops or planning sessions: the IRTP Working Group Session in Peradeniya, Sri Lanka; the Deepwater Workshop in Calcutta, India; the Cold Tolerance Workshop in Suweon, Korea; and the WARDA Workshop in Ibadan, Nigeria.

Participants in monitoring tours observed

Table 2. Number and sources of more than 100,000 seed packets of rice varieties and lines distributed through the IRTP nurseries from IRRI in 1978. (Includes nursery sets screened for different stresses at IRRI.)

Nursery[a]	Sets dispatched (no.)	Entries[b] (no.)	Entries from: National programs, Improved, No.	National programs, Improved, %	National programs, Traditional, No.	National programs, Traditional, %	IRRI, Improved, No.	IRRI, Improved, %	IRRI, Germplasm bank, No.	IRRI, Germplasm bank, %	Packets (no.)
Yield											
• Wetland											
IRYN-E	99	27[c]	20	74			7	26			8,019
IRYN-M	77	27[c]	19	70			8	30			6,237
IRYN-L	29	29[c]	19	76			6	24			2,169
• Dryland											
IURYN	71	27[c]	12	44			15	56			5,652
General observational											
IRON	112	386	217	56			161	42	7	2	42,726
Physiochemical stress											
IUIRON	92	191	91	48			87	46	13	7	17,261
IRLRON	74	261	87	33	7	3	157	60	10	4	18,914
IRARON	2	137	84	60			42	30.3	1	0.7	276
IRBATON	30	72	8	11	6	8	53	74	5	7	2,169
IRCTN	80	236	94	40	37	16	80	33	14	6	11,769
IRDWON	25	74	45	61	16	22	12	16	1	1	1,[illegible]

Continued on next page

Table 2 continued

Nursery[a]	Sets dispatched (no.)	Entries[b] (no.)	Entries from: National programs: Improved No.	Improved %	Traditional No.	Traditional %	IRRI: Improved No.	Improved %	Germplasm bank No.	Germplasm bank %	Replicate (no.)
Biological stress											
• Diseases											
IRBN	66	527	203	39	63	12	261	49			34,702
IRTN	15	249	86	35	17	7	136	54	11	4	3,725
• Insects											
IRBPHN	38	134	52	39	11	8	38	27	35	26	5,692
IRGMN	24	113	73	65	6	5	32	28	2	2	3,651
Miscellaneous											
• Stress-resistant donors											
SB	21	20	9	45			9	45	2	1	400
SHB	20	20	5	25	1	5	11	55	3	15	400
• Deepwater and flood tolerance	12	28	8	29	15	53	4	14	1	4	336
• Sheath blight collaborative	6	152	81	53	11	7	44	29	16	11	700
Total	862	2,704	1,223	45	190	7	1,170	43	121	5	168,368

[a]IRYN-E = International Rice Yield Nursery-Early; IRYN-M = International Rice Yield Nursery Medium; IRYN-L = International Rice Yield Nursery-Late; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRLRON = International Rainfed Lowland Rice Observational Nursery; IRARON = International Rice Arid Regions Observational Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep-Water Observational Nursery; IRBN = International Rice Blast Nursery; IRTN = International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; SB = stem borer; SHB = sheath blight. [b]Including check varieties. [c]With three replications each.

and planned IRTP nurseries, and discussed collaborative research projects of mutual interest to scientists in national rice improvement programs. Participants in the virus monitoring tour focused on the virus collaborative project; those in the drought resistance monitoring tour in India, on the development of a collaborative breeding program for drought-prone areas. The African and South American tours laid the groundwork for future collaboration in rice improvement. The tour in the Indus River plains of Pakistan and India resulted in the development of increased germplasm exchange and cooperation between scientists in the two countries.

Recommendations made by the monitoring tours are published in individual reports, which are available at IRRI.

COMMUNICATION AND DATA DISSEMINATION

Publications that disseminate the vast amount of information and observations from the nurseries, planning and review sessions, and monitoring tours increased considerably in 1978. Nearly 16,000 copies of the following publications were distributed:

Program highlights
- 1977 International Rice Testing Program
- Highlights of 1977 IRTP nurseries
- Planning and review meetings
- Working Group Meeting (Sri Lanka)
- Advisory Group Meeting (IRRI)
- Report of a Rice Cold Tolerance Workshop (Korea)

Nursery reports and fieldbooks
- 1973 IRYN final reports
- 1974 IRYN final reports
- 1977 Preliminary and final reports

Yield: IRYN-E (Early)
IRYN-M (Medium)
IRYN-L (Late)
IURYN (Upland)

General observational: IRON

Physicochemical stress:
IURON (Upland)
IRCTN (Cold)

IRSATON (Salinity- alkalinity)
IRDWON (Deep water)

Biological stress:

IRBN (Blast)
IRSHBN (Sheath blight)
IRTN (Tungro)
IRBPHN (Brown planthopper)
IRGMN (Gall midge)
IRSBN (Stem borer)

- 1978 fieldbooks
  - Fieldbooks for 15 nurseries printed by computer
  - 1978 IRTP nurseries master fieldbooks

Monitoring tour reports

- Rice Improvement in South India and Sri Lanka
- Report of the Monitoring Tour to the Southern Region of South America (printed in English and Spanish at CIAT)
- Rainfed Rice in Indonesia
- Observations on Deepwater Rice in Thailand, Bangladesh, and India
- Rice Improvement Activities in Four West African Countries
- Observations on Rice Improvement in Indus River Plains of Pakistan and India
- Yield and Observational Nurseries (with Focus on Long-Duration Rice)
- Observations on Rice Virus Diseases in Indonesia, Thailand, and India
- Breeding for Drought Resistance in North and Eastern India and Northeast Thailand

Copies at all IRTP publications are available at IRRI.

RESEARCH LEADS FROM IRTP

Much feedback goes to national and IRRI scientists from nurseries and from discussions and observations of rice scientists during monitoring tours. The information gives research leads to the national programs and to IRRI's GEU program. It also helps IRRI more effectively meet the needs of national program scientists. The following are a few of the research leads from the IRTP:

- Because donors for resistance to many major and minor stresses are being identified, the use of resistant donors in breeding programs and cooperative genetic studies should be intensified in areas where different strains or biotypes exist.
- Because varieties from Sri Lanka, southern India, Malaysia, and Indonesia perform well with irrigation in the West African countries in the same latitude zone, more materials from those sources should be tested at the sites in the latter region.
- Because the dryland environment markedly influences the response of semidwarf, intermediate-height, and tall varieties, a collaborative research project should determine the plant type best suited to selected dryland conditions.
- Because varieties that react differentially to blast at various sites are being identified, studies on the genetics of blast resistance should be intensified and a new international set of differentials identified and used.
- Because the biotypes of brown planthoppers in South Asia are distinct compared with those in Southeast Asia, collaborative biotype and genetic studies involving the two regions should be intensified.
- Because several varieties in the IRBPHN show good field resistance but do not have major genes for resistance, collaborative studies evaluating such varieties against different biotypes in various countries should be enlarged.
- Because there is strong evidence that biotypes of gall midge exist and the Thailand biotype seems to be distinct from the others, collaborative genetic studies should be started.
- Because donors for various traits that contribute to cold tolerance have been identified, they should be used more extensively.
- Because plant response to alkalinity and salinity is greatly influenced by growth stage, weather, and soil, there should be more testing of varieties for tolerance for alkalinity and salinity in relation to these factors the areas where the problems exist.

Integrated GEU program

Plant Breeding Department, Office of Information Services, and all GEU Departments

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The GEU program placed increasing emphasis on assistance to national scientists by providing germplasm and making crosses for them, providing early generation and fixed lines, and inviting them to make selections from materials growing at IRRI.

EXCHANGE OF GERMPLASM

Plant Breeding Department

Requests for 14,948 packets of seed of improved breeding lines were filled for scientists in 39 countries. The International Rice Testing Program sent an additional 69,087 packets of GEU's best improved lines and varieties to national programs. From the germplasm bank 7,647 packets of seed were supplied to 159 foreign researchers. F_2 seeds from 1,024 crosses were sent to scientists in 12 countries.

IRRI LINES NAMED IN NATIONAL PROGRAMS

Plant Breeding Department

Twelve IRRI lines were named as varieties in national programs in 1978 (Table 1). That brought the number of IRRI lines named in national programs to 64. With the varieties named directly by IRRI the grand total is 75. The IRRI lines named as varieties in national programs are described below:

Asahan (IR2071-621-2-3), a semidwarf sister line of IR36 and IR42, has long slender grains. It is resistant to bacterial blight, tungro, grassy stunt, and brown planthopper, and was recommended for irrigated culture in Indonesia.

IR36 (IR2071-625-1-252) was officially approved for cultivation in Indonesia. It is widely grown there, and is suitable for dry seeding (*gogo-rancah*) and dryland culture. Indonesians prefer IR36 to other semidwarf varieties. Outstanding features of IR36 are cited in the 1976 Annual Report.

IR38 (IR2070-423-2-5-6) was officially approved for cultivation in Indonesia. It is most popular in East Java , here biotype 2 of the brown planthopper is most prevalent. Its outstanding features are cited in the 1976 Annual Report.

IR43 (IR1529-430-3) was recommended for dryland culture in the Philippines. IR43 has good drought resistance and showed superior performance at several sites in the International Upland Rice Yield Nursery. IR43 has long slender grains and matures in 120 days. It is resistant to blast, bacterial blight, and green leafhopper. It was also approved for cultivation in Cuba as IR1529.

IR44 (IR2863-38-1) is a semidwarf selection with long slender grains and high amylose. It has sturdy straw and high yield potential. It is resistant to bacterial blight, tungro, green leafhopper, and biotypes 1 and 2 of the brown planthopper; and moderately resistant to blast. IR44 is recommended for irrigated culture in the Philippines.

IR45 (IR2035-242) was recommended for dryland culture in the Philippines. It has good drought resistance and long slender grains, and

Table 1. IRRI lines named as varieties in different countries in 1978.

Variety name	Selection no.	Cross	Country
Asahan	IR2071-621-2	IR1561-228-1-2//IR24[4]/*O. nivara*//CR94-13	Indonesia
IR36	IR2071-625-1	IR1561-228-1-2//IR24[4]/*O. nivara*//CR94-13	Indonesia
IR38	IR2070-423-2	IR20[8]/*O. nivara*//CR94-13	Indonesia
IR43	IR1529-430-3	IR305-3-17-1-3/IR661-1-140-3	Philippines
IR44	IR2863-38-1	IR1529-680/CR94-13//IR480	Philippines
IR45	IR2035-242	IR1416-128-5/IR1364-37-3-1//IR1824-1	Philippines
IR46	IR2058-78-1	IR1416-131-5/IR1364-37-3-1//IR1366-20-3-1/IR1539-37-3-1	Philippines
IR1529	IR1529-430-3	IR305-3-17-1-3/IR661-1-140-3	Cuba
NN3A	IR2071-625-1	IR1561-228-1-2//IR24[4]/*O. nivara*//CR94-13	Vietnam
NN4A	IR2070-734-3	IR20[8]/*O. nivara*//CR94-13	Vietnam
NN5A	IR2071-179-3	IR1561-228-1-2//IR24[4]/*O. nivara*//CR94-13	Vietnam
PR 103	IR661-1-140-3	IR8/IR127-2-2	India (Punjab)
Prasad	IR1561-216-6	IR579-48-1-2/IR747B2-6-3	India (Uttar Pradesh)
Tamale 1	IR1820-210-2	IR1539-60/IR1416-128-5	Ghana

is resistant to blast, green leafhopper, and biotypes 1 and 3 of brown planthopper. It matures in 120 days.

IR46 (IR2058-78-1-3-2-3) is the first IRRI line to be recommended for rainfed wetland culture in the Philippines. It has given high yields in rainfed wetland fields at several sites. It has long, slender, and translucent grains. It is resistant to blast, bacterial blight, and biotypes 1 and 3 of brown planthopper, and moderately resistant to tungro.

IR1529 (IR1529-430-3) was named in Cuba.

NN3A (IR2071-625-1-252), named in Vietnam, is the selection named IR36 in the Philippines (1976) and in Indonesia (1978). It is now replacing IR26 and TN73-2 (IR1561-228) in the Mekong Delta where biotype 2 of brown planthopper is widespread.

NN4A (IR2070-734-3-6-4), named in Vietnam, is a sister selection of IR32 and IR38. It has medium-long, translucent grains and is resistant to blast, bacterial blight, tungro, green leafhopper, and biotypes 1 and 2 of brown planthopper.

NN5A (IR2071-179-3-4), also named in Vietnam, is a sister selection of IR36 and IR42. It has long, slender, translucent grains and is resistant to blast, bacterial blight, tungro, grassy stunt, green leafhopper, and biotypes 1 and 2 of brown planthopper.

PR103 (IR661-1-140-3) is synonymous with IR24, named by IRRI in 1971. It was recommended in India (Punjab state) as a late-planted crop.

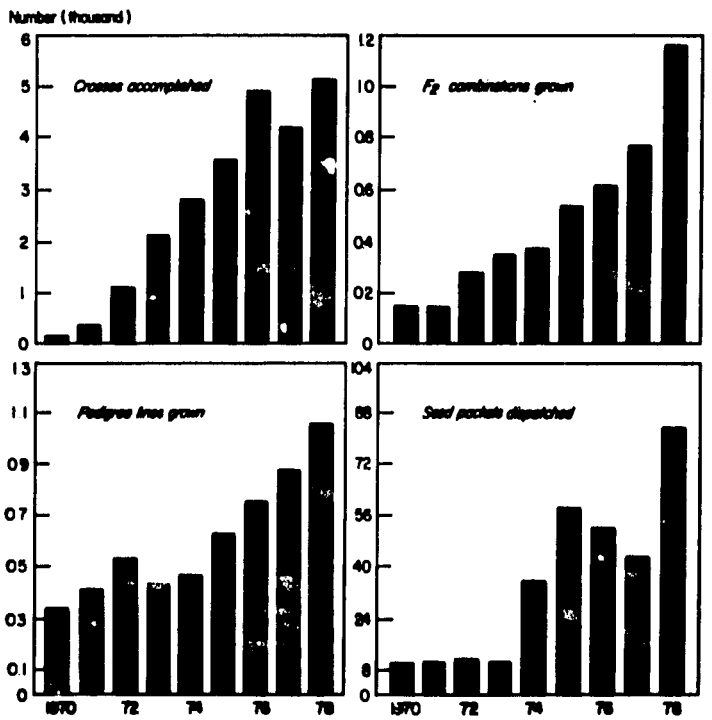
Prasad (IR1561-216-6-2) was recommended in India (U.P. State). It is early maturing and high yielding with long, slender, and translucent grains.

Tamale (IR1820-210-2), named in Ghana, is high yielding and has improved plant type, long slender grains, and blast resistance.

BREEDING OPERATIONS

Plant Breeding Department

IRRI continued to emphasize high-volume crossing to generate improved germplasm for diverse agroclimatic conditions and to diversify the genetic makeup of the breeding lines. In 1978 breeding operations increased (Fig. 1).



1. Growth of the IRRI GEU program. 1970–78.

Expansion of IRTP activities caused the increase in the number of seed packets dispatched.

Breeding work in 1978 concentrated on materials for irrigated areas with good water control, rainfed wetland areas, dryland areas, deepwater areas, adverse-soil areas, and areas with adverse temperature. Major attention was given to exposing early segregating breeding material to diverse agroclimatic conditions for development of improved germplasm suitable for various regions. To carry out this aspect of breeding more effectively, several collaborative projects were developed with national program scientists.

Hybridization. The hybridization block consisted of 317 dry-season and 293 wet-season entries. It had newly identified unimproved donor parents and breeding lines with resistance to specific diseases, insects, and other plant stresses (Table 2). It also included several new entries with submergence tolerance, drought resistance, and tolerance for brown planthopper in the field plus outstanding lines in the IRTP nurseries.

Total crosses were 5,003, of which 2,188 were single and 2,815 multiple (Table 3). Crossing for rainfed wetland areas was emphasized and a number of crosses combined drought resistance and flood tolerance with improved agronomic characteristics for rainfed culture. One hundred seventy-nine crosses were made to initiate genetic studies on heat tolerance, submergence tolerance, blast resistance, and ratooning ability.

Table 2. Composition of 1978 IRRI hybridization block.

Problem areas	Donor parents (no.)	
	Dry season	Wet season
Agronomic characteristics	105	75
Disease resistance	36	33
Insect resistance	26	47
High protein	6	3
Drought resistance	33	39
Adverse soils	20	18
Deepwater and flood tolerance	19	33
Cold tolerance	19	14
Miscellaneous	66	32
Total	317	293

Table 3. IRRI crosses made in 1978.

Target or problem	Dry-season crosses (no.)		Wet-season crosses (no.)	
	Single	Multiple	Single	Multiple
Dryland areas	46	112	—	75
Irrigated wetland areas	170	262	126	98
Rainfed wetland areas	262	1111	300	600
Adverse-soil areas	33	77	36	40
Sheath blight resistance	180	—	15	3
Blast resistance	87	41	23	21
Stem borer resistance	—	—	36	—
Deepwater areas	334	—	3	—
Cold tolerance areas	210	40	101	329
Long vegetative phase	46	—	—	—
Whorl maggot resistance	8	—	—	—
Miscellaneous	47	93	36	—
Total	1401	1636	687	1179

Testing of breeding lines and germplasm. In 1978, 107,444 progenies from 1,082 cross combinations were screened for various GEU traits (Table 4). In replicated yield trials in the dry season, 356 improved breeding lines from 140 crosses, and 537 lines from 185 crosses were evaluated. In observational trials more than 1,000 improved breeding lines and varieties were evaluated.

The germplasm bank supplied a total of 31,941 seed packets of *O. sativa* accessions and 911 samples of other *Oryza* species to problem-area scientists for screening. From the germplasm bank planting, 6,216 accessions were screened for resistance to bacterial blight and 2,103 accessions for resistance to sheath blight.

NEW LINES WITH MULTIPLE ATTRIBUTES

All GEU Departments

Most of the improved breeding lines for irrigated areas have broad-spectrum resistance to diseases and insects (Table 5). Improved breeding lines resistant to all three biotypes of the brown planthopper have been developed.

Several breeding lines mature earlier than IR36 — the most popular variety of 110 days

Table 4. Number of progenies in the 1978 pedigree nursery screened for GEU traits, IRRI.

Traits	Progenies (no.)	Cross combinations (no.)
Insect resistance		
Brown planthopper		
Biotype 1	56,778	889
Biotype 2	57,836	984
Biotype 3	15,784	127
Green leafhopper	62,886	889
Whitebacked planthopper	5,741	94
Rice whorl maggot	1,487	28
Stem borer (yellow)	800	2
Disease resistance		
Blast		
IRRI	82,944	973
Leyte, Philippines	4,832	33
Bacterial leaf blight		
X_o 4	86,234	966
X_o 6	4,834	34
Grassy stunt virus	537	32
Rice tungro virus	38,982	496
Tolerance for drought, adverse soils, and flood		
Drought		
Field	4,032	87
Greenhouse	162	10
Soil salinity and alkalinity	9,313	187
Flood tolerance		
Submergence	247	17
Internode elongation	2,917	48
Grain quality characteristics		
Seed size and appearance	88,857	815
Gel consistency	33,086	403
Amylose content	9,080	229
Protein per seed	3	1
Grain elongation	115	5
Total of different progenies screened	107,444	1,082

growth duration — and have comparable grain yields (Table 5).

Relatively long growth duration and intermediate plant stature have been emphasized for some rainfed wetland conditions where one crop is feasible. Lines IR4219-35-3-3, IR4570-83-3-3-2, IR9264-321-3, and IR9288-0-0-B240-1 combine good eating quality with plant type, growth duration, and other characteristics suitable for rainfed wetland situations.

Only a few lines for dryland rice culture have been identified. Two (IR3839-1 and IR6115-1-1-1) have high levels of drought resistance and intermediate plant stature.

IR4422-480-2-3-3 and IR9884-54-3 combine a high level of tolerance for salinity with grain yield, and are also resistant to major diseases and insects (Table 5).

BREEDING METHODS

Plant Breeding Department

The pedigree method was used in developing breeding lines with multiple resistance to insects and diseases. The backcross method transferred brown planthopper resistance from Babawee and Rathu Heenati, and green leafhopper resistance from *Oryza glaberrima*.

To develop photoperiod-sensitive improved breeding lines, the rapid generation advance technique was followed. About 50 improved breeding lines of intermediate stature and resistance to major insects and diseases were identified. Several were promising in tests at two sites in India, Yezin in Burma, and IRRI (Table 6).

Induction of monogenic recessive, male sterile mutants. The application in 1978 of the chemical mutagen ethyleneimine to IR36 produced four monogenic recessive male sterile mutants. The mutants showed complete fertility under controlled pollination, but gave no seed when selfed. In the field, the male sterile gave about 15–34% seed set when outcrossed with neighboring pollen donors.

To develop the breeding scheme for composite populations and facilitate frequent recombination, 26 crosses were made between the mutant and the donors of disease and insect resistance, tolerance for adverse soils, and good agronomic characters. The possible use of the male sterile mutants in the IRRI breeding program is outlined in Figure 2.

INTERNATIONAL RICE GENETIC SURVEY

Office of Information Services and Plant Breeding Department

An international rice genetic survey was initiated in 1978 to establish a bank of permanent records on the genetic ancestry of rice varieties and on hybridizations made in national programs. The origin of more than 1,000 older varieties still widely grown by farmers or often

Table 5. Important characteristics of selected promising lines, IRRI, 1978.

Designation and cross	Ht (cm)	Growth duration (days)	Amylose content (%)	Reaction[a] to: Blast	Bacterial blight	Tungro	Grassy stunt	Green leafhopper	BPH biotype[b] 1	2	3	Special traits and potential[c]
Irrigated rice												
IR2061-35-3-1, IR841-65/ IR1017-3//CR94-13	110	130	15	R	R	R	R	R	R	R	S	Aromatic, excellent grain, I.
IR4629-53-6-4, IR2061-125-37/ CR94-13	110	125	25	R	R	R	R	R	R	R	S	Very vigorous, I
IR4629-66-1-3-2, IR1702-74-3/ IR2061-494//IR2061-478-2	115	120	26	R	R	R	—	R	R	S	R	Excellent sturdy line, I
IR4629-66-3-3-2, IR1702-74/ IR1721-11//IR2061-481-2	115	130	22	R	R	R	R	R	R	R	S	I, RW
IR4629-110-1-2, Nam Sagui/ IR2071-639//IR2061-214	113	118	26	R	R	R	—	R	R	R	S	Very sturdy stem, I
IR4629-221-3-3-3-2, IR2061-465-1-5/ IR2071-625-1	102	105	25	R	R	—	R	R	R	R	S	Early maturing, I
IR4630-200-3-3-3-1, IR26/ IR2053-621-1//IR2071-625-1	102	105	21	R	R	R	—	R	R	R	S	Early maturing, I
IR4224-117-3-3-3-2, IR2153-14-1-6/ IR26//IR2071-625-1	103	106	24	R	R	—	—	R	R	R	S	Early maturing, I
IR13149-143-1, Cauvery/2*IR2071 -625-1	90	100	25	R	R	—	—	R	R	R	S	Early maturing, I
IR13240-10-1, IR30/Bahawee/ IR2071-625-1	108	108	25	R	R	—	R	R	R	R	R	Resistant to 3 biotypes of BPH; I
Rainfed wetland rice												
IR4219-35-3-3, IR34/IR480-5-9-3	130	135	27	MR	R	R	—	R	R	S	R	Intermediate height, I, RW
IR5853-110-6, Nam Sagui/ IR2071-639//IR2061-214	107	118	27	R	R	R	—	R	R	R	S	Drought resistance, I, RW
IR5854-321-3,Mahsuri/2*IR2061-213	125	140	27	R	R	R	—	R	R	R	S	Intermediate height, RW
IR5858-9-0-5240-1, Tarao Beo/ IR2061-213-2-1S//IR34	130	170	—	—	R	—	—	R	R	S	R	Photoperiod sensitive, RW
IR4422-488-2-3-3, IR2049-134-2/ IR2061-125-37	110	121	25	MR	R	R	R	R	R	S	R	Salinity tolerant[d], RW
IR5854-84-3, Nona Bokra/ IR2070-414//IR34	112	123	—	MR	R	—	—	R	R	R	S	Salinity tolerant, RW
Dryland rice												
IR5629-1, Pulta I-2/IR1529-680// IR442-2/IR1 21	96	115	25	R	R	S	S	R	S	S	S	Drought resistant, D
IR5115-1-1-1, IR1529-680/ Moroberekan	93	128	—	R	S	S	S	R	S	S	S	Drought resistant, D

[a]R = resistant, MR = moderately resistant, S = susceptible. [b]Brown planthopper. [c]Potentially suited to certain growing conditions, I = irrigated, RW = rainfed wetland, D = dryland.

Table 6. The photoperiod-sensitive progeny by rapid generation advance rated outstanding at different locations, IRRI, 1978.

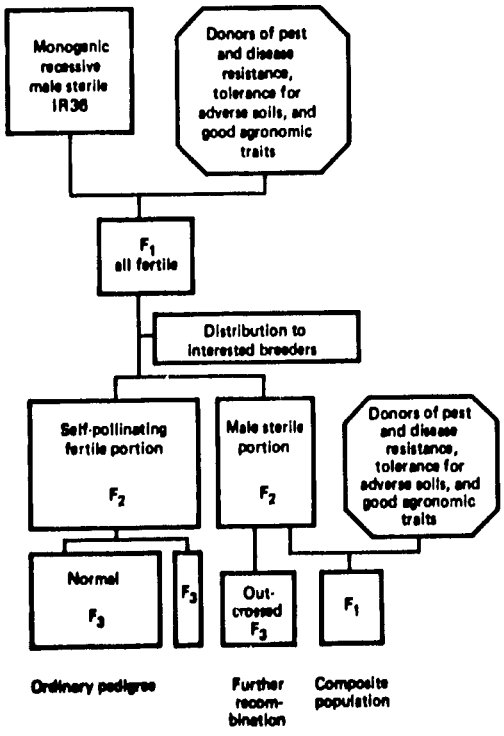
Designation	Days (no.) to flowering		Reaction* to		
	Wet season	Dry season	Bacterial blight	Brown planthopper	Green leafhopper
IR7732-0-0-A86-1, Tersao Bao/IR34	123	95	R	R	R
IR8274-0-0-Bu7-1, Sersh Krahem/IR28//IR34	123	95	R	R/S	R
IR8289-0-0-A146-1, Tersao Bao/IR2061-213-2-16//IR34	139	95	R	R	R/S
IR8289-0-0-B240-1, "	143	81	R	R	R
IR8289-0-0-B304-1, (floater) "	139	88	R	R	S
IR8289-0-0-B326-2, "	132	80	R	R	MS
IR8289-0-0-B342-1, "	140	88	R	R	MR

*R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, R/S = segregating.

used as parents in crossbreeding programs was recorded. The genetic background of more than 700 of those varieties was traced to their original progenitors. Similar data were compiled for about 350 rices released by national rice improvement programs during the post-IR8 era. The records are available to rice scientists.

Progenitor data cards were completed for the parents of all varieties developed by hybridization, pure line selection, or mutation. If a parent was developed by crossbreeding, cards were made for each of its progenitors. The parents in more than 12,000 hybridizations made in national programs were recorded on punched computer cards. The data bank will, for example, enable a scientist, who is screening varieties from a half dozen nations for resistance, to trace the ancestry of the resistant rices and find common ancestors that could be the sources of the resistance.

The survey included a request to scientists in the national rice improvement programs to submit lists of older varieties, newly released varieties, and elite breeding lines, and hybridization records since the initiation of crossbreeding at each station. Researchers may request information on the background of specific rice varieties.



2. Use of monogenic male sterility. IRRI, 1978.

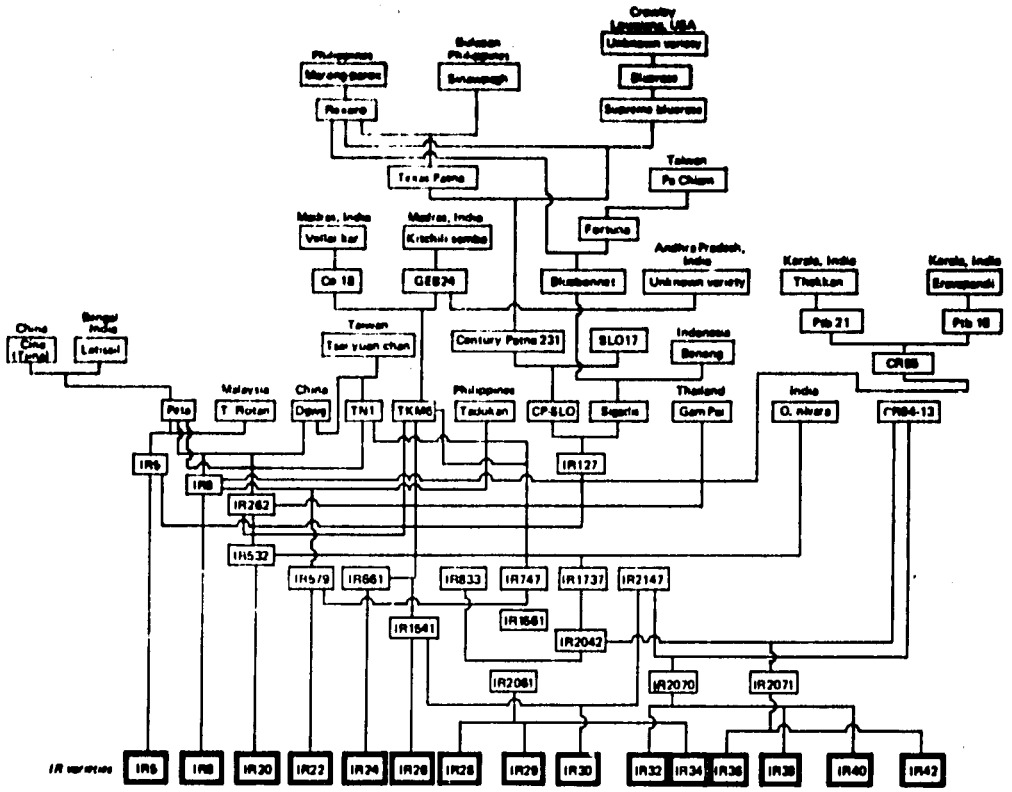
GENETIC INTERRELATIONSHIPS OF IMPROVED RICE VARIETIES

Office of Information Services and Plant Breeding Department

Maternal origin of IR and national varieties. The genetic ancestry of 15 named IR varieties, including 4 named as IR varieties by the Philippines, was traced. All varieties are from crosses made at IRRI, involving 11 parents that trace to 18 original land races from 8 countries (Fig. 3). All IR varieties trace to the maternal parent *Cina* via Indonesia. Thus, components of the cytoplasm of all IR varieties are similar.

Eight of 13 new varieties released in Bangladesh since 1968 derive from the female progenitor Cina. Cina is the ultimate maternal ancestor of 22% of the improved varieties in India released since 1960.

In 1975, more than half of the rice land in



3. The derivation of IR varieties. Female parents are on the left, male parents on the right. 1978.

Indonesia was estimated to be planted to six varieties, which all trace maternally to Cina. Of 27 varieties released in Indonesia from 1965 to 1975, 20 are female derivatives of Cina.

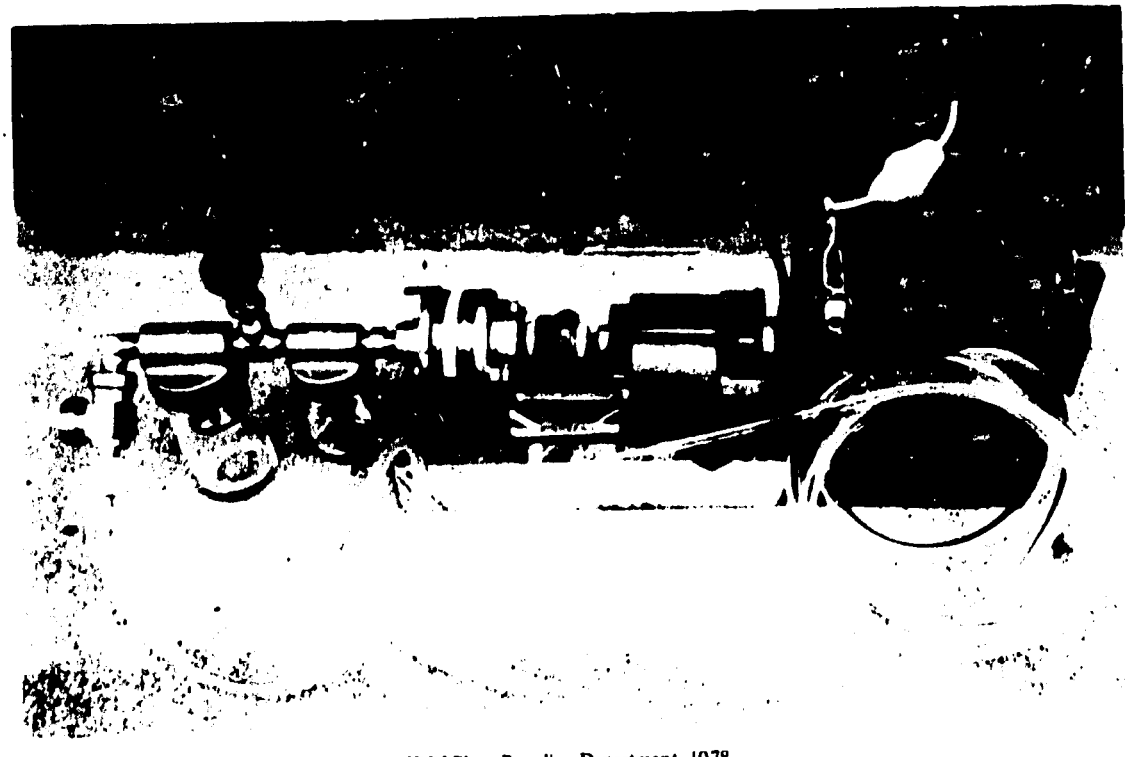
In Korea, Tongil and its selections are the most widely grown. Cina is the ultimate maternal parent of Tongil and also of a new popular variety, Yushin.

By 1977, 68% of the Philippines' rice land was planted to improved varieties, mostly the IR, Cina-derivative varieties. A list of 20 Sri Lanka improved varieties was compiled; 15 of the varieties derive maternally from Cina. Of 12 improved varieties released in Thailand since 1969, 3 have Cina as their ultimate female progenitor.

Maternal origin of potential improved varieties. To determine the maternal base that might be expected in future varieties, the female parentage of elite breeding lines and of female parents used in recent crosses was traced.

Seventy-nine elite varieties and breeding lines from 10 nations and IRRI were in the 1978 early, intermediate, and late-maturing sets in the International Rice Yield Nursery grown at about 45 sites in 20 nations. About 60% of the IRYN entries trace back to Cina. National program breeders acquire much of their introduced genetic materials through such trials.

From 36 to 92% of the elite breeding lines included in nurseries and in IRRI screening trials for tolerance for salinity, alkalinity, iron toxicity, phosphorus deficiency, and zinc deficiency are progeny of Cina. Cina is also the ultimate female progenitor of more than half of the most promising IRRI lines developed for intermediate amylose, high protein, and resistance to the striped stem borer. Forty-four percent of the female parents of the first 20,000 crosses (1962–77) made at IRRI derived maternally from Cina. The trend, however, is declining. Although 53% of the crosses made in



4. Portable vacuum emasculator developed in IRRI Plant Breeding Department, 1978.

1974 had Cina cytoplasm, only 37% of the crosses had it in 1977.

PORTABLE VACUUM EMASCULATOR

Plant Breeding Department

Several of the major rice improvement programs in Asia use an emasculator that is rather expensive (more than US$500) and not easily portable. Its use is essentially limited to a greenhouse or screenhouse with a 220-V AC power supply, which makes it impractical for many small rice improvement programs.

L. E. Crane and H. M. Beachell of Beaumont, Texas, USA, designed the first portable vacuum emasculator for rice in the early 1950s. J. E. Scott of the Beaumont station made some further modifications. Many of their ideas were used in building the portable emasculator shown in Figure 4. The emasculator has a pump that develops a continuous vacuum (508 mm Hg), powered by a 12-V DC electric motor that develops 1/25 hp at 4,000 rpm. Accessories include an air filter, an anther trap, tygon tubing, disposable pipette, and appropriate fittings. Power is provided by a small 12-V motorcycle battery that is periodically recharged.

The portable emasculator, including the battery and carrying box, weighs 4.4 kg. A properly designed box will permit the unit to float. The capacity of the unit, with 1 operator, ranges from 6 to 12 panicles/hour. The entire unit, including a box and a small battery charger, costs about $150. Prices may vary from country to country, depending on the local availability of the components. Units may be purchased at cost through the Plant Breeding Department, IRRI.

Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics Department

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GERMPLASM BANK

As of 31 December 1978 the germplasm computer data bank contained 1,314,870 records representing 1) complete information on varietal origin, seed source, and name; and 2) all available information on 38 basic morphoagronomic characteristics (1976 Annual Report) and 37 GEU traits (1976 Annual Report) for 38,535 registered accessions of *O sativa*. The germplasm bank information retrieval system, which was developed and completed in late 1976 to provide instant access to and retrieval of information from the germplasm data bank, was used constantly by GEU scientists. The most common requests were for retrieval of accessions that satisfy a combination of specific traits. Other requests were for the retrieval of all accessions having data on a particular GEU trait or of all accessions from a specific country of origin.

For evaluation of cultivars from the germplasm bank under the GEU program, computer-generated data sheets containing information on accession number, name, and characters relevant to the specific test were provided to GEU scientists. The use of the standard data sheets facilitates data collection, simplifies data encoding, and minimizes errors commonly encountered in manually prepared data sheets.

Data on the 38 basic morphoagronomic characteristics of about 26,000 accessions in the germplasm data bank were analyzed to identify features that are of general interest to rice researchers. The information has proved useful in identifying varieties with unusual characters such as heavy grains, very early maturity, and high protein.

BREEDING AND TESTING

Breeding records of all crosses made at IRRI are computerized. The names and sources of the 2 immediate parents for each of the 25,066 crosses so far made at IRRI are stored in the history-of-cross data file. Information on the immediate parentage of IRRI crosses can be retrieved and reproduced at a slight cost. That has made possible the publication and distribution to rice researchers of the first 2 volumes of *Parentage of IRRI Crosses*, each of which describes 10,000 crosses.

Another use of the history-of-cross file is in searching for crosses that share some common features. Thus, a computer program that will search for all IRRI crosses that involve a given parent has been developed.

A computer-based system for the inventory of all selected lines from IRRI crosses has been developed. The inventory system records all selected plants or lines in each generation and prints back a fieldbook that identifies the pedigree of those selections, for use in the nursery of the succeeding generation. The system is now operational for the F_1 and F_2 nurseries, the pedigree nursery, the observational yield trials, the hybridization blocks, the replicated yield trials, and the elite lines. The inventory also maintains the performance records on various traits evaluated by the GEU scientists of all selected lines for all generations from as early as F_3 to the advanced trials, such as the replicated yield trials. Thus, in evaluating the merits of any line, breeders and GEU scientists can be aided by a complete historical performance of that line and of any of its relatives.

INTERNATIONAL RICE TESTING PROGRAM

The International Rice Testing Program (IRTP) coordinates the sharing and testing of varieties and breeding lines by the world's rice scientists. It distributes a large number of nursery sets to many test sites in various countries each year and receives a large volume of data from them.

The primary objective for computerizing the management of IRTP data is to increase the accuracy and speed with which data coming from different nurseries with diverse requirements are analyzed and summarized. IRRI now has a computerized data management system that verifies the validity of the data; checks, for each test site, the adequacy of the stress level needed for a meaningful evaluation; subjects the data to statistical analysis; and summarizes and evaluates the reliability of the results. The system also provides computer-generated fieldbooks for the various nurseries as well as a master fieldbook.

Control and management of rice pests

Diseases

Plant Pathology Department

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BLAST

The severe 1978 blast epidemic in Korea, which struck previously resistant varieties, and the increasing severity of sheath rot throughout the rice-growing world emphasize that rice fungus diseases are not yet satisfactorily managed. Host resistance is generally recognized as the most effective and economic means of controlling fungus diseases. Emphasis in fungus disease control has been shifted to better understand the genetic variability of the pathogens, especially *Pyricularia oryzae* and *Rhynchosporium oryzae*, and to develop more reliable control methods. Disease resistance is a function not only of the rice plant but also of the disease-inciting pathogens.

Leaf spore-trapping efficiency. The number of lesions that develop on a rice leaf is a component of blast resistance. The number of lesions that develop on the rice plant has correlated well with the number of conidia deposited on the leaf. Because blast-resistant varieties such as Carreon and Tetep consistently show only few lesions of any type, their spore-trapping efficiency and that of IR36 were compared with the efficiency of the susceptible check IR442.

The efficiency of spore trapping was assessed with the dip method of inoculation that was expected to reflect both the degree of hydrophobicity of the rice leaf surfaces and the resultant inoculum runoff that would naturally occur in the field.

Plants were grown in a glasshouse until they were 3 to 4 weeks old. Fully developed second leaves, with tips downward, were then individually dipped in a conidial suspension (about 20 conidia/low-power microscope field) of *P. oryzae* isolate race P38. The leaves were dipped for 20 seconds, then drained for 20 seconds. Midsegments from the upper third of the leaves were stained with aniline blue and the spores on

Table 1. Deposition of *Pyricularia oryzae* conidia on adaxial leaf surfaces of blast-resistant and susceptible (IR442) rice varieties. IRRI, 1978.

Nature of infection	Conidia[a] (no./microscope field 12.5 × 20)			
	Carreon	Tetep	IR36	IR442
Artificial	1.9	0.9	1.6	3.9
"	1.4	4.1	2.5	3.5
"	1.1	1.5	1.5	2.3
Natural	5.6	3.6	[b]	10.8

[a]Figures are means of about 200 observations on segments from 3 leaves. [b]Not investigated.

Table 2. Effect of various concentrations of fungicide suspensions on the germination of spores of blast, *Cercospora* leaf spot, and leaf mold pathogens. IRRI, 1978.

Treatment[a]	Conen (% formulation)	Spore germination[b] (%)		
		Blast	*Cercospora* leaf spot	Leaf mold
Control (sterile distilled H_2O)	—	94	83	96
Hinosan TCP (35% WP)	0.20	0	0	0
	0.14	0	11	0
	0.08	3	64	0
	0.06	1	57	0
CGA 49104 (50% WP)	0.24	0	1	0
	0.12	2	4	0
	0.06	8	2	0
	0.03	75	97	26
Cercobin M (70% WP)	0.24	17	7	1
	0.125	31	4	1
	0.06	22	6	7
	0.025	67	2	12
PP389 JF 5616 (50% WP)	0.64	68	4	0
	0.32	78	58	13
	0.16	82	34	58
	0.08	87	83	68
Benlate (50% WP)	0.24	84	38	68
	0.12	82	84	82
	0.06	82	76	82
	0.03	88	74	38

[a]WP = wettable powder. [b]After 24-hour incubation.

the adaxial surface were counted under a microscope. The experiment was repeated three times.

The spore-trapping efficiency of Carreon, Tetep, and IR36 leaves seemed less than that of IR442 (Table 1).

Chemical control. Eighteen fungicides were evaluated for control of blast disease in 1978. Five were evaluated in the laboratory for inhibition of spore germination of the blast pathogen. In a preliminary trial, Hinosan TCP, CGA 49104, and Cercobin M controlled the pathogen, especially at higher test concentrations (Table 2).

Twelve systemic fungicides at various application rates were tested as seed treatment for leaf blast control. Preliminary results showed that CGA 49104 gave effective control. Its efficacy lasted more than 1 month after seeding (Table 3). Phytotoxic effects were observed with all three application rates, especially the two higher rates. Lower and nonphytotoxic rates are being tested. Two other fungicide samples, PP389 JF5816 and Cercobin M, also controlled leaf blast, especially at the two higher test rates.

In a field evaluation, eight fungicides were applied twice as weekly spray (the first spray of flowering) to control neck blast on IR442-2-58. Control was achieved with Benlate, Hinosan TCP, CGA 49104, Top Cop, and M7007 PB20 (Table 4). In a similar study using C22, Dithane M-45, and the five fungicides also were effective (Table 5).

Table 3. Effect of seed treatment with systemic fungicides used at various rates of applications for leaf blast control, IRRI, 1978.

Treatment[a]	Fungicide per kg seed	Lesions[b] (no./seedling)		
		1st reading[c]	2d reading[d]	3d reading[e]
Control	—	30.7	188.1	181.9
CGA 49104 (50% WP)	40 g	0	0	0
	32 g	0	0	0
	16 g	0	1.9	1.9
PP389 JF 5816 (50% WP)	40 g	0	7.3	12.8
	32 g	0.2	19.4	19.6
	16 g	0	47.1	67.6
Cercobin M (70% WP)	40 g	0.8	1.6	1.8
	32 g	3.6	8.1	11.6
	16 g	8.0	102.2	137.4
Fuji-One (40% EC)	40 ml	26.6	82.6	109.9
	32 ml	15.7	82.5	95.9
	16 ml	24.4	89.5	95.6
Benlate (50% WP)	40 g	3.8	89.6	117.4
	32 g	6.5	122.4	147.8
	16 g	5.6	169.3	231.0
Dolcene MX (76% WP)	40 g	19.9	121.5	139.6
	30 g	6.5	95.2	141.2
	20 g	20.2	137.5	164.0
RH 2161 (24.2%)	8 ml	20.9	140.1	195.6
	4 ml	15.6	89.5	111.6
	2 ml	17.5	169.5	177.2
BAS 3302F (82% WP)	40 g	32.3	169.2	192.5
	20 g	19.6	222.6	249.7
	10 g	16.2	269.3	229.6
BAS 3060F (75% WP)	40 g	8.5	192.1	197.8
	20 g	22.6	149.6	176.2
	10 g	30.7	223.8	227.4
Bucan (65% WP)	10 g	21.1	149.8	169.0
	5 g	17.4	121.6	141.8
	2.5 g	22.9	139.5	167.6
TCMTB (10% dust)	30 g	25.0	213.4	219.3
	10 g	30.3	171.7	192.3
	5 g	99.6	236.2	227.1
Vitavax (75% WP)	3.2 g	34.7	169.2	169.2
	2.8 g	41.4	116.6	162.2
	2.4 g	26.0	169.6	162.7

[a]WP = wettable powder, EC = emulsifiable concentrate. [b]Mean of 25 seedlings. [c]Taken 3 wk after seeding. [d]Taken 4 wk after seeding. [e]Taken 5 wk after seeding.

Table 4. Effect of fungicide sprays on control of neck blast on [illegible] in a dryland field.[a] IRRI, 1978.

Treatment	Application rate (formulation/ha)	Neck blast infection (%)	Field grains (%)	Grain yield (t/ha)
Benlate ([illegible] WP[b])	1 kg	18.2 a	80.2 a	1.13 a
Hinosan TCP (35% WP)	1 kg	25.1 b	74.2 ab	1.02 ab
CGA 49104 (50% WP)	2 kg	27.0 b	70.9 ab	0.91 ab
Top Cop (84.4%)	6 liters	30.0 b	72.8 ab	0.88 ab
M7007 PB20 (20% WP)	1 kg	32.2 b	75.8 ab	0.88 ab
M9963	1 kg	32.9 bc	70.7 ab	0.91 ab
Dithane M-45 (80% WP)	2 kg	34.8 bc	70.0 ab	0.74 b
RH 2161 (24.2%)	1 liter	38.9 bc	70.9 a	0.83 ab
Control (unsprayed)	—	50.6 c	71.6 b	0.70 b

[a]Mean of 5 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Wettable powder.

Table 5. Effect of fungicide sprays on control of neck blast on C22 in a dryland field.[a] IRRI, 1978.

Treatment	Application rate (formulation/ha)	Neck blast infection (%)	Grain yield (t/ha)
Hinosan TCP (35% WP)	1 kg	10.5 a	1.64 bc
Dithane M-45 (80% WP)	2 kg	10.7 a	2.24 a
Top Cop (84.4%)	6 liters	11.7 ab	1.51 c
CGA 49104 (50% WP)	2 kg	13.1 ab	1.52 c
Benlate (50% WP)	1 kg	13.9 ab	1.98 ab
M7007 (PB20 (20% WP)	1 kg	13.9 ab	2.08 a
M9963	1 kg	17.1 bc	1.98 ab
RH 2161 (24.2%)	1 liter	17.7 bc	2.10 a
Control (unsprayed)	—	22.5 c	1.30 c

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

SHEATH BLIGHT

Chemical control. Chemical control is the only method available for successful management of sheath blight disease because no satisfactory source of resistance is available. A follow-up test on iprodione 50 WP and validamycin was conducted in the 1978 dry season to further assess their efficacy in sheath blight control.

The test was in a randomized complete block design with 7 treatments (7.2 m²) and 4 replications. The plants were inoculated at the booting stage with the use of rice grain culture.

Iprodione, which was previously used at 3.0 kg/ha in 4 sprays, was applied at 2.0 and 1.0 kg/ha in 3 and 2 sprays at 1-week intervals. Validamycin, which was effective at the rate of 1.5 liters/ha in 1975 but performed poorly at the same rate in 1977, was tested at 2.0 liters/ha.

Iprodione gave good control, even at a reduced rate of 1.0 kg/ha with 3 sprays. Higher rates of validamycin did not substantially

Table 6. Effect of timing and number of fungicide sprayings on control of sheath blight in the paddy field.[a] IRRI, 1978.

Treatment	Time (days) of inoculation before or after 1st spray	Sprayings (no.)	Rate (per ha)	Sheath blight disease rating[b,c]	Yield[c] (t/ha)
Iprodione	2 after	3	2.0 kg	3.1 a	6.21 ab
Iprodione	4 before	2	2.0 kg	4.0 b	6.11 ab
Iprodione	2 after	3	1.0 kg	4.2 b	6.29 a
Iprodione	4 before	2	1.0 kg	5.0 c	6.12 ab
Validamycin	2 before	3	2.0 liters	5.5 d	5.69 b
Validamycin	4 before	3	2.0 liters	5.2 cd	5.80 ab
Control (untreated)	—		—	6.0 e	4.44 c

[a]Mean of 4 replications, each with a plot area of 7.2 m². [b]Rated on a scale of 0 to 9: 0 = no infection observed, 9 = most severe infection. [c]In a column, means followed by a common letter are not significantly different at the 5% level.

increase its efficacy. Both fungicides increased the yield of IR1317-392-1-2 (Table 6).

Two wet-season experiments to evaluate four herbicides were destroyed by typhoons.

LEAF SCALD

Chemical control. Among five fungicides evaluated in the laboratory, Hinosan TCP most effectively controlled the germination of spores of the leaf scald pathogen (Table 2). It was followed closely by CGA 49104.

Effect of temperature. The effect of temperature on the growth of *Rhynchosporium oryzae* was studied, with 5 temperatures ranging from 15°C to 35°C at intervals of 5°C. Growth was daily measured for 7 days; the growth rate was slow at 15°C, maximum at 25°C, and zero at 35°C (Table 7).

Effect of different media. A study of the effect of different media on the growth of the leaf scald fungus found no remarkable differences (Table 8).

SHEATH ROT

In screenhouse tests conducted to establish the pathogenicity of *Acrocylindrium oryzae*, the organism was isolated from infected grains and subsequently cultured on sterilized rice grains. Test plants of IR1487-372-1-1 were inoculated by inserting 2-week-old inoculum in single-grain culture 1) on the ligule, 2) 1–2 cm deep between the leaf sheath and the stem, or 3) inside the flag leaf sheath just above the floret.

Disease development was observed daily for 30 days. Insertion between the leaf sheath and the stem of 62-day-old plants was an efficient pathogenicity test; 93% of the inoculated tillers showed infection. Disease symptoms appeared 5 days after inoculation; severely rotted leaf sheaths appeared at the point of inoculation a few days later. Inserting the culture inside the flag leaf sheath also produced characteristic disease symptoms 7 days later. The percentage of infection was low (46%) when the inoculum was placed on the ligule.

In previous trials, insertion between the leaf sheath and the stem of 50-day-old plants gave a higher percentage of infection; 97% of the inoculated leaf sheaths showed the disease. The studies indicate that *A. oryzae* is not a weak pathogen and can incite disease even in the absence of plant injury. This screening technique can be used in developing resistant varieties.

Table 7. Growth of *Rhynchosporium oryzae* at different temperatures. IRRI, 1978.

Temperature (°C)	Sporulation	Growth (mm) at daily readings						
		1	2	3	4	5	6	7
15	None	4.4[a]	8.4	12.2	18.6	24.2	28.4	36.6
20	Fairly abundant to abundant	8.4	17.4	29.6	44	49.2	62.8	76.2
25	Abundant to very abundant	11.2	24.8	43.2	59.4	69.6	82.8	85.0
30	Fairly abundant to very abundant	6.8	13.0	19.4	23.0	29.6	31.6	36.2
35	None	0	0	0	0	0	0	0

[a]Av of 3 plates.

Table 8. Growth of *Rhynchosporium oryzae* on different media. IRRI, 1978.

Medium	Growth (mm) at daily readings							
	1	2	3	4	5	6	7	8
V-8 juice	6	16	25.6	36.4	52.6	59.2	71.6	84.0
Coconut agar	3.6	13.4	31.0	37.0	47.4	60.8	72.8	78.0
Leaf decoction	9.2	17.2	31.0	41.8	53.8	62.0	77.2	82.0
Prune agar	7.2	16.2	26.6	35.8	47.0	56.8	68.2	78.0
Oatmeal	6.6	16.5	28.5	39.63	49.6	63.0	70.3	81.8
Potato dextrose agar	7.8	15.4	26.0	36.4	22.5	56.8	68	76.2
Yeast extract agar	6.0	18.0	28.0	40.0	50.0	56.0	72.0	78.0
Potato sucrose agar	8.0	19.0	29.0	38.0	48.0	60.0	68.0	76.0

NEW BACTERIAL DISEASE

A new disease was observed on IR129-192-2 plants in the International Rice Yield Nursery in 1978. The plants were infected until the maximum tillering stage. Infected plants had browned and water-soaked stem tissue at the basal internode, and rotted, giving off a foul odor. The symptoms indicated that the infection was probably caused by bacteria.

The infected tissues were isolated on peptone sucrose agar (PSA) and incubated at 30°C for 48 hours. Colonies were milky white, with irregular margins and rough surfaces at high temperature; they produced gas on Wakimoto's medium. A brown pigment diffused to the medium at 3 days after incubation. It was fluorescent under ultraviolet light.

Pathogenicity was tested by the multineedle prick method with a 24-hour culture of the bacterial isolate on a detached stem. The isolate was incubated at 30°C for 24 hours. The inoculated stems showed light- to dark-brown discolorations. Potted IR8 plants at the maximum tillering stage were also inoculated by the syringe technique. Symptoms began to appear 4 days later. The lesions extended upward and downward from the inoculation point, and the leaf sheath became dark brown. The lesions were restricted to the inoculated internodes, which became soft and discolored. Senescence of the outer leaves and leaf sheaths of infected plants was accelerated.

In initial bacteriological studies, the bacterium produced weak fluorescent pigment on King's B medium and did not form colonies typical of *Erwinia carotovora* on modified Drigaski's medium. The causal bacterium may be similar to the bacteria that cause *bacterial bruzone disease* of rice in Hungary, or *sheath brown rot* of rice in Japan. According to other researchers, the pathogen was closely related to *Pseudomonas marginales*, but different from a strain of *E. carotovora* that causes sheath rot.

LEAF BLIGHT AND KRESEK

Earlier studies (1977 Annual Report) suggested that no difference in pathogenicity resulted from cross inoculating rice with bacterial strains from plants infected with leaf blight and kresek. But the strain groups differed markedly in response to factors associated with the paddy (Table 9). The kresek strains appeared more tolerant of zinc sulfate and less sensitive to antibiotics, and survived longer in paddy water in the laboratory. Most kresek strains were sensitive to similar bacteriophage strains but the leaf blight strains varied in sensitivity to phage strains. Their growth in different dilutions in peptone sucrose medium did not differ.

The leaf blight strains appeared to be an ecotype distinct from the kresek strain. The strains select different infection courts in the rice plant. The kresek strains appear more adaptable to the paddy and cause infection, initiated primarily through the plant roots during transplanting, through the bacteria surviving in the paddy. Infection by the leaf blight strains usually starts from leaves.

Kresek infection developed in seedlings raised in seedbeds infested with *X. oryzae*. Kre-

Table 9. Difference between *Xanthomonas oryzae* strains causing leaf blight and kresek (wilt) symptoms of rice. IRRI, 1978.

Characteristic	Reaction	
	Leaf blight strain	Kresek strain
Pathogenicity		
Leaf blight	+	+
Kresek	+	+
Growth rate on peptone sucrose agar	Good	Good
Tolerance for Zn compounds	Less	More
Sensitivity to antibiotics	More	Less
Phage strains sensitivity	Different reaction	Similar reaction
Survival in paddy	Shorter duration	Longer duration

Table 10. Kresek development as affected by flooding of seedlings of different ages for 24 h in the seedbed. IRRI, 1978.

Age of seedlings at flooding (days)	Kresek* (%)	
	PXO 61	PXO 82
0	0 a	0 a
5	2.1 ab	1.1 a
9	2.8 b	0 a
14	10.0 c	0 a
21	11.4 c	9.7 b

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

sek incidence was higher when the seedbed was infested shortly before transplanting (Table 10). No kresek was found when the seedbed was infested at the time of sowing and transplanted 21 days later.

When the bacterial suspension at different concentrations was incorporated into the soil, more kresek was produced on transplanted than on direct-seeded rice (Table 11). In transplanted rice, the kresek percentage and inoculum dosages were linearly correlated: higher dosages resulted in more kresek infection. Injury of plant roots at transplanting may be associated with high kresek incidence. Therefore, wounded roots are an important route for kresek infection.

Seedlings raised in ordinary seedbeds had similar amounts of kresek regardless of the absence or presence of root injury induced by clipping. Dapog seedlings with uninjured roots produced considerably less kresek than those with injured roots (Table 12).

The results confirm that kresek infection is related to root injury, infection depends on bacterial survival in the nursery or the main field, and the leaf blight strain PXO 61 may not survive in the paddy.

Survival of *X. oryzae*. The bacteriophage method was used to study the survival of the bacterial blight pathogen in rice leaf tissues and in pure culture incubated at different temperatures. The sensitivity of the method, evaluated with pure culture, was revealed by plaque count.

The phage multiplied rapidly and the plaque counts correlated with the concentration of the

Table 11. Kresek incidence on IR8 transplanted or direct seeded in soil infected with different inoculum levels of *Xanthomonas oryzae*. IRRI, 1978.

Inoculum serial dilution	Kresek[a] (%)			
	Sterile soil		Unsterile soil	
	Transplanted	Direct seeded	Transplanted	Direct seeded
10^{-2}	32.9 a	0.3 d	26.9 a	1.5 g
10^{-3}	17.4 ab	0.5 d	23.2 a	0.8 g
10^{-4}	8.0 bc	0.3 d	10.2 f	2.3 g
10^{-5}	1.4 c	0 d	1.3 f	1.5 g

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Optical density of reading 2, and about 10^8 cells/ml at 10^{-2} dilution.

Table 12. Kresek incidence on seedlings raised in ordinary and dapog seedbeds and later artificially infected with a bacterial suspension of *Xanthomonas oryzae* by the root-dip method. IRRI, 1978.

Seedbed[a]	Kresek[b] (%)			
	PXO 61		PXO 62	
	Uninjured roots	Injured roots	Uninjured roots	Injured roots
Ordinary				
21 DS	10.4 d	12.6 d	16.1 d	14.4 d
14 DS	20.3 d	27.8 c	37.9 c	39.8 c
7 DS	65.3 ab	65.3 ab	78.3 a	68.4 ab
Dapog[c]				
7 DS	12.6 d	56.8 b	26.7 c	56.0 b

[a]DS = days after seeding. [b]Root injury induced by means of clipping. In a column, any two means followed by a common letter are not significantly different at 5% level. [c]Dapog: seedlings raised on concrete beds or plastic trays lined with newspapers or polyethylene sheets.

bacterial suspension. The efficiency of the method indicated that a bacterial suspension of 10^3 cells/ml of a specimen can give positive and reliable results. When infected leaves were kept at different temperatures, the bacterial population was high in leaf tissues at 10°C for 19 days but could not be detected in leaf tissues at 30°C and higher. The population was low at 20°C.

Results with pure culture were similar. A pure culture of the strain PXO 61 was incorporated into water-saturated soil, then incubated at 10, 30, and 50°C. The bacterium was detected by the clipping method of inoculation 21 days after incubation at 10°C, but not at 30 and 50°C (Table 13). When rice leaves infected with the bacteria-soil suspension were incubated for 14 days at 30°C, no typical lesions were observed, but some typical colonies of *X. oryzae* were isolated from the necrotic tissues (atypical lesions).

Kresek control. Zinc compounds affected kresek development in the greenhouse and the growth of *X. oryzae* in the laboratory (1977 Annual Report). The effectiveness of zinc compounds and of a copper-based fungicide (Kocide) were further tested with IR8 in the field in the dry season. Twenty-one-day-old seedlings were artificially inoculated by dipping their roots in a bacterial suspension of PXO 61 for 5 to 10 minutes, then dipping them in the chemical solutions before transplanting. Measurement on either a tiller or hill basis indicated

Table 13. Survival of *Xanthomonas oryzae* in 2 soil types at different temperatures, as detected by leaf clipping method of inoculation. IRRI, 1978.

Soil infusion	Detection[a] of the bacterium at								
	10°C			30°C			50°C		
	0 DI	7 DI	21 DI	0 DI	7 DI	21 DI	0 DI	7 DI	21 DI
Dryland soil not sterilized	+ (12.6)	+ (8.6)	+ (12.5)	+ (13.1)	—	—	+ (12.0)	—	—
Dryland soil sterilized	+ (13.0)	+ (6.7)	+ (16.1)	+ (12.7)	—	—	+ (10.2)	—	—
Wetland soil not sterilized	+ (13.4)	+ (8.5)	+ (15.2)	+ (13.3)	—	—	+ (9.3)	—	—
Wetland soil sterilized	+ (12.4)	+ (8.1)	+ (14.4)	+ (13.1)	—	—	+ (8.6)	—	—
X. oryzae + water	+ (13.8)	+ (7.7)	+ (14.6)	+ (13.1)	—	—	+ (9.7)	—	—

[a]+ or − = positive or negative for leaf blight symptoms. Figures in parentheses denote lesion length in cm. DI = days after incubation.

that Kocide controlled kresek better than zinc sulfate or zinc oxide (Table 14). Zinc oxide gave no control because it is less water soluble, and in solution was lower than the indicated percentage (2%). Considering natural infection, however, all three chemicals controlled kresek infection somewhat, with Kocide and zinc sulfate giving the higher percentages of control.

A preliminary measurement by the plaque count method of the bacteriophage population in water samples from different plots showed a higher phage population in the control than in the chemical-treated plots. That suggests that the chemicals affected bacterial survival in the field and led to less kresek infection.

TUNGRO

Field epidemiology. The statistical field study of the epidemiology of rice tungro virus in 37 farmers' fields in 5 provinces of Luzon, Philippines, was continued. Disease incidence was observed, vector insects were collected, and their infectivity was determined every 2 weeks from November 1977 to October 1978.

The incidence of tungro and the number of vector insects and infective insects were low during the study period (Table 15).

Forecasting outbreaks. Although the epidemiology of tungro has been studied since 1972 and considerable information is available, many factors that affect disease outbreaks, and interactions among such factors, remain obscure. Arriving at positive prediction — of impending tungro outbreaks — is complicated because outbreaks require the presence of all factors that increase tungro incidence. Negative prediction — no tungro outbreak — is simple and reliable: no outbreak will occur if any factor required for the outbreak is absent or unfavorable.

Six predictions for tungro outbreaks in the study area were made in June of each year from 1973 to 1978. Only the 1974 prediction was positive; however, no outbreak occurred because a green leafhopper control program artificially reduced the vector population. The other predictions were for low tungro incidence, including that in 1975, when a highly susceptible line, IR1561-228-3-3, was planted in 68% of the study fields. All five negative predictions were correct.

Table 14. Effectiveness of some selected chemicals on the control of kresek on IR8 in the field. IRRI, 1978 dry season.

Treatment	Control (%)			
	Artificial inoculation[a]		Natural infection	
	Hill basis	Tiller basis	Hill basis	Tiller basis
Zinc sulfate (2.5%)	14.4	30.9	74.4	86.7
Zinc oxide (2.0%)	−6.2	−15.5	59.8	74.3
Kocide (1.0%)	53.5	69.8	93.3	94.3
Water	0.0	0.0	0.0	0.0

[a]Artificial inoculation by the root-dip method before chemical treatment.

Table 18. Tungro incidence and vector insects classified by month, province, field, and cultivar in study fields in Luzon, Philippines, November 1977 to October 1979.

	Observations (no.)	Tungro: Fields (%)	Tungro: Incidence (%)	Tungro vectors[a]: Collections (no.)	Tungro vectors[a]: Av no./10 sweeps	Tungro vectors[a]: Tested[b] (no.)	Tungro vectors[a]: Infective (%)
			Month				
November 1977	97	10.8	0.02	48	4.8	966	0
December	74	5.2	0.01	31	2.4	430	0
January 1978	89	3.9	0.01	60	1.4	447	0
February	74	3.0	0.01	28	2.8	482	0
March	78	3.2	0.01	48	5.3	713	0
April	74	3.1	0.01	54	3.6	947	0.06
May	92	0.	0	65	1.6	461	0
June	74	2.1	0.01[b]	51	1.7	436	0
July	74	3.8	0.01	47	6.8	818	0
August	93	0	0	58	2.1	543	0
September	74	0	0	41	0.3	55	0
October	89	0	0	36	0.9	186	0
			Province				
Bulacan	260	4.1	0.01	187	2.8	1801	0.06
Laguna	208	0	0.	127	2.2	1275	0
Nueva Ecija	130	10.3	0.03	83	4.2	1103	0
Pampanga	162	0	0	89	2.0	980	1
Tarlac	216	1.2	0.01[b]	111	3.3	1298	0
			Type of field				
Seedbeds	52	0	0	52	5.2	836	0
Paddy	519	1.2	0.01[b]	247	1.8	1611	0
Stubble	230	7.4	0.02	230	4.1	3872	0.03
Idle	175	0.	0	47	0.4	117	0
			Rice cultivar				
IR26	543	3.3	0.01	364	2.7	4013	0
IR28	70	0	0	52	3.8	880	0.17
IR40	36	0	0	19	8.1	328	0
IR42	68	0	0	46	2.4	428	0
IR1561-228-3-3	16	0	0	9	1.2	87	0
Others	71	0.1	0.02	48	3.6	882	0

[a]*Nephotettix virescens*, *N. nigropictus*, and *Recilia dorsalis*. [b]The actual figures are much less than 0.01.

The five negative predictions were based on the absence or limitation of the essential factors for tungro outbreaks. Tungro incidence is determined by the population and activity of the vector insect, quantity and quality of virus sources, susceptibility of the rice variety to the virus and its vector insect, biotic and abiotic environments, and time. A tungro outbreak cannot occur if one factor is absent or unfavorable. The information gathered on tungro vectors, virus sources, and rice varieties follows.

Vectors. Tungro vectors include *Nephotettix virescens*, *N. nigropictus*, and *Recilia dorsalis*. Considering the insect population in paddy fields and the efficiency of tungro transmission, *N. virescens* is the most important.

For negative prediction, all factors that reduce the tungro vector population, such as insecticide application, natural enemies, and bad weather, can be ignored because they can never reverse a negative prediction. Therefore, attention should be on factors that increase the insect population.

Under favorable climatic conditions, only food and time determine increases in insect populations. Tungro vectors die without food and cannot propagate without time. Field vegetation determines food. The maximum time for insects to propagate is 4 to 5 months — the period from prediction to harvest. The propagation rate of every biological entity is always limited, and even with no food shortage, a few insects cannot produce a large population in a short time.

Luzon, particularly the study area, has a distinct dry season that includes the period from

April to early June; however, occasional rains may occur. If rainwater is sufficient in April-June, the vegetation — particularly regenerated rice stubble growth — may not be a limiting factor for the insect population. When rain is scarce, vegetation is scanty, and the limited food causes a low vector population. This observation should be verified. The number of tungro vectors in this period determines the number of insects at early rice growth, the stage when the plants are most susceptible.

Farmers plow the fields at the end of the dry season, when water is adequate. Plowing destroys the vector's eggs and nymphs, but it also compels the adults to move, often to the nearby seedbeds to lay eggs on the seedlings. Checking the vector insects in the seedbeds by sweep net is, therefore, essential for negative prediction. If both nymphs and adults are found, it can be assumed that the adult insects have been in the seedbeds for more than 10 days. Negative prediction cannot be made when many tungro vectors are present, but outbreaks can be avoided if insecticides are applied immediately and repeatedly. If 0, 1, or 2 insects/20 sweeps are observed, the insects cannot build up a large population within the regular time required for seedlings to be ready for transplanting. After transplanting, the number of tungro vectors in the paddies must be determined repeatedly. If they are few, no tungro outbreak is possible unless viruliferous insects migrate over long distances in large numbers. As the few tungro vectors in the paddies take time to propagate, the rice plants simultaneously grow older. Older plants are less susceptible to tungro, and so yield losses are small.

Negative prediction of tungro outbreaks is warranted if no or few vector insects are in idle fields, stubble fields, seedbeds, and paddy fields. The correlation between the number of vectors (3/10 sweeps) in April-June and tungro incidence (.03%) in paddy fields in June-October supports that conclusion. A similar correlation for 1973–77 was reported in the 1977 Annual Report.

Virus sources. In the Luzon study area, infected rice plants are the main virus sources. From April to June when not many rice crops are standing, the regenerated growth of infected rice stubble becomes the main source and a place for perpetuation of vector insects.

For negative prediction, therefore, the situation of the virus sources in the area should be examined by inspecting the tungro infection of the regenerated rice stubble growth, volunteer plants, and standing rice crops. Because the virus sources are sometimes difficult to observe, the infectivity of the insects caught from idle fields, stubble, seedbeds, and paddy fields should be tested. Such insects should immediately be confined in test tubes with seedlings of a susceptible variety. If the infection of the regenerated growth, volunteer plants, and standing crops, and the infectivity of insects are extremely low, a tungro outbreak cannot occur. The virus needs time to multiply to a sufficient level.

Rice variety. If a variety is highly resistant to both the virus and the vector insects, tungro outbreaks are unlikely, especially over a large area.

Many other elements or conditions unfavorable for tungro outbreaks can be used for negative prediction. For instance, extensive and proper insecticide application at critical times would reduce the vector and thus increase the reliability of the negative prediction.

Preventing outbreaks. The prevention of tungro outbreaks involves elimination or reduction of factors favorable for the disease. The principal control measures are the roguing of diseased plants, plowing of fields immediately after harvest, or application of insecticide to kill vector insects before harvest to prevent their transfer to other fields. Few of the measures are practical. Information from the study fields in Luzon indicates that tungro outbreak can be prevented by two practical measures — the use of resistant varieties and the control of vector insects.

One cannot visually determine if insects are infective, but their presence in seedbeds or paddies can be determined by sweep net or direct observation. Farmers should learn to observe tungro vectors in the seedbeds, particularly during plowing or harvest of adjacent fields. If all farmers in a large area can simultaneously kill vectors in the seedbeds, the chance of tungro outbreaks would be greatly reduced.

Table 16. Number of tungro vectors collected by light trap and tested during periods of low rice tungro incidence at IRRI, 1972–78.

Period[a]	Vector insects		Tested insects (no.)	Infective insects (%)
	No./ collection	Ratio[b]		
1972	2741	63:36:9	1801	0.4
1972–73	499	56:36:8	3818	1.5
1973–74	1691	59:40:10	4464	3.2
1974–75	849	61:29:10	5829	2.2
1975–76	885	69:21:10	4611	1.1
1976–77	293	46:32:22	4277	0.5
1977–78	339	32:25:43	4684	1.3

[a]Data for 1972 were collected Aug.–Oct. For all other years, data are for Nov.–Oct. [b]*Nephotettix virescens*: *N. nigropictus*: *Recilia dorsalis*.

Light trap. Trapping of tungro vectors at IRRI continued. Insects were trapped by light once weekly between 1700 hours and 1 hour after sunset. Some insects were tested for infectivity.

The average number of tungro vectors in each trap was 143, 16, 34, 56, 106, 154, 172, 115, 377, 1,275, 1,092, and 1,683 for each consecutive month from November 1977 through October 1978.

During the last 6 years, tungro incidence at IRRI did not seem closely related to the number of trapped tungro vectors or the percentage of infective insects. Both the number of trapped vectors and the percentage of infective insects may have been too low to cause high tungro incidence (Table 16).

Effect of temperature on Nephotettix virescens *movement.* Temperature affects the transmission of rice tungro virus by *N. virescens* (1974 Annual Report). Tungro spreads less at low day/night temperatures (24/16°C) than at high temperatures (30/22°C), perhaps because temperature affects the insect's frequency of movement. The movement of *N. virescens* adults on TN1 seedlings in three Koitron KB-10D growth cabinets at 15, 25, and 35°C was observed at hourly intervals from 0800 to 1700 hours.

The insects' movement varied with temperature. The percentage of insects that moved, the average number of moves per insect, and the average of seedling-to-seedling moves per insect were higher at high temperatures, but the insect movements between 25 and 35°C did not differ significantly (Table 17). At high temperatures, the insects visited more seedlings but stayed for shorter periods on each.

In most of tropical Asia, the temperature does not fluctuate drastically during the rice-growing season. Hence, temperature may not contribute significantly to tungro outbreaks under natural conditions in the tropics.

RAGGED STUNT

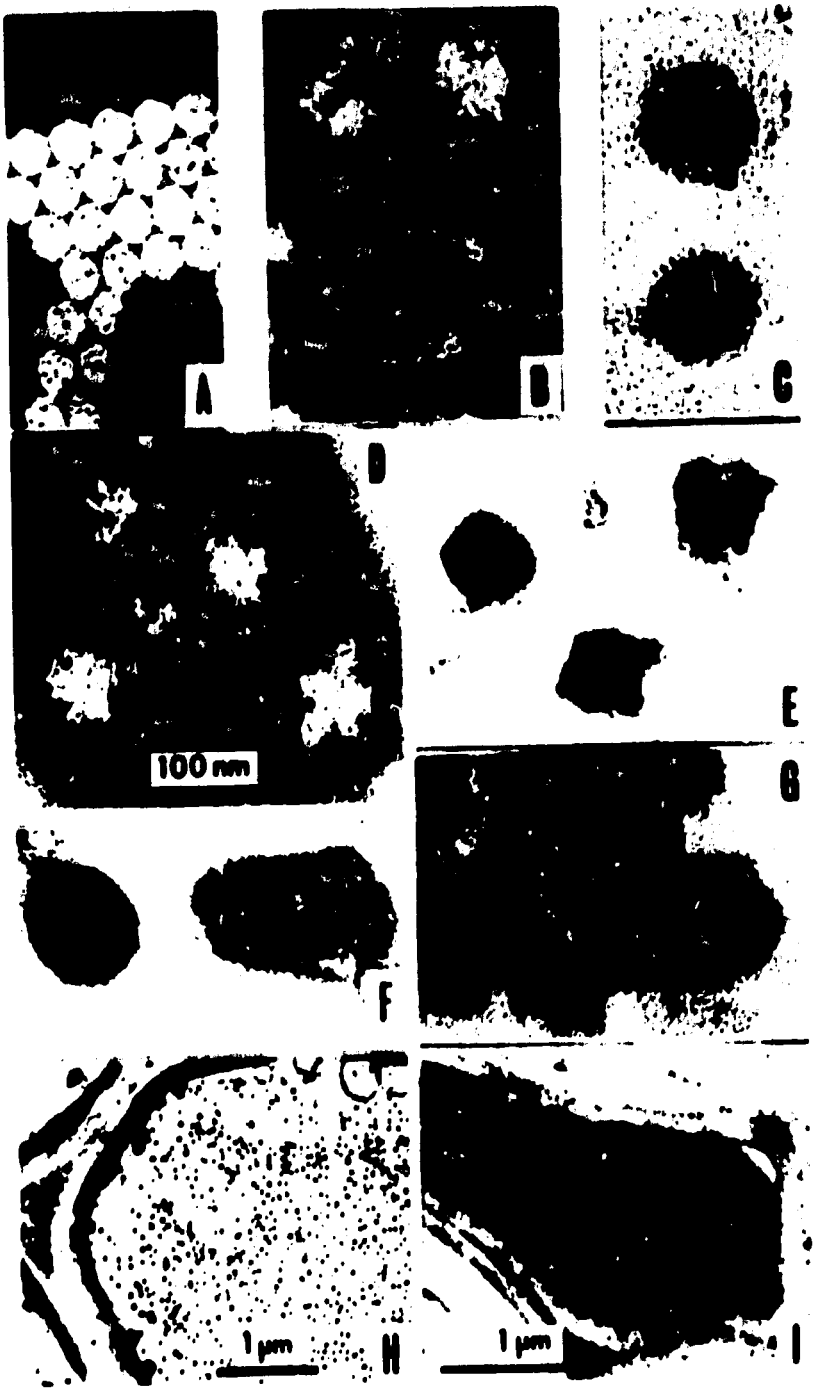
Rice ragged stunt, a new virus disease (1977 Annual Report), was reported in the Philippines, India, Indonesia, Sri Lanka, and Thailand. Its incidence was lower in 1978 than in 1977, particularly in the Philippines. The reasons remain obscure, however.

Identification. Studies on ragged stunt have been continued, in collaboration with Hokkaido University, Japan. Ragged stunt shares some similarities in symptomatology with rice black-streaked dwarf, which occurs in temperate regions (China, Japan, and Korea). Plants with either disease show stunting, leaf twisting, and swollen veins; however, minor differences exist in shape, size, and color of the swollen veins. The other symptoms such as ragged leaves, tillering, and nodal branches differ. Only planthoppers transmit both ragged stunt and black-streaked dwarf viruses, but the transmit-

Table 17. Effect of temperature on movement of *Nephotettix virescens*.[a] IRRI, 1978.

Temperature (°C)	Insects that moved (%)	Moves (no./ insect)	Seedling-to-seedling moves (no./ insect)	Seedlings visited (no./ insect)	Insects' visiting duration (h/seedling)
15	38 a	0.8 a	0.7 a	1.6 a	6.7 a
25	46 b	1.2 b	1.0 b	1.9 b	4.4 b
35	50 b	1.9 b	1.4 b	2.2 b	4.2 b

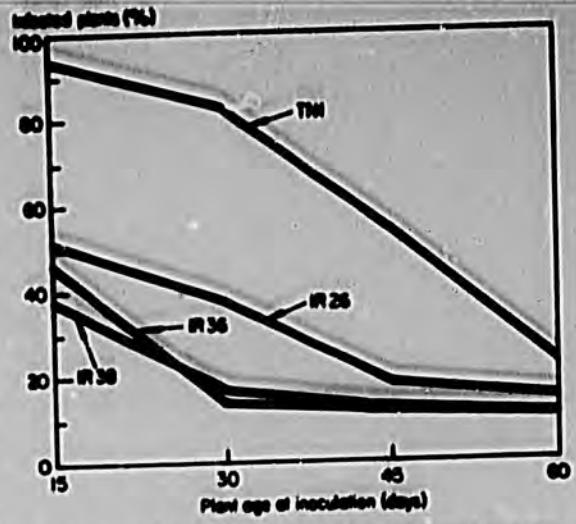
[a]In a column, means followed by a common letter do not differ significantly at the 5% level.



1. Electron micrographs of rice ragged stunt virus particles in a purified preparation stained in phosphotungstic acid (A); in deep preparations stained in phosphotungstic acid (B), and uranyl acetate (C); in deep preparations prefixed with glutaraldehyde and stained in phosphotungstic acid (D), uranyl acetate (E), and uranyl formate (F); in an ultrathin section (G), scattered (H), and arranged in a crystalline array (I) in phloem cells. Magnification of (A) to (G) is the same as in (D).

Table 18. Differences between the black-streaked dwarf and the ragged stunt diseases, IRRI, 1978.

	Black-streaked dwarf	Ragged stunt
Distribution	Temperate regions	Tropical regions
Symptoms		
Stunting	Severe	Moderate
Tillering	Excessive	Not excessive
Leaves	Not ragged	Ragged
Basilica veins	Irregular	Narrow, elongate
Virus particles	Spherical, 69 nm in diam	Spherical, 40 nm in diam
Vector insect	*Laodelphax striatellus*	*Nilaparvata lugens*
Host plants	Infects barley, corn, oat, and wheat	Does not infect barley, corn, oat, and wheat



2. Infection of rice varieties inoculated with ragged stunt virus at various plant ages. IRRI, 1978.

ting species differ. The diseases also differ in host range (Table 18). Although the virus particles vary in size according to the compounds used for fixing and staining (Fig. 1), the particles of purified ragged stunt are smaller than those of black-streaked dwarf virus. The results suggest that ragged stunt and black-streaked dwarf viruses are not identical and that ragged stunt may be a new member of plant reovirus. Its nucleic acid type and genome structure remain to be investigated.

The properties of ragged stunt, determined by the infectivity of *N. lugens* after injection of a ragged stunt preparation, indicated that the disease's dilution end point was 10^{-4}, the longevity in vitro was 7 days at 4°C, and the thermal inactivation point was 60°C for 10 minutes. The virus remained stable at pH 5 to 9.

Host range. IRRI studies of the host range of ragged stunt used corn (Hawaii Supersweet No. 9) and sorghum (Cosor 3). Eighteen plants of each test species were infested with viruliferous brown planthoppers at 10 insects/plant. No test plant became infected but the insects lived for 3 days on test plants of both species.

In contrast, *Oryza barthii* (acc. no. 100122), *O. glaberrima* (acc. no. 100132, 100133, 100152, 100156, 100158, 100855, and 100975), *O. spontanea* (acc. no. 101145 and 101147), and *O. nivara* (acc. no. 101508) showed more than 90% infection after inoculation. *O. latifolia* (acc. no. 100165 and 100170) showed about 20% infection. None of a total of 41 seedlings of *O. australiensis* (acc. no. 100410, 101144, and 101397) became infected after inoculation.

A weed, *Echinochloa glabrescens*, growing naturally in the rice field exhibited ragged leaves, a ragged stunt symptom. The plants were used as virus source for a transmission study. None of the 1,475 TN1 seedlings infested with 120 insects that were given an acquisition access time of 1 day on 3 pots of *E. glabrescens* became infected. None of the 477 TN1 seedlings infested with 55 insects that were given an acquisition access time of 3 days on the same weed plants exhibited symptoms of ragged stunt. On the other hand, none of 300 *E. glabrescens* plants infested with viruliferous brown planthoppers became infected.

Plant age at inoculation. Four rice varieties at different plant ages were infested with viruliferous brown planthoppers. The percentage of ragged stunt infection, regardless of variety, decreased with plant age at the time of inoculation (Fig. 2).

Dual infection. TN1 plants were dually infected with both grassy stunt and ragged stunt. Four weeks later, the plants were 49 cm tall, while those infected with only ragged stunt or grassy stunt were 70 or 53 cm tall. The tiller numbers were 10 for plants with ragged stunt, 38 for those with grassy stunt, and 35 for the dually infected ones.

Insects

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INSECTICIDE EVALUATION

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Insecticides and application methods found effective in the laboratory were evaluated in the field.

Greenhouse and laboratory studies *(Entomology)*. The striped stem borer and leaf folder were added to 1978 greenhouse and laboratory studies, which previously included the brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper (GLH).

Contact toxicity. Insecticides were topically applied with a microapplicator and Potter's spray tower to determine their contact toxicity. LD_{50} (lethal dosage required to kill 50% of test insects) values of insecticides applied to the BPH, WBPH, and GLH with the microapplicator are in Table 1. Decamethrin, a synthetic pyrethroid, had the lowest LD_{50} value on the three hoppers. Insecticides that least adversely affect natural enemies are being sought. The LD_{50} values of insecticides commonly used for hopper control differed little on *Cyrtorhinus lividipennis*, a predator of hopper eggs and nymphs (Table 2).

Table 1. LD_{50}* values of insecticides applied topically to the brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH). IRRI, 1978.

Insecticide	LD_{50} (µg/g)		
	BPH	GLH	WBPH
BPMC	2.24	3.28	1.63
MIPC	1.56	3.15	2.51
Methyl parathion	6.73	7.92	1.74
Endosulfan	3.60	8.66	4.80
Decamethrin	1.17	0.03	0.32
Diazinon	5.95	8.35	6.77

*Lethal dosage required to kill 50% of test insects.

Table 2. LD_{50}* values of insecticides applied topically to *Cyrtorhinus lividipennis* Reuter. IRRI, 1978.

Insecticide	LD_{50} (µg/g)
Carbofuran	1.52
BPMC	1.52
Metolkarnate	3.42
MIPC	1.71
Monocrotophos	1.12
Methyl parathion	2.66
Decamethrin	0.28
Bumicidin	5.52

*Lethal dosage required to kill 50% of test insects.

The topical application technique was used to determine the resistance of the BPH to insecticide at IRRI. Tests in 1977 had indicated the BPH's sevenfold resistance to carbofuran and monocrotophos, both of which have been extensively used at IRRI (Table 3). After being reared free of insecticide exposure for about 14 generations, the hoppers remained resistant to carbofuran but not to monocrotophos.

The Potter's spray tower was used in comparing insecticides for toxicity to the BPH and GLH (Table 4.). The combination of cypermethrin and chlorfenvinphos caused rapid knockdown of both hoppers. The GLH was most susceptible to the combination MTMC + phenthoate and azinphos ethyl + phenthoate, whereas DPX 3853 and MK501 were selectively most toxic to the BPH. For the first time in 1978, several insecticides were tested against *Rivula* sp., a greenish caterpillar that has recently become a pest of rice seedlings in the Philippines. Several compounds were highly effective against it (Table 5).

Foliar spray. Insecticides were tested as foliar spray against the three hoppers, striped stem borer, and leaf folder.

The same insecticides tested in the Potter's spray tower (Table 4) were also tested in one foliar spray test. Ethion, and the combination cypermethrin + chlorfenvinphos, were also effective as foliar spray, and DPX 3853 was effective against all three hoppers. In two additional tests, ethion, isoxathion, FMC 35001, and FMC 27289 provided residual activity against the three hoppers.

Minimum effective rates of application were determined for some insecticides that previously proved effective against hoppers. At 200 g a.i./ha most of the compounds provided initial control of the three hoppers. Only FMC 35001, however, was effective at 7 days after treatment (DAT) (Table 6). It was also the only insecticide effective against the BPH at the 50-g rate 1 DAT.

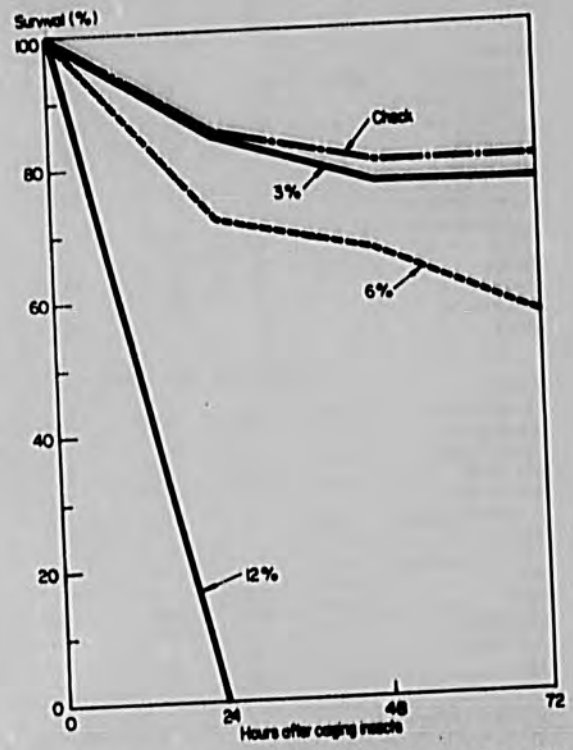
In 1978 a technique for testing insecticides against the striped stem borer and leaf folder was developed. Most insecticides tested pro-

Table 6. Susceptibility of brown planthopper adults' resistance to insecticides, IRRI, 1977–78[a].

Insecticide	1977 tests			1978 tests		
	LD_{50} (µg/g)		RR[b]	LD_{50} (µg/g)		RR
	Greenhouse culture	Field-collected culture		Greenhouse culture	Field-collected culture	
Carbofuran	0.14	1.00	7.30	2.90	20.60	7.17
Methomyl	1.80	5.55	3.08	2.14	6.48	2.85
BPMC	1.57	5.69	2.97	2.92	5.07	1.73
MIPC	1.42	3.26	2.31	1.85	3.61	2.61
Monocrotophos	0.55	3.88	6.61	2.73	3.02	1.10
Parathion	4.07	5.78	1.42	4.30	3.70	0.84

[a]LD_{50} = Dosage required to kill 50% of test insects. [b]Resistance ratio = $\frac{LD_{50}\text{ field-collected insects}}{LD_{50}\text{ greenhouse culture}}$

1. Survival of adult brown planthopper when caged on rice plants sprayed with guazatine at 3, 6, and 12%. IRRI greenhouse, 1978.



2. Survival of adult brown planthopper when caged on rice plants sprayed with neem oil at 3, 6, and 12%. IRRI greenhouse, 1978.

vided good stem borer control (Table 7). In two leaf folder tests (Table 8), the leaf folder was highly susceptible to most insecticides.

The oil of neem (*Azadirachta indica*) and anona (*Anona reticulata*), and a fungicide, guazatine, were applied as foliar spray and evaluated as BPH antifeedants. Anona appeared to act as a contact poison rather than as an antifeedant. Both the 6 and 12% spray rates of guazatine were effective against hoppers (Fig. 1), but the 12% neem oil spray rate was significantly more effective than the 6%

Table 4. Contact toxicity of insecticides at 0.04% applied with Potter's spray tower against the brown planthopper (BPH) and green leafhopper (GLH). IRRI, 1978.

Insecticides	Mortality[a] (%)			
	1 HT	4 HT	24 HT	48 HT
		BPH		
MTMC + phenthoate	11 c	21 c	44 bc	62 c
Azinphos ethyl + phenthoate	34 b	41 b	58 bc	70 bc
DPX 3853	9 c	20 c	50 bc	75 bc
Dichlorvos + chlorfenvinphos	1 d	3 d	36 bc	72 bc
Cypermethrin + chlorfenvinphos	86 a	94 a	98 a	100 a
Ethion	0 d	0 d	30 cd	71 bc
MK501	24 b	41 b	59 bc	86 b
Acephate LC	1 d	3 d	46 bc	87 b
Acephate LE	2 d	17 c	63 b	77 bc
Check	0	0 d	11 d	11 d
		GLH		
MTMC + phenthoate	33 b	81 b	98 a	98 a
Azinphos ethyl + phenthoate	51 a	72 b	100 a	100 a
DPX 3853	1 c	1 de	10 c	32 c
Dichlorvos + chlorfenvinphos	0 d	4 cde	50 b	63 b
Cypermethrin + chlorfenvinphos	57 a	100 a	100 a	100 a
Ethion	0 c	3 cde	41 b	61 b
MK501	2 c	5 cd	33 b	43 bc
Acephate LC	0 c	4 cde	30 b	40 bc
Acephate LE	2 c	13 c	43 b	56 b
Check	0 c	0 e	3 c	3 d
		Difference (BPH - GLH)		
MTMC + phenthoate	-22**	-60**	-54**	-36**
Azinphos ethyl + phenthoate	-17**	-31**	-42**	-30**
DPX 3853	8**	19**	40**	43**
Dichlorvos + chlorfenvinphos	1ns	1ns	-15ns	9ns
Cypermethrin + chlorfenvinphos	8ns	-6*	-2ns	0ns
Ethion	0ns	-3ns	-9ns	10ns
MK501	22**	36**	26*	43**
Acephate LC	1ns	-1ns	16ns	47**
Acephate LE	2ns	2ns	20ns	21ns
Check	0ns	0ns	8ns	8ns

[a]In a column, means followed by a common letter are not significantly different at the 5% level. HT= hours after treatment at which mortality readings were taken.

Table 5. Effect of selected insecticides on the control of *Nivula* sp., a rice seedling pest. IRRI, 1978.

Insecticide[a]	Mortality[b] (%)	
	Contact poison	Foliar spray (0.04%)
Monocrotophos 16.8 EC	100.0 a	100.0 a
Diazinon 20 EC	100.0 a	100.0 a
Azinphos ethyl 40 EC	100.0 a	100.0 a
Carbofuran 20 F	32.5 b	95.0 a
Chlorpyrifos 15.8 EC + BPMC 15.8 EC	42.5 b	100.0 a
Methyl parathion 50 EC	7.5 c	82.5 a
Metaldehyde 30 EC	2.5 c	0.0 c
Perthane 48 EC	0.0 c	30.0 b
MIPC 50 WP	0.0 c	0.0 c
Control	0.0 c	0.0 c

[a]EC = emulsifiable concentrate, F = flowable, WP = wettable powder. [b]Av of 4 replications. Contact poison was applied with Potter's spray tower. Mortality of 10 third-instar larvae was determined 48 h after treatment.

(Fig. 2). No insect survived at any of the test rates 48 hours after the insects were caged on the anona-sprayed plants.

Both anona and guazatine had high antifeedant activity at all concentrations tested; neem oil had high antifeedant activity at only the 12% concentration. Further detailed studies on the feeding activity of BPH on neem-sprayed plants indicated that the higher oil concentrations of emulsified neem reduced feeding duration and intensified the hoppers' search for a suitable feeding site or even their avoidance of plants (Fig. 3)

Further studies to determine the effect of neem oil on BPH growth, fecundity, oviposition, and hatching were conducted. The first instars of all the three BPH biotypes were highly susceptible to neem oil: only 3–9% of the nymphs on the 3% neem oil-treated plants became adults, in contrast with 67–88% in the control, where the nymphs became adults in a comparatively shorter period; on plants that received higher spray concentrations all nymphs died before becoming adults (Table 9). The fecundity of all the three biotypes on neem oil-treated plants was greatly reduced; at 100% concentration, the total number of eggs laid was 10–25% of those laid on control plants (Table 10). The oviposition of hoppers caged on neem oil-sprayed plants was also strongly deterred (Table 11). Egg hatchability was not affected, however.

Neem oil was also tested for control of BPH in the field. Plots (220 m²) planted to IR1917-3-17, a BPH-susceptible rice, were each sprayed with 0, 3, 6, and 12% neem oil-vegetable oil

Table 6. Minimum effective rate of foliar spray application of different insecticides for control of brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH). IRRI greenhouse, 1978.

Insecticide[a] (g a.i./ha)	Mortality[b] (%)								
	BPH			GLH			WBPH		
	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
Monocrotophos 16.8 EC									
200	100 a	20 bc	0 c	100 a	96 a	20 b	100 a	36 b	8 b
100	78 bc	15 bc	0 c	100 a	43 c	10 bc	100 a	23 bcd	5 b
50	33 ef	8 cd	0 c	100 a	33 cd	0 d	100 a	23 bcd	5 b
25	24 fg	5 cd	0 c	100 a	20 de	0 bc	80 bc	3 e	3 b
Carbofuran 12 F									
200	100 a	35 b	0 c	100 a	70 b	20 b	100 a	10 cde	0 b
100	80 ab	13 bc	0 c	100 a	50 c	3 cd	100 a	8 cde	0 b
50	63 cd	10 bc	0 c	100 a	5 efg	0 d	63 cd	5 de	0 b
25	28 ef	8 cd	0 c	100 a	3 fg	0 d	25 ef	0 e	0 b
FMC 39001 48 EC									
200	100 a	88 a	33 a	100 a	100 a	100 a	100 a	100 a	80 a
100	100 a	33 b	18 ab	100 a	100 a	20 b	100 a	20 bcd	5 b
50	100 a	20 bc	10 bc	100 a	100 a	0 d	100 a	10 cde	0 b
25	28 ef	18 bc	10 bc	100 a	55 bc	0 d	83 bc	0 e	0 b
A 4717 24 EC									
200	88 ab	30 b	0 c	85 a	18 def	0 d	60 cd	8 cde	0 b
100	50 de	18 bc	0 c	53 b	10 defg	0 d	25 ef	5 de	0 b
50	23 fg	15 bc	0 c	15 bcd	10 defg	0 d	18 f	5 de	0 b
25	18 fg	13 bc	0 c	15 bcd	0 g	0 d	3 gh	3 e	0 b

[a]EC = emulsifiable concentrate, F = flowable. [b]Insects were caged on plants at 1, 7, and 14 days after treatment (DAT). Mortality was determined 48 h after caging. In a column, means followed by a common letter are not significantly different at 5% level.

Table 7. Activity of insecticides applied as 0.04% foliar spray on potted plants for striped stem borer control. IRRI greenhouse, 1978.

Insecticide[a]	Mortality[b] (%)			
	1 DAT	7 DAT	14 DAT	21 DAT
M 8174 20 EC	95 a	75 abc	44 de	52 c
Azinphos ethyl + MTMC 33 EC	94 a	92 ab	73 bcd	76 bc
Cypermethrin + chlorfenvinphos 18.9 EC	85 a	100 a	97 ab	43 c
Ethion 48 EC	80 a	95 ab	90 abc	98 ab
MTMC + phenthoate 40 EC	77 ab	22 de	68 bcd	72 bc
Methomyl 20 EC	77 ab	47 cde	30 ef	60 c
R 677 25 WP	74 ab	98 ab	100 a	97 ab
Perthane 45 EC	44 bc	61 bcd	57 cde	100 a
DPX 3953 24 EC	42 bc	87 ab	77 bcd	100 a
MK 501 50 WP	25 cd	69 bc	44 de	97 ab
Control	5 d	8 e	7 f	10 d

[a]EC = emulsifiable concentrate, WP = wettable powder. [b]Av of 4 replications, each consisting of 20 freshly hatched larvae placed on treated cut stems. Larval mortality readings were taken 48 h after each infestation. DAT = days after treatment. Means followed by a common letter are not significantly different at 5% level.

emulsion at 1 liter/ha with an ultra-low-volume (ULV) sprayer at 20, 40, 60, 80, and 100 days after transplanting (DT). The number of BPH nymphs and adults was recorded daily, and their predators weekly on 30 rice hills/plot in each treatment. The incidence of BPH-transmitted grassy stunt, ragged stunt, and tungro, and other plant pests was also recorded. Tungro and grassy stunt were negligible in all treatments, but ragged stunt was significantly reduced in the treatment with 12% neem oil (34% in treated plots and 57% in the untreated plots). Other pests (whorl maggot, stem borers, and rice bug), predators such as spiders and mirid bugs, and parasitoids were not affected by neem oil at the concentrations tested.

Paddy-water application. Eight insecticides were tested as granular formulations against the

Table 8. Activity of insecticides applied as 0.05% foliar spray on potted TN1 plants for leaf folder control, IRRI greenhouse, 1978.

Insecticides	Formulation[a]	Mortality[b] (%)
First test		
FMC 27289	40 EC	100 a
Permethrin	10 EC	100 a
Monocrotophos	16.8 EC	100 a
Cypermethrin	40 EC	98 ab
CGA 12223	50 EC	98 ab
Chlorfenvinphos	20 EC	98 ab
Methyl parathion	50 EC	93 abc
BPMC	31.5 EC	90 bc
Carbofuran	12 F	90 bc
Endosulfan	35 EC	85 bc
FMC 35001	40 EC	83 bc
Azinphos ethyl	40 EC	83 bc
A 47171	24 EC	75 bc
Prepamur	20 EC	73 c
Metalkamate	30 EC	33 d
MIPC	50 WP	23 de
Vamidothion	40 EC	13 de
Perthane	45 EC	5 e
Second test		
Triazophos	40 EC	100 a
Decamethrin	2.5 EC	98 ab
AC 64475	25 EC	95 ab
Methomyl	20 EC	92 ab
Diazinon	20 EC	89 ab
S 3206	20 EC	89 ab
Decamax	2 EC	89 ab
Fenthion	50 EC	87 ab
Phosphamidon	50 EC	87 ab
MTMC + phenthoate	40 EC	87 ab
M 8174	20 EC	87 ab
Phenthoate	50 EC	78 bc
MTMC + azinphos ethyl	33 EC	71 bc
Ethion	48 EC	51 cd
DPX 3953	23.5 EC	27 de

[a]EC = emulsifiable concentrate, F = flowable, WP = wettable powder. [b]Ten larvae/replicate. Values adjusted using Abbott's formula. Means followed by a common letter are not significantly different at 5% level.

striped stem borer in greenhouse studies. Only CGA 12223 provided effective control up to as long as 10 DAT (Table 12).

Root-zone application. Laboratory and field studies at IRRI have shown that applying carbofuran to the soil gave more effective control. Thus, evaluation of new compounds was continued to determine their activity in the root zone. In 1978 tests, the new compounds FMC 27289, bendiocarb, FMC 35001, and CGA 12223 applied in the root zone were as effective as carbofuran (Table 13).

Fumigation. The effect of fumigation has not been determined in foliar spray and paddy-water application studies. In 1978, a cage that allowed comparison of the mortality of hoppers in contact with the treated plants and that of hoppers caged above treated plants was devised. The hoppers in the fumigation part of the cage were given untreated plant as food.

Results of a foliar spray test are in Table 14. All the insecticides had a distinct fumigant effect on the BPH, with carbofuran and Perthane the most effective. Only metalkamate had a fumigant effect on the GLH, indicating that the insecticides tested had a selective toxic effect on the two hopper species. The high fumigant activity of Perthane on the BPH may be the reason for its effectiveness as a spray against the BPH in the field (1977 Annual Report).

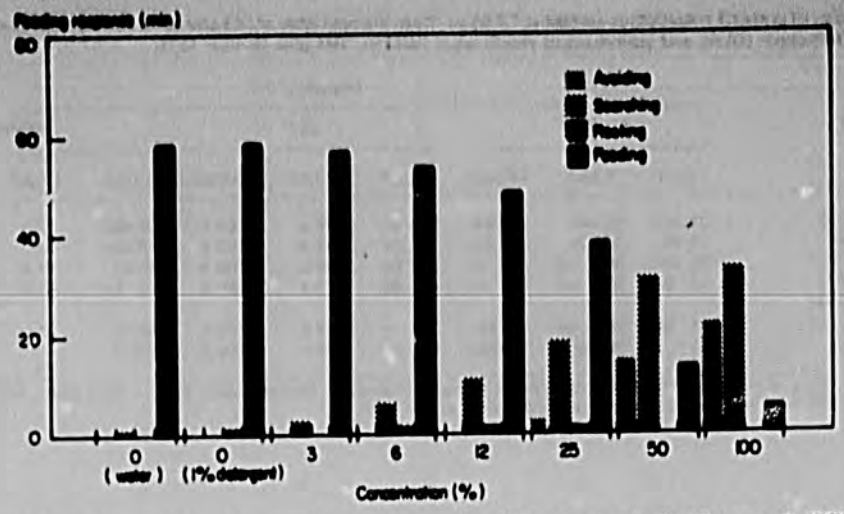
A fumigation study in which granules were applied to the paddy water showed less distinct differences in mortality between the two hopper species than the foliar spray study, although the GLH was again generally less susceptible. BPH mortality at 96 hours after caging (HC) in the fumigation cage was similar to that in the cage where the insects had direct contact with the plant, except in the acephate treatment which caused a higher mortality as a fumigant.

Field studies *(Entomology).* Insecticides were

Table 9. Growth of 3 brown planthopper biotypes on rice plants sprayed with neem oil.[a] IRRI insectary, 1978.

Neem oil concn (%)	Biotype 1			Biotype 2			Biotype 3		
	Nymphs becoming adults (%)	Growth period (days)	Growth index	Nymphs becoming adults (%)	Growth period (days)	Growth index	Nymphs becoming adults (%)	Growth period (days)	Growth index
0 (water)	88 a	20.3 b	4.3 a	67 a	21.5 a	3.1 a	83 a	21.1 b	3.9 a
0 (0.1% detergent)	88 a	20.6 b	4.2 a	67 a	21.1 a	3.2 a	78 a	20.9 b	3.7 a
3	7 b	22.8 a	0.8 b	3 b	22.3 a	0.7 b	9 b	23.2 b	0.5 b
6, 12, 25, 50, 100	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]

[a]First-instar nymphs of biotypes 1, 2, and 3 were caged, respectively, on 30-day-old TN1, Mudgo, and ASD 7 plants sprayed with neem oil with an ultra-low-volume applicator. Each figure is an av of 10 replications, each with 10 nymphs. In a column any means followed by a common letter are not significantly different at 5% level. Growth index is calculated as the ratio of percentage of nymphs becoming adults to growth period; mean of indices of individual replicates. [b]All nymphs died.



3. Feeding behavior of *Nilaparvata lugens* (biotype 1) on TN1 plants sprayed with neem oil. IRRI, 1978.

evaluated in the field as foliar spray, and in paddy-water application and soil incorporation. Selected insecticides were used to compare effectiveness of the application methods against various insect pests. Timing of insecticide application for BPH control was studied.

Foliar spray. The effectiveness of new insecticides as foliar spray against the whorl maggot and stem borer is indicated in Table 15. Fensulfothion and CGA 12223 controlled deadheart damage by stem borer. However, fensulfothion and the pyrethroids fenvalarate and cypermethrin caused BPH resurgence. Whiteheads were also more numerous after

Table 10. Number of fertile eggs laid by 3 brown planthopper biotypes caged for 20 days on rice plants sprayed with neem oil. IRRI insectary, 1978

Neem oil concn[a] (%)	Fertile eggs[b] (no./female)		
	Biotype 1	Biotype 2	Biotype 3
0 (water)	313 a	147 a	205 a
0 (0.1% detergent)	268 ab	126 a	182 ab
3	264 ab	114 a	184 abc
6	251 ab	118 a	184 abc
12	231 ab	83 a	114 bcd
25	162 b	32 b	98 d
50	82 c	28 b	57 de
100	47 c	15 b	52 e

[a]Plants sprayed with neem oil with an ultra-low-volume applicator. [b]Number of fertile eggs based on emergence of nymphs; av of 5 replications. Biotypes 1, 2, and 3 were caged on 1-month-old potted TN1, Mudgo, and ASD 7 plants, respectively. Means followed by a common letter are not significantly different at 5% level.

Table 11. Ovipositional response and egg hatch of brown planthopper biotype 1 on TN1 rice plants sprayed with neem oil.[a] IRRI insectary, 1978.

Neem oil concn (%)	Eggs laid (no./10 females per 12 h)	Eggs hatched (%)
0 (water)	134 a	87 c
0 (0.1% detergent)	120 a	87 c
3	108 a	94 abc
6	74 ab	90 bc
12	69 bc	96 ab
25	51 c	90 abc
50	45 c	98 a
100	45 c	84 c

[a]Based on number of nymphs that emerged and eggs remaining unhatched in plants; av of 10 replications. Gravid females were caged for 12 h on 1-month-old potted TN1 plants sprayed with neem oil with an ultra-low-volume applicator. Means followed by a common letter are not significantly different at 5% level.

Table 12. Activity of granular insecticide broadcast on potted plants at 0.5 kg a.i./ha for striped stem borer control. IRRI greenhouse, 1978.

Insecticide[a]	Mortality[b] (%)			
	1 DAT	5 DAT	10 DAT	20 DAT
CGA 12223 3 G	100 a	100 a	100 a	26 a
Mephosfolan 3 G	46 b	46 b	17 cd	30 a
Acephate 3 G	9 cd	24 b	17 cd	25 a
FMC 27280 2.5 G	29 bc	18 b	36 b	24 a
FMC 38001 2.5 G	8 cd	25 b	17 cd	23 a
Isofenphos 5 G	0 d	41 b	25 bc	30 a
Metolkarbate 3 G	31 bc	35 b	18 bcd	18 ab
Carbofuran 3 G	53 b	30 b	8 d	10 bc

[a]G = granular. [b]Av of 4 replications, each containing ca 50 freshly hatched larvae placed on treated cut stems of rice plants at 1, 5, 10, and 20 days after treatment (DAT). Mortality was determined at 48 h after each infestation. Means followed by a common letter are not significantly different at 5% level.

Table 13. Activity of granular insecticides applied at 1.0 kg a.i./ha in the root zone of rice plants for control of brown planthopper (BPH), green leafhopper (GLH), and whiteheaded planthopper (WBPH). IRRI greenhouse, 1978.

Insecticide[a]	Mortality[b] (%)								
	BPH			GLH			WBPH		
	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
FMC 27289 2.5 G	23 abc	60 abc	85 ab	53 b	78 a	100 a	33 abc	75 a	85 a
Carbofuran 3 G	15 abc	38 bc	98 ab	30 bc	95 a	100 a	43 abc	90	100 a
Bendiocarb 5 G	15 abc	30 cd	70 b	30 bc	88 a	100 a	60 ab	78 a	100 a
FMC 30001 2.5 G	10 bc	15 cd	63 b	43 bc	83 a	98 a	20 bc	68 a	85 a
FMC 27289 + FMC 30001 2.5 G + 2.5 G	8 bc	28 cd	85 ab	8 c	83 a	100 a	50 ab	93 a	100 a
CGA 12223 3 G	5 c	60 abc	80 ab	50 bc	90 a	100 a	100 a		

[a]G = granular. [b]Av of 4 replications, each consisting of 10 insects caged on treated plants. DAT = days after treatment. Means followed by a common letter are not significantly different at 5% level.

Table 14. Contact and fumigant effect of different insecticides applied as 0.4% foliar spray on potted plants to control brown planthopper (BPH) and green leafhopper (GLH). IRRI greenhouse, 1978.

Insecticide[a]	Mortality[b] (%)											
	BPH						GLH					
	Contact			Fumigation			Contact			Fumigation		
	1 HC	24 HC	96 HC	1 HC	24 HC	96 HC	1 HC	24 HC	96 HC	1 HC	24 HC	96 HC
Cypermethrin 40 EC	63	100	100	0	5	58	65	100	100	0	3	5
Metolkarbate 30 EC	30	100	100	0	33	58	8	100	100	0	36	45
Carbofuran 12 F	23	100	100	3	48	85	30	100	100	0	3	3
Monocrotophos 16.8 EC	8	100	199	0	23	53	43	100	100	0	0	0
Methomyl 20 EC	8	73	100	0	20	55	48	100	100	0	0	0
Perthane 46 EC	3100	100	0	18	80	38	100	100	0	0	0	0
Diazinon 20 EC	0	95	100	3	10	32	0	100	100	0	0	13
Ethion 48 EC	0	85	100	0	8	60	3	93	100	0	0	0
Azinphos ethyl 40 EC	0	100	100	0	18	58	5	100	100	0	0	0

[a]EC = emulsifiable concentrate, F = flowable. [b]Insects placed in the cage 1 day after plants were treated. Mortality readings were taken at 1, 24, 96 h after caging (HC).

Table 15. Foliar spray application of insecticides for control of rice insect pests on variety IR20.[c] IRRI, 1978 wet season.

Insecticide[a]	Whorl maggot damage[b] 31 DT	Stem borer deadhearts (%)		Whiteheads (%)	BPH		Hopperburn (%)	Yield (t/ha)
		47 DT	73 DT	114 DT	Number[d] 60 DT	Number[d] 93 DT	100 DT	
A 47171 24 EC	6 b	5 ef	30 e	0.8 ab	1	57 a	0	1.32 d
Fenoulfothion 63 EC	3 a	0 a	2 a	2.0 bcd	40	3355 d	50	1.32 d
Phosphamidon 50 SC	3 a	4 b	12 bc	2.2 bcd	7	91 ab	0	2.06 ab
Fenvalerate 20 EC	3 a	5 bc	9 b	1.9 bcd	1	128 c	0	2.42 abc
Fenthion 50 EC	4 a	9 cde	16 cd	2.5 cd	8	72 ab	0	2.54 ab
Bendiocarb 80 WP	4 a	10 def	18 cd	1.7 bcd	5	163 ab	0	2.15 abcd
FMC 30001 46 EC	4 a	2 ab	12 bc	2.2 bcd	5	269 bc	0	2.34 abc
CGA 12223 50 EC	3 a	1 a	2 a	2.1 bcd	6	299 ab	0	2.81 a
Perthane 46 EC	6 b	16 f	36 e	1.4 abcd	1	68 a	0	1.88 cd
Cypermethrin 40 EC	3 a	6 bcd	14 bc	3.2 d	32	2500 d	0	2.15 abcd
Sumicidin 75 EC	4 a	9 cde	23 d	0.9 abc	9	128 ab	0	1.84 bcd
Control	7 b	13 ef	33 e	0.5 a	12	127 ab	0	1.28 d

[a]In a column, means followed by a common letter are not significantly different at 5% level. DT = days after transplanting. [b]All insecticides were applied 5 times at 14-day intervals starting 5 days after transplanting. EC = emulsifiable concentrate, SC = emulsifiable concentrate, WP = wettable powder. [c]Based on scale 0-9; 0 = no damage; 9 = severe feeding lesions causing curling and leaf breaking. [d]Total of 10 hills.

Table 16. Evaluation of insecticides applied as canopy foliar spray at 0.75 kg a.i./ha for control of the brown planthopper (BPH) on variety IR22. IRRI, 1978 wet season.

Insecticide	BPH population[a] (no./10 hills) Before application 60 DT	After application 66 DT	Reduction[b] (%)
Chlordimeform	21,788	1,054	95 a
A 47171	14,819	1,437	91 a
Ethion	13,307	2,101	83 a
Permethrin	24,482	17,499	28 b
FMC 35001	11,871	10,451	11 c
Control	15,170	17,280	−15 c

[a]DT = days after transplanting. [b]In a column, means followed by a common letter are not significantly different at 5% level.

cypermethrin and several other treatments than in the control.

Chlordimeform, A47171, and ethion provided excellent BPH control in a field experiment where the BPH population was extremely high (Table 16). These compounds are highly promising.

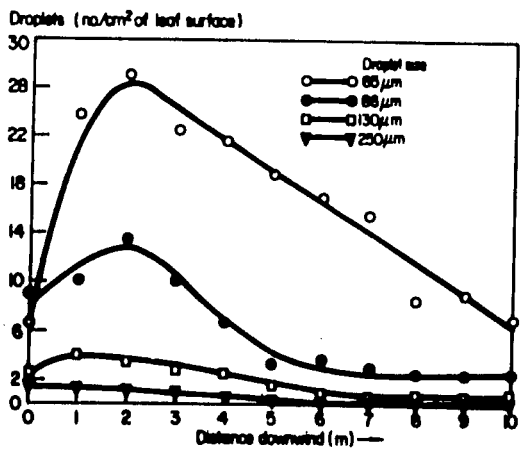
Foliar sprays of acephate were combined with various spreader-stickers to determine the value of adding spreader-stickers to the spray solution. The spreader-stickers had no effect on whorl maggot and stem borer control and did not increase residual activity against BPH.

Basic studies to determine the feasibility of using the hand-held ULV applicator for rice insect control were continued in 1978. The effect of spray droplet size on deposition on the plant was determined. The smallest droplet size tested (65 μm) provided the largest number of droplets per square centimeter on the leaf at 11 DT (Fig. 4). Peak deposit occurred 2 m downward from the ULV applicator. Tests conducted at 3 growth stages indicated that the 65-μm droplet size gave the greatest number of droplets per square centimeter of plant surface (Table 17).

Figure 5 further illustrates the effect of plant growth stage on the deposit of 65-μm droplets on the leaf. Because of the high leaf area index few droplets were deposited at 60 DT. At early growth high wind velocity results in more spray deposit near the applicator.

The distribution of 65-μm droplets on the various plant parts at different growth stages is shown in Table 18. Even in a young crop, few droplets reached the leaf sheath where the BPH feeds. Higher insecticide volumes may be necessary for adequate coverage at later growth stages.

The ULV technique was compared with three other application methods for whorl maggot control. Control equal to that obtained through



4. The effect of droplet size on deposition downwind at 11 days after transplanting (1 liter at a 5-m swath).

Table 17. Deposit of ultra-low-volume sprays as affected by droplet size and plant age in wetland rice variety IR42. IRRI, 1978 dry season.

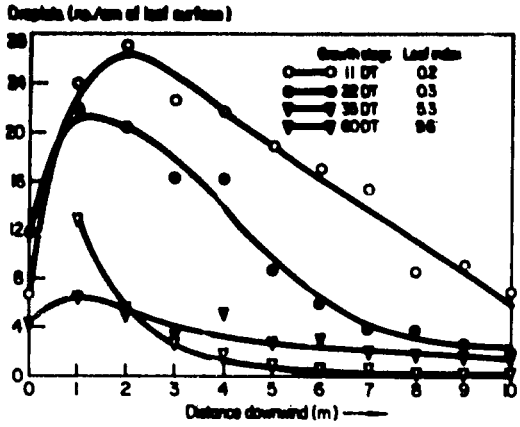
Droplet size (μm)	Droplets (no./cm²) on plant[a] 11 DT	22 DT	60 DT
65	16.1 a	10.5 a	2.6 a
86	6.1 b	7.1 a	0.7 b
130	1.8 c	0.7 b	0.3 b
250	0.4 c	0.1 b	0.1 b

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

Table 18. Distribution of 65-μm droplets on leaves of IR42 at 4 growth stages. IRRI, 1978 dry season.

Leaf area	Droplets[a] (no./cm² of leaf surface) 11 DT	22 DT	36 DT	60 DT
Upper leaf	17 b	12 b	6 c	4 c
Lower leaf	28 a	17 b	4 c	3 c
Leaf sheath	3 c	2.2 c	0.3 c	0.1 c

[a]In a column or row, means followed by a common letter are not significantly different at 5% level. Av taken over a single 10-m swath at a volume rate of 0.5 liter/ha. DT = days after transplanting.



5. Effect of growth stage on deposition downwind of 65 μm droplets applied at 1 liter/ha in a 5-m swath at 4 growth stages indicated in days after transplanting (DT).

broadcast application of granules, soil incorporation of granules, and a high-volume sprayer was achieved with an ULV formulation of carbofuran.

Paddy-water application. The effectiveness of four paddy-water broadcast applications of new insecticides is shown in Table 19. CGA 12223 was effective against whorl maggot; CGA 12223, ethoprop, and cartap against yellow stem borer. Incidence of ragged stunt virus was lowest in the CGA 12223, ethoprop, cartap, and carbofuran treatments.

Diazinon has reportedly given poor whorl maggot control in paddies where the water level is low. The effect of water level on the effectiveness of diazinon, carbofuran, and lindane applied into the paddy water for whorl maggot control was studied. Whorl maggot damage at 31 DT was higher in the plots with 2–6 cm standing water than in those that were saturated. However, water level had no distinct effect on the efficacy of the various insecticides.

Soil incorporation. Seven insecticides were tested for their effectiveness against the early pests whorl maggot and stem borer (Table 20). Carbofuran, CGA 12223, and ethoprop controlled whorl maggot at 19 DT but only carbofuran controlled it for as long as 33 DT. Only carbofuran prevented deadheart damage. Carbofuran- and CGA 12223-treated plants were significantly taller than the control.

Comparison of application methods. Metalkamate, carbofuran, and triazophos were tested as foliar spray and paddy-water application for activity as a BPH ovicide. Only a foliar spray of triazophos decreased egg hatch.

In tests of insecticides as foliar spray, paddy-water application of granules, and incorporation into the soil for stem borer control, all treatments provided control (Table 21). Carbofuran was more effective when incorporated into the soil than when applied by the two other methods. CGA 12223 was more effective as foliar spray than when incorporated into the soil.

Paddy-water application and soil incorporation of carbofuran at time of planting were compared for BPH and GLH control. The mortality of hoppers on artificially infested carbofuran-treated plants is indicated in Figure 6. Soil incorporation was most effective against

Table 19. Effect on rice pests in variety IR20 of applying insecticides to paddy water at 1 kg a.i./ha.[a] IRRI, 1978 dry season.

Insecticide[b]	Whorl maggot damage[c] 19 DT	Whorl maggot damage[c] 33 DT	Stem borer damage: Deadhearts (%) 37 DT	Stem borer damage: Whiteheads (%) 114 DT	Plant ht (cm) 54 DT	Ragged stunt (%) 92 DT	Yield (t/ha)
CGA 12223 3 G	2.3 a	3.0 a	0.1 a	0.5 a	69 ab	8 a	4.62 a
Ethoprop 10 G	3.0 ab	4.3 b	0.2 ab	1.7 abc	66 a	10 a	4.23 a
MIPC 8 G	5.0 cd	7.0 c	0.7 c	4.9 bcd	81 cde	17 b	3.13 bc
Benthiocarb 5 G	5.7 cd	6.3 c	0.7 c	4.1 bcd	59 de	19 b	3.24 bc
Acephate 3 G	4.3 bc	5.0 b	0.8 c	5.3 cd	63 bcd	19 b	3.61 b
Cartap 10 G	5.0 cd	7.0 c	0.5 bc	0.1 a	61 cde	8 a	4.25 a
Carbofuran 3 G	1.7 a	2.3 a	0.1 a	1.1 ab	72 a	8 a	4.76 a
Control	6.3 d	9.0 d	1.8 d	6.4 d	57 e	24 b	2.82 c

[a]In a column, means followed by a common letter are not significantly different at 5% level. [b]Insecticides were applied 4 times at 20-day intervals starting 5 days after transplanting (DT). G = granular. [c]Based on scale of 0–9: 0 = no damage, 9 = severe feeding lesions causing leaf breaking.

Table 20. Evaluation of granular insecticides incorporated into soil at 1.0 kg a.i./ha for whorl maggot and stem borer control in variety IR26.[a] IRRI, 1978 dry season.

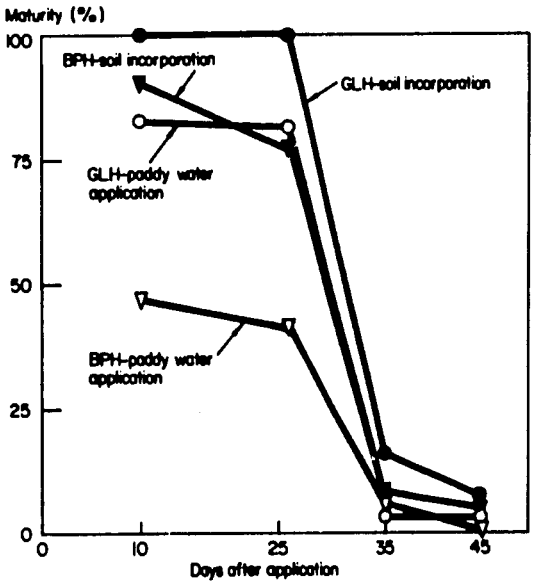
Insecticide	Formulation[b]	Whorl maggot damage[c] 19 DT	Whorl maggot damage[c] 33 DT	Stem borer deadhearts (%) 37 DT	Plant ht (cm) 34 DT
CGA 12223	3 G	2 b	7 b	1.2 abc	65 b
Ethoprop	10 G	3 c	8 bc	2.6 cd	56 c
Cartap	10 G	5 d	9 bc	1.6 bc	55 c
Bendiocarb	5 G	4 cd	8 bc	2.0 bcd	56 c
MIPC	8 G	4 cd	9 c	1.1 ab	56 c
Carbofuran	3 G	0 a	1 a	0.3 a	77 a
Acephate	3 G	5 d	9 c	3.3 d	58 c
Control		7 e	9 c	1.5 bcd	56 c

[a]In a column, means followed by a common letter are not significantly different at 5% level. [b]G = granular, DT = days after transplanting. [c]Based on a scale 0–9: 0 = no damage, 9 = severe feeding causing curling and breaking of leaves.

Table 21. Evaluation of insecticides and application methods for stem borer control in variety IR26. IRRI, 1978 wet season.

Insecticide (1 kg a.i./ha)	Formulation[a]	Method of application[b]	Deadhearts[c] (%) 35 DT
FMC 35001	48 EC	F	1.1 abcde
FMC 35001	5 G	B	3.5 def
FMC 35001	5 G	SI	1.8 abcde
FMC 27289	48 EC	F	1.8 abcde
FMC 27289	5 G	B	1.0 abcde
FMC 27289	5 G	SI	0.6 abc
CGA 12223	50 EC	F	0.4 ab
CGA 12223	3 G	B	1.0 def
CGA 12223	3 G	SI	12.0 g
Carbofuran	12 F	F	0.5 abc
Carbofuran	3 G	SI	0.2 a
BPMC	3 G	B	5.9 f
BPMC	3 G	SI	5.7 f
Cypermethrin	40 EC	F	1.3 abcde
Phosphamidon	50 EC	F	1.9 bcde
Fenvalerate	20 EC	F	3.3 f
Phosphamidon	50 SC	F	1.1 abcde
Fenvalerate + BPMC	75 EC	F	1.0 abcde
Control			12.0 g

[a]EC = emulsifiable concentrate, G = granular, F = flowable, SC = soluble concentrate. [b]F = foliar spray 2 times, 5 and 19 days after transplanting (DT); B = broadcast 2 times, 5 and 25 DT; SI = soil incorporation at last harrowing. [c]In a column, means followed by a common letter are not significantly different at 5% level.

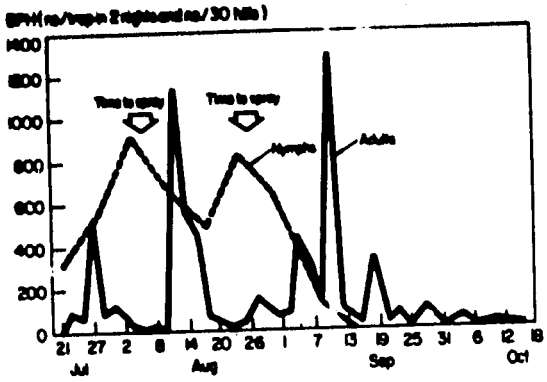


6. Mortality of the brown planthopper (BPH) and green leafhopper (GLH) on plants treated with carbofuran at 2 kg a.i./ha applied to paddy water or incorporated into the soil. IRRI, 1978.

both species at 10 and 24 days after application. None of the treatments were effective at 35 days. The same treatments against whorl maggot gave equal control. There was an unexplainable increase in whiteheads in the treated plots. Paddy water application increased plant height 12 cm and soil incorporation 16 cm above that of the control at 52 DT.

The effects of three methods of applying carbofuran — soil incorporation, paddy water application, and foliar spray — were compared. Soil incorporation was the most effective for whorl maggot control. Only repeated paddy water applications controlled late stem borer attack. Hopper resurgence occurred in the repeated paddy water treatment and in the treatment consisting of six applications of a foliar spray.

FMC 35001 has been effective against insects in greenhouse studies (*see* 1977 Annual Report). In 1978 it was tested in the field as root soak, capsule in root zone, applied as a liquid



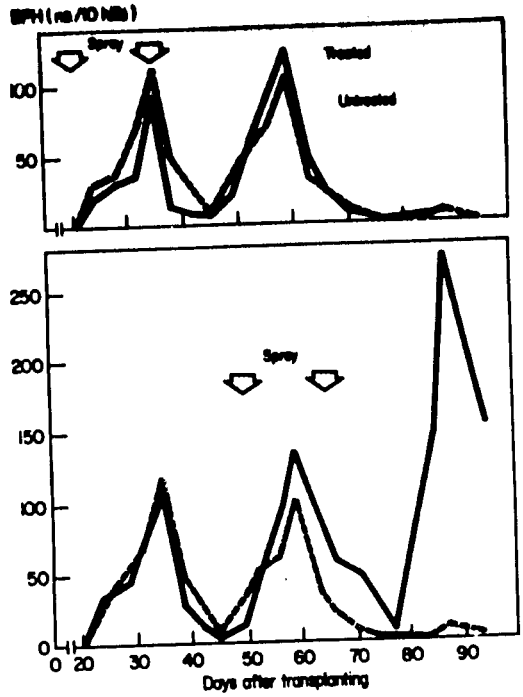
7. Catches of brown planthopper adults in a kerosene light trap and field population of nymphs in a farmer's field, Victoria, Laguna, Philippines, 1978 wet season. Nymphal population based on the average for four varieties: IR20, IR22, IR36, and elite line IR4432.

band in the root zone, incorporated into the soil, paddy water broadcast, and as foliar spray. The insecticide was effective against the whorl maggot when injected into the soil with the liquid band applicator or when incorporated into the soil. Some of the treatments had more deadhearts and whiteheads than the control.

Timing of insecticide application. In studies in a farmer's field, dates of peak light trap catches of BPH were compared with dates of peak nymphal populations within the field. Peak light trap catches occurred about 10–12 days before peak nymphal populations were observed in the field (Fig. 7). By that time most eggs in the plant had hatched and the hopper was most exposed to insecticide. That is the proper time to spray provided the economic threshold has been reached.

Brown planthopper resurgence *(Entomology).* BPH resurgence was studied in the field and greenhouse during 1978.

Field studies. Two field tests determined the effect of time and number of insecticide applications on BPH resurgence. In the first study foliar sprays of methyl parathion at the recommended rate (0.75 kg a.i./ha) during the early growth stages did not cause hopper resurgence (Fig. 8). One spray at 50 DT caused a significant increase in the second BPH generation, but had no effect on the third generation. All treatments receiving a foliar application at 65 DT had high BPH populations in the third generation, but in the

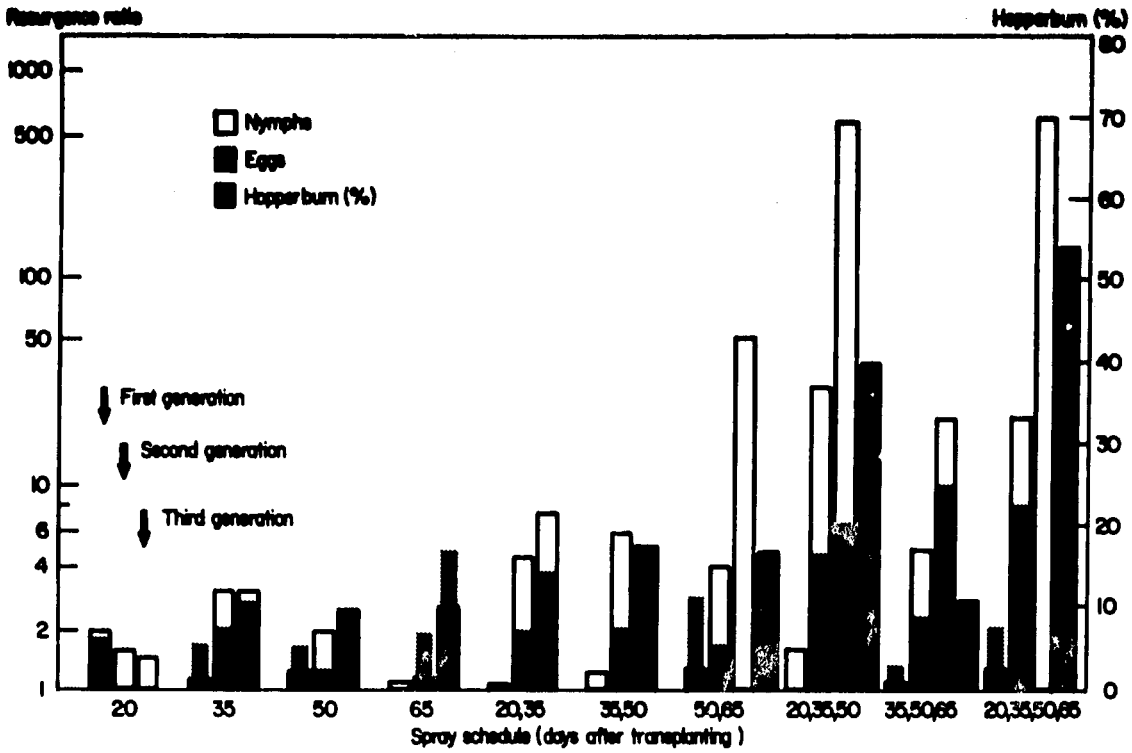


8. Resurgence of brown planthopper (BPH) population on variety IR22 when exposed to sprays of 0.75 kg a.i. methyl parathion/ha. IRRI, 1978.

untreated plots the population of the third generation was almost nil.

In the second study, decamethrin was applied as a canopy spray at 0.025 kg a.i./ha. Regardless of time of application, a single application caused a small increase in hopper number, which was not significantly higher than that of the untreated control (Fig. 9). Two applications caused a significant increase in hoppers in the third generation at all application dates, with the highest increase after application at 50 and 65 DT. The highest population and most severe hopperburn occurred in the treatment with four applications. From the two studies it is apparent that repeated applications of certain insecticides beginning about 35 DT are most likely to cause BPH resurgence.

Greenhouse evaluation of insecticides for BPH resurgence. Observations on the effect of predators in the two field resurgence studies were not conclusive. Greenhouse studies were conducted to determine the role of insecticides in inducing resurgence in the absence of natural



9. Hopper resurgence ratio of eggs and nymphs of *N. lugens* and % hopperburn damage as affected by time and frequency of decamethrin spray in wetland rice variety IR22. IRRI, 1978 wet season. Five randomly selected hills per replicate were sampled and dissected for egg numbers. Figures shown are average values of four replications sampled at 26, 54, and 75 days after transplanting (DT). Nymphs were observed 34, 62, and 81 DT. Hopperburn percentage was recorded at 88 DT. Hopper resurgence ratio was estimated by dividing the number of nymphs observed in treated plots by the number of nymphs in the untreated check plots.

enemies. Several commonly used sprayable and granular formulations of insecticides were included. The reproductive rate of hoppers on plants protected with insecticides was the criterion used in the evaluation.

Twenty-three insecticides belonging to four classes were tested as foliar sprays. In general, organophosphates and synthetic pyrethroids tended to cause resurgence, while carbamates and organochlorines did not (Table 22). But there were exceptions in both groups. A47171, FMC 35001, vamidothion, BPMC, and Perthane were significantly better than others in reducing the reproductive rate of BPH. Methyl parathion, fenitrothion, decamethrin, diazinon, and fenthion increased the reproductive rate of hoppers, making resurgence likely.

BPH resurgence after the application of insecticide granules was also studied. When BPH were placed on rice plants 30 days after cartap, phorate, or diazinon at 1.0 kg a.i./ha was incorporated into the soil, their reproductive rate increased significantly (Table 23).

With diazinon, mephosfolan, and aldicarb the reproductive rate of BPH was higher at 0.5 kg/ha than at 1.0 kg a.i./ha. That indicated the danger of BPH resurgence when low dosages of granular insecticides are used, either for economic reasons or because of defective distribution.

Table 23. Evaluation of foliar spray insecticides on brown planthopper resurgence in variety TN1. IRRI Inceptory, 1978.

Insecticide[a]	Formulation EC[b] (%)	Class[c]	Reproductive rate[d] (no. of nymphs)
A 47171	24	OP	107.0 a
FMC 36001	48	C	115.3 a
Vamidothion	40	OP	116.7 a
BPMC	50	C	120.0 a
Perthane	45	OC	124.7 a
Carbophenothion	40	OP	136.0 ab
FMC 27289	48	C	156.7 abc
FMC 31768	24	C	161.0 abc
Endosulfan	35	OC	182.3 abcd
Control (water spray)	—	—	207.3 bcde
Acephate	40	OP	210.7 bcde
Phosphamidon	50	OP	211.3 bcde
Methomyl	19.3	C	214.0 cde
Azinphos ethyl	40	OP	238.7 def
AC 64475	25	OP	252.3 defg
Dasanox	23	OC	253.3 efg
Cypermethrin	40	P	255.7 efgh
Triazophos	40	OP	262.7 efghi
Monocrotophos	16.8	OP	269.0 efghi
Methyl parathion	50	OP	297.0 fghij
Fenitrothion	20	OP	322.0 ghij
Decamethrin	2.5	P	334.7 hij
Diazinon	20	OP	336.0 ij
Fenthion	50	OP	353.0 j

[a]Insecticides were foliar sprayed at 0.04% concn (except for cypermethrin and decamethrin, sprayed at 0.002%) on 20-, 30-, and 40-day-old plants. [b]EC = emulsifiable concentrate. [c]C = carbamate, OC = organochlorine, OP = organophosphate, P = pyrethroid. [d]From eggs laid by 2 females/7 days. Females were released 15 days after third spraying. Means followed by a common letter are not significantly different at 5% level.

Table 28. Effect of insecticides as granules incorporated into soil at 1 kg a.i./ha on brown planthopper resurgence in variety TN1. IRRI Inceptory, 1978.

Treatment[a]	Reproductive rate[b] (no. of nymphs)
Aldicarb	202.7 cd
Bendiocarb	188.0 cde
Carbofuran	189.7 cde
Cartap	388.7 a
Thiofanox	247.0 c
Diazinon	306.3 ab
FMC 27289	117.7 e
FMC 31768	137.7 de
FMC 36001	160.3 cde
Isazophos	282.7 b
Mephosfolan	226.0 cd
Phorate	354.7 a
Triazophos	199.3 cd
Control	235.0 c

[a]Granules were incorporated into soil when plants were 35 and 47 days old. [b]From eggs laid by 2 females/7 days. Females were released 30 days after second application of granules. Means followed by a common letter are not significantly different at 5% level.

Reduced reproduction of BPH on plants receiving FMC 27289 and FMC 31768 at 1.0 kg a.i./ha is also of practical significance in the selection of insecticides for BPH control.

Effect of insecticides on the orientational response of BPH. The orientational response of BPH, as influenced by insecticide odor and insecticide-induced plant growth, was studied. The odor given off by four insecticides sprayed on rice plants did not influence the orientation of BPH (Table 24), but improved plant growth effected by foliar sprays of insecticides did. Plants sprayed with methyl parathion had significantly more tillers and leaves, and more BPH alighted on them. Plants treated with decamethrin and diazinon, two insecticides that cause resurgence, and Perthane, a nonresurgence-inducing insecticide, did not, however, grow better than the control.

Insecticide sprays on rice and feeding rate and damage by BPH. Rice plants labeled with ^{32}P were used in studying the influence of four insecticide sprays on the relative feeding rate of BPH. The sap ingested by the hoppers was assessed indirectly by measuring the radioactivity of the BPH as well as that in the filter paper that absorbed the BPH-excreted honeydew. The feeding rate was higher by 61, 43, and 33% in plants treated with decamethrin, methyl parathion, and diazinon than in the control (Table 25), but it was lower by 25% in Perthane-treated plants.

In another experiment that used honeydew excretion as an index to feeding rate, BPH feeding increased on rice plants protected with decamethrin and methyl parathion, and significantly decreased on those treated with Perthane.

The damage caused by BPH on plants sprayed with different insecticides also varied significantly. The same population of BPH caused hopperburn soonest on plants sprayed with resurgence-causing insecticides. The results suggest that increased damage to the rice crop by BPH after application of certain resurgence-causing insecticides might be due to the increased feeding of hoppers. Reduced feeding in plants protected with Perthane has practical significance in BPH control.

Insecticide application and changes in the major and minor elements in rice plants. Quan-

Table 24. Effect of foliar spray of insecticides on plant growth and on the orientation of the brown planthopper as influenced by odor stimulus and plant growth.[a] IRRI Insectary, 1978.

Insecticide[b]	Orientation (% adults alighting) as influenced by[c]		Changes in plant growth		
	Odor stimulus[d]	Plant growth[e]	Tillers (no.)	Leaves (no.)	Ht (cm)
Methyl parathion	24.3 a	31.5 a	9.9 a	32.4 a	76.3 a
Decamethrin	27.4 a	28.6 b	7.6 b	27.4 ab	75.4 a
Diazinon	25.9 a	23.2 c	6.8 b	23.5 b	71.6 ab
Perthane	27.2 a	23.4 c	7.2 b	23.5 b	68.6 b
Control	26.0 a	24.[illegible] c	7.2 b	23.5 b	74.7 a

[a]In a column, means followed by a common letter are not significantly different at 5% level. [b]Insecticides foliar sprayed at 0.04% concn (except for decamethrin sprayed at 0.002%), on 20-, 30-, and 40-day-old plants. [c]Transformed (arcsin) values. Fifty macropterous females were released in the center of each cage and plants were arranged in a circle at 39-cm radius to test odor stimulus, and at 60-cm radius to test plant growth effect. [d]Mean percentage from 1 to 9 days after spraying. [e]Mean percentage from 18 to 20 days after third spraying.

Table 25. Feeding rate of the brown planthopper on variety TN1 as influenced by foliar sprays of insecticides.[a] IRRI, 1978.

Insecticide[b]	Honeydew excretion (cm^2)	Radioactivity[c]
Decamethrin	13 a	6308 a
Methyl parathion	12 ab	5587 ab
Diazinon	12 abc	5185 b
Perthane	7 d	2955 d
Control	9 bcd	3912 c

[a]In a column, means followed by a common letter are not significantly different at 5% level. [b]Insecticides foliar sprayed at 0.04% concn (except for decamethrin sprayed at 0.002%) on 20-, 30, and 40-day-old plants. Insects were placed on plants 15 days after third spraying. [c]Radioactive counts in filter paper, fifth-instar nymphs, and in the excreted honeydew. Nymphs fed on ^{32}P-treated plants for 24 h. Activity/5 s in GM counter (Nuclear Chicago Model No. 8400).

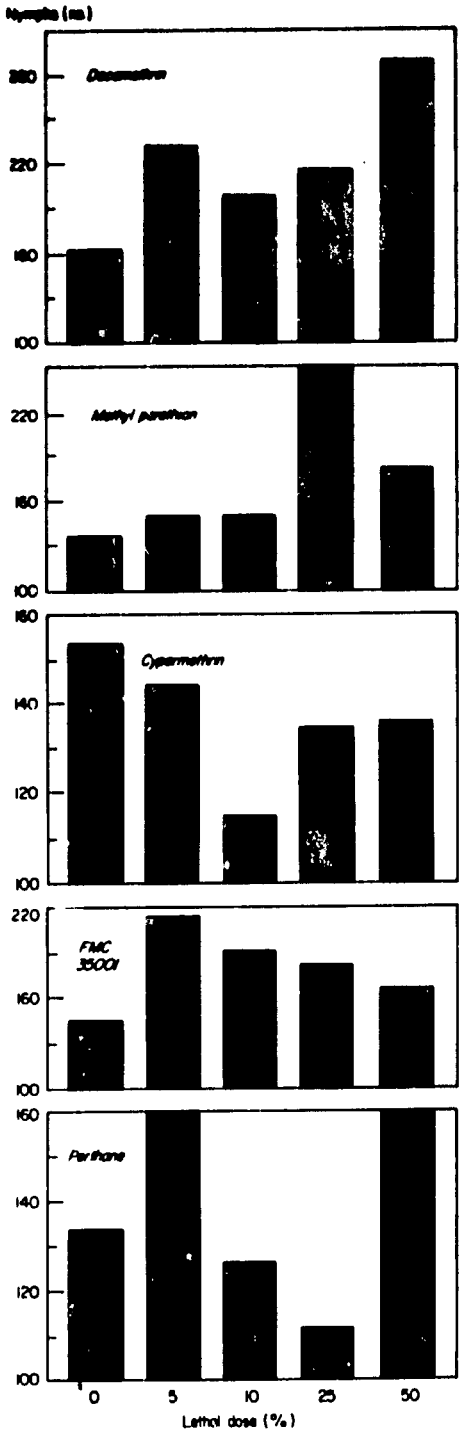
titative differences in the major and minor elements in rice plants treated with foliar spray or granular insecticides were studied to relate their role in BPH resurgence. Plant contents of nitrogen, phosphorus, potassium, magnesium, calcium, and zinc did not differ significantly. Although differences in copper and iron content among sprayed plants, and in manganese content among granule-treated plants were apparent, they did not contribute to resurgence.

Sublethal doses of insecticides and BPH reproduction. The relationship between use of low dosages of insecticides and BPH resurgence was studied. Five insecticides — three (decamethrin, methyl parathion, and cypermethrin) known to cause resurgence and two (FMC 35001 and Perthane) known not to — were tested. BPH treated with four lethal doses of decamethrin and methyl parathion differed significantly in reproductive rate (Fig. 10). Topical application of sublethal doses of methyl parathion and decamethrin on the fifth-instar nymphs significantly increased the reproductive rate of the resulting adults. Highest reproductive stimulation occurred at LD_{25} with methyl

Table 26. Effect of certain insecticidal granules applied at low dosages on the nymphal duration and percentage of resulting females of brown planthopper on variety TN1.[a] IRRI Insectary, 1978.

Insecticide[b]	Rate (kg a.i./ha)	Mean nymphal duration[c] (days)					Total nymphal duration (days)	Females (%)
		1st instar	2d instar	3d instar	4th instar	5th instar		
Aldicarb	0.25	2.4 a	2.7 cd	3.1 c	2.6 abc	2.4 abc	13.2 d	54.1 a
	0.10	2.3 a	2.4 bc	2.7 abc	2.4 a	2.3 a	12.1 c	43.1 a
Metalkamate	0.25	2.2 a	2.3 ab	2.6 ab	2.4 a	2.5 ab	12.0 c	50.0 a
	0.10	2.2 a	2.1 a	2.4 a	2.3 a	2.5 ab	11.5 ab	57.3 a
Diazinon	0.25	2.2 a	2.3 ab	2.6 ab	2.5 ab	2.3 a	11.9 bc	55.0 a
	0.10	2.1 a	2.1 a	2.4 a	2.3 a	2.3 a	11.2 a	48.1 a
Carbofuran	0.25	2.6 a	2.8 d	2.6 ab	2.9 c	2.9 c	13.8 e	39.2 a
	0.10	2.3 a	2.6 cd	2.7 abc	2.8 b	2.7 bc	13.1 d	30.9 a
Control	—	2.5 a	2.6 cd	2.8 abc	2.9 c	2.7 bc	13.5 de	46.9 a

[a]Mean of 3 replications. In a column, means followed by a common letter are not significantly different at 5% level. [b]Granules were incorporated into the soil at 10 days after transplanting (35 days after seeding). [c]Freshly hatched nymphs were released at 5/plant 37 days after application of granules.



10. Effect of lethal doses of insecticides on the reproductive rate of *N. lugens* on variety TN1. IRRI insectary, 1978. Lethal doses of technical materials were applied topically on fifth-instar nymphs that emerged from eggs laid by 2 females in 7 days. The difference between doses was statistically significant.

parathion and at LD_{50} with decamethrin. With Perthane, cypermethrin, and FMC 35001, the four dosages tested produced no significant difference in reproductive rate.

Low dosages of granular insecticides and BPH nymphal duration and sex ratio. The effect of soil incorporation of low dosages of granular insecticides on the nymphal duration of BPH was studied. The duration of four nymphal stadia differed significantly among treatments (Table 26). The total nymphal duration also varied among treatments.

Insecticides and resurgence of WBPH and GLH. Diazinon, methyl parathion, and decamethrin, which cause BPH resurgence at IRRI, also cause WBPH resurgence (Table 27). Diazinon appears to cause greater resurgence than the two other insecticides. Perthane decreased the reproductive rate of BPH (25%) and that of WBPH (27%) possibly by reducing the feeding of hoppers. Not one of the four insecticides tested with GLH caused resurgence.

Fate of carbofuran in flooded soil and the rice plant *(Soil Microbiology).* The imbalance of carbofuran in plants grown in culture solution containing ^{14}C-carbofuran, reported in the 1977 Annual Report, suggested loss of carbofuran from the plant through vaporization.

More direct evidence of the loss was obtained by trapping the circulating air from the chamber enclosing the plant and the culture solution. ^{14}C-carbofuran was added to the culture solution and the ^{14}C-compounds were trapped by a series of ethylene glycol and 1 N NaOH solutions. Carbofuran was trapped in ethylene glycol solutions 24 hours after treatment. ^{14}C trapped in ethylene glycol was mainly or wholly carbofuran during 10 days and ranged from 9 to 19% of the absorbed carbofuran. The vapor loss of carbofuran was directly related to the amount of water lost by transpiration.

Carbofuran loss as affected by application methods was examined. Carbofuran loss from rice was more rapid with floodwater application than with root-zone application.

Degradation of carbofuran as affected by other carbamate pesticides. A pesticide that persists in the soil may affect the decomposition of another pesticide. Interaction among chemi-

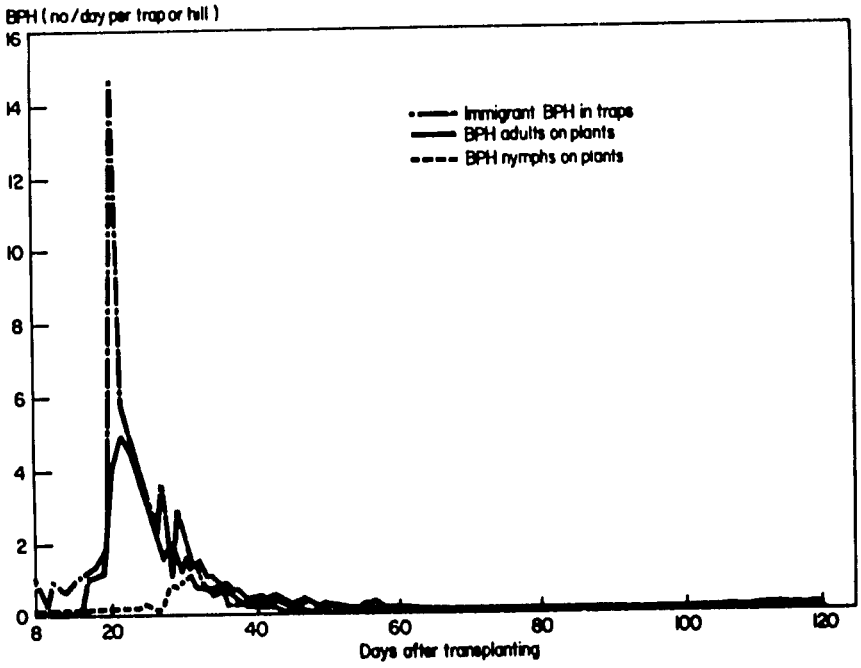
Table 27. Reproductive rate of brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper (GLH) in relation to foliar sprays of insecticides on variety TN1.[a] IRRI Insectary, 1978.

Insecticide[b]	Concn (%)	Nymphs hatched					
		BPH		WBPH		GLH	
		Number[c]	Increase or decrease (%)	Number[c]	Increase or decrease (%)	Number[c]	Increase or decrease (%)
Decamethrin	0.002	321.3 a	+93.8	198.3 b	+28.5	[d]	[d]
Methyl parathion	0.04	291.5 ab	+75.8	213.8 ab	+38.6	117.0 a	+37.6
Diazinon	0.04	275.3 b	+66.0	248.3 a	+60.9	137.8 a	+62.1
Perthane	0.04	125.0 d	−24.6	113.3 d	−26.6	110.3 a	+28.8
Acephate	0.04	[d]	[d]	[d]	[d]	76.3 a	−10.2
Check (water spray)	—	165.8 c	—	154.3 c	—	86.0 a	—

[a]In a column, means followed by a common letter are not significantly different at 5% level. [b]Insecticides were sprayed 20, 30, and 40 days after planting. [c]Mean of 4 replications. Hatched from eggs laid in 7 days by 2 females of BPH and WBPH and 5 females of GLH. Hoppers were placed on plants 10 days after third spraying. [d]Not tested.

cally related compounds is expected to be more severe. The decomposition of ^{14}C-carbofuran in a flooded Maahas soil, as affected by the simultaneous presence of nonradioactive carbamate compounds such as benomyl, carbaryl, and benthiocarb, was studied. Only the presence of carbaryl accelerated the decomposition of carbofuran. Carbofuran decomposed more rapidly in the soil that was treated with carbaryl four times than in the untreated soil. On the other hand, the decomposition of ^{14}C-carbaryl was slightly affected by the presence of carbofuran in the flooded soil. Carbaryl decomposed more rapidly in the soil repeatedly treated with carbofuran than in untreated soil. The data suggest that the degradation of carbofuran and that of carbaryl in flooded soil influence each other.

Effects of carbofuran on nitrogen transformation in flooded soil. The effects of carbofuran on nitrogen mineralization, urea hydrolysis, ni-



11. Trends of immigration of macropterous brown planthopper (BPH) and their buildup in 11- x 20-m IR1917-3-17 rice plots. Hopper numbers are based on daily catches in yellow pan oil-water traps and visual counts on plants. IRRI, 1978 dry season.

trification, and phototrophic nitrogen fixation were studied. Carbofuran at 25 μg/g dry soil slightly enhanced urea hydrolysis. Algal nitrogen fixation in the flooded soil was enhanced by carbofuran at 6 kg a.i./ha applied in floodwater. The enhancement was not direct, because active algal nitrogen fixation occurred in carbofuran-treated soil only after most of the carbofuran was decomposed. In carbofuran-treated soil, the floodwater turned transparent; in the control soil, it was turbid. The initial concentration of carbofuran in floodwater was 15 ppm. Carbofuran at 35 ppm inhibited nitrogen fixation by *Gloeotrichia*. Carbofuran up to about 20 ppm neither inhibited nor stimulated mineralization and nitrification.

CULTURAL CONTROL OF BROWN PLANTHOPPER

Entomology Department

Monitoring field colonization. Immigrant BPH were successfully monitored in rice with yellow pan oil-water traps. A major peak of immigrant hoppers occurred about 20 DT in the 1978 dry season (Fig. 11). The trend in the arrival of immigrant hoppers on rice plants was similar. The BPH colonizers were monitored as efficiently with 4 traps as with 32 traps placed around the rice fields (Table 28). Because BPH numbers were extremely low during the entire crop period, insecticidal treatments for their control were unnecessary.

Host plants of brown planthopper. The agroecosystem in which rice grows includes several species of grasses and weeds. The suitability of *Oryza* species, grasses, and weeds for the growth and development of BPH biotype 1 was tested. Ten first-instar BPH were caged on each of 19 test plants, which included 5 IRRI accessions of *Oryza* and 14 species of weeds and grasses commonly associated with cultivated rice in the Philippines. The percentages of nymphs that became adults on *O. glaberrima*, *O. nivara*, and *O. rufipogon* were as high as those on TN1, although the nymphs' growth period was the shortest on TN1 (Table 29). The study showed that a few *Oryza* species can serve as suitable hosts of BPH but that weeds and grasses are only marginally adequate.

Table 28. Efficiency of 4, 8, 16, and 32 yellow pan oil-water traps in monitoring the macropterous immigrant brown planthopper (BPH) in rice fields in a 117-day crop period.[a] IRRI, 1978 dry season.

Traps (no./plot)	BPH (no./trap)	Yield (t/ha)
4	72 a	3.1 a
8	75 a	3.5 a
16	81 a	3.1 a
32	78 a	3.0 a

[a]IR1917-3-17, a BPH-susceptible selection, was planted in 220-m² plots. Each treatment was replicated 4 times. Means followed by a common letter are not significantly different at 5% level.

Table 29. Growth of *Nilaparvata lugens* (biotype 1) on selected *Oryza* species and weeds commonly associated with cultivated rice.[a] IRRI insectary, 1978.

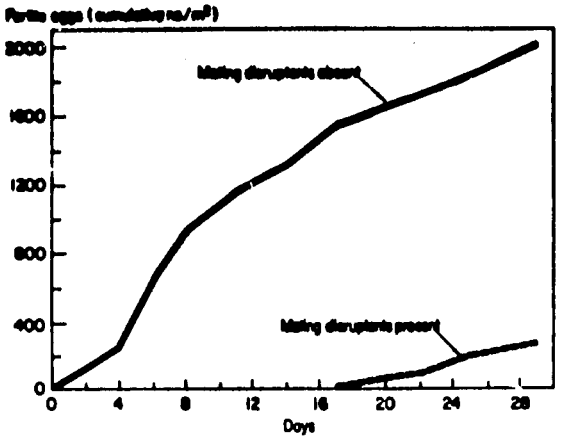
Plant species[b]	Nymphs becoming adults (%)	Growth period (days)	Growth index[c]
O. grandiglumis (Acc. no. 101764)	8 b	24.1 a	1.3 d
O. glaberrima (Acc. no. 100832)	91 a	20.2 b	4.5 ab
O. glaberrima (Acc. no. 102556)	93 a	20.7 b	4.3 ab
O. nivara (Acc. no. 103407)	89 a	20.7 b	4.2 b
O. rufipogon (Acc. no. 101448)	87 a	19.9 d	4.3 ab
O. sativa TN1 (control)	91 a	17.9 d	4.9 a
Eleusine indica	7 b	19.5 bc	0.9 d
Cyperus difformis	9 b	18.0 cd	2.5 c

[a]Av of 10 replications. In a column, means followed by a common letter are not significantly different at 5% level. [b]Other weed species included in the experiment but found highly unsuitable as BPH hosts were: *C. iria*, *Echinochloa colona*, *E. crus-galli*, *Fimbristylis littoralis*, *Imperata cylindrica*, *Leersia hexandra*, *Leptochloa chinensis*, *Monochoria vaginalis*, *Paspalum distichum*, *Scirpus maritimus*, *Sphenoclea zeylanica*, and *Zizania latifolia*. [c]Computed as the ratio of percentage of nymphs becoming adults to the growth period; mean of indices of individual replicates.

SEX PHEROMONES OF STEM BORERS

Entomology Department

In an earlier collaborative work with the Tropical Products Institute, London, U.K. (1977 Annual Report), pheromone-mimic compounds disrupted the orientation of *Chilo suppressalis* male moths to synthetic-pheromone traps. Actual disruption of mating by these compounds was demonstrated in 100-m³ cages in 1978. The mimics were released from a double layer of polythene vials (8/m³) suspended in the rice canopy. Each vial contained 1 mg of



12. Fertile eggs laid on susceptible plants by stem borer *Chilo suppressalis* moths, released every day or every 2 days in field cages with or without vials containing mating disruptants. IRRI, June 1978.

formate mating disruptants, released at a rate of 10-2 g/ha per day in the first 2 weeks. Ninety-nine pairs of moths placed inside the cage for 27 days did not lay fertile eggs on the rice plants in the first 2 weeks (Fig. 12).

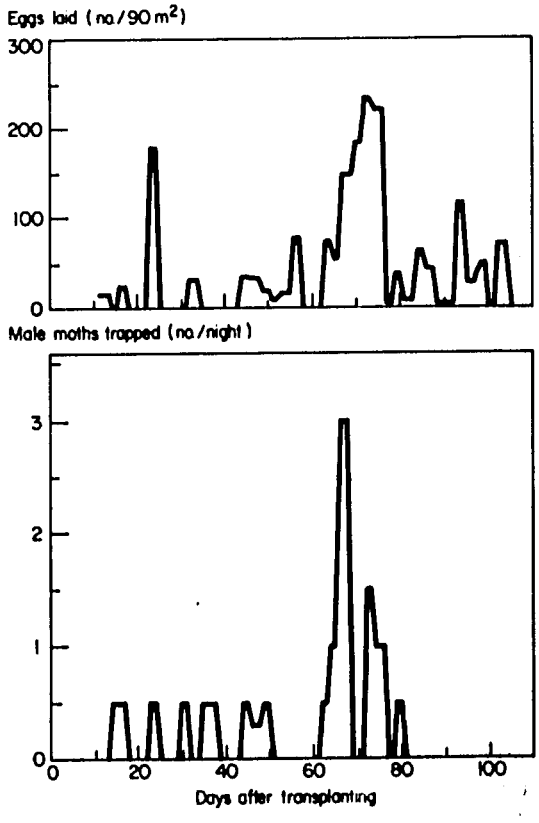
A practical use of pheromone traps is monitoring of pest behavior and density. Traps used in 1978 were each baited with a polythene vial containing 100 μg of pheromone. Observations in three crops confirmed earlier findings that the peak number of male moths was caught at about 60 DT (1977 Annual Report). As expected, the peak in egg density on the crop occurred at the same time or slightly later (Fig. 13). Pheromone traps would indicate the efficient time for applying sprayable insecticides — when stem borer eggs are hatching. Pheromone trap catches at IRRI were better indicators of oviposition than light trap catches. The size of the former may also be a measure of the need to protect a crop against stem borers. In 2 of 3 trials, about 200 eggs/24 hours per 90 m² of crop were laid when each trap caught 1 male moth per night.

Preliminary attempts to improve the design of pheromone traps were made. The water-oil trap appears to be efficient, but is cumbersome. When traps were baited with polythene vials, the water-oil traps caught the most moths, but cylindrical (15- × 40-cm) sticky traps compared favorably with the water-oil traps if all traps were baited with rubber septum dispensers. In water-oil traps, the rubber dispensers were as good as the more expensive polythene vials, and could be used with much lower doses of the pheromones.

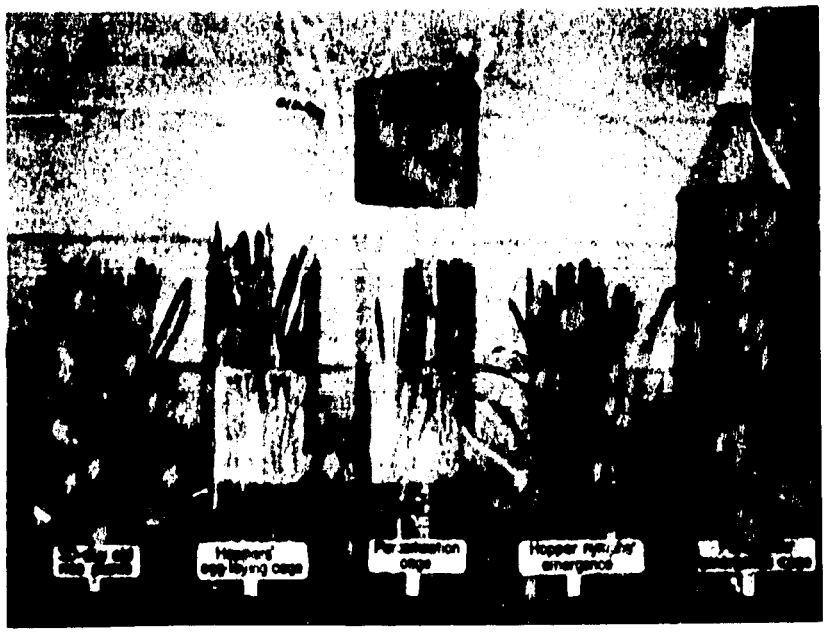
BIOLOGICAL CONTROL OF INSECTS

Entomology Department

Insects parasitic on hoppers. *Parasites of eggs.* A major egg parasite at IRRI is *Anagrus flaveolus* (Mymaridae). Its adults lived an average of 4.2 days at 30°C when kept on 30% honey solution. In an insectary and in the presence of many BPH eggs, they lived 5 days, each female parasitizing an average of 21 eggs — 17 of those on the first day. If the egg density per female parasite increased from 10 to 30, parasitism increased. Egg age had no effect on



13. Comparison of *Chilo suppressalis* oviposition on transplanted rice selection IR1917-3-17 and moth catches in 3 pheromone traps. Bay, Philippines, 1978 wet season.



14. Method of mass-rearing the egg parasite *Anagrus flaveolus* in an insectary. IRRI, 1978.

the parasitism of BPH and WBPH eggs. For BPH eggs, plant age had little effect, but very young plants were slightly preferred.

The parasitization behavior of *Anagrus*, on the BPH was observed in detail. The female adult found an egg mass in a plant within a minute by drumming the plant with its antennae. It took another 30 minutes to bore into the leaf sheath, and to find and parasitize the first egg.

A method for mass-rearing *Anagrus* was developed (Fig. 14). The BPH eggs laid in 30-day-old plants were exposed to adult *Anagrus*. Unparasitized planthoppers hatched in 1 week and were removed. *Anagrus* adults emerged several days later and were easily collected by attracting them to light at the top of the cage. This method increased the parasite population by 1.5 times each generation.

Another parasite of BPH eggs is *Oligosita* sp. (Trichogrammatidae). Adults lived 3.4 days at 30°C on honey solution. In an insectary they lived 4 days where each female parasitized 10 eggs — 8 of them on the first day. Plant age did not affect parasitism of BPH eggs by *Oligosita*.

BPH eggs parasitized by *Anagrus* become yellow or reddish, but those parasitized by *Oligosita* become yellow with a black band. When the parasite species are reared together, *Anagrus* dominates *Oligosita*. The *Anagrus* larva kills that of *Oligosita* if multiple parasitism of a BPH egg occurs.

Eggs of BPH, WBPH, and GLH were laid separately in 30-day-old potted plants in a greenhouse. The plants were placed weekly in wetland and dryland rice fields and in nearby uncropped areas. After 3 days the plants were taken to the greenhouse for egg parasitism determination by rearing and dissection. (Eggs with attached plant tissue were reared on moist filter paper in covered petri dishes.) In most cases parasitism of BPH eggs was the same for all sites; sometimes it was highest in wetland fields. Location also did not seem to greatly affect egg parasitism in the two other pest species. All species experienced about 30% parasitism. During a 1-year period there were no clear trends in percentage of parasitism, but sometimes there was one peak in parasitism for each major cropping period. Weekly measurements showed that parasitism ranged from 5 to 90%, but was commonly between 15 and 55%. Weekly changes were usually within 10 and 20%, but the maximum reached 75%.

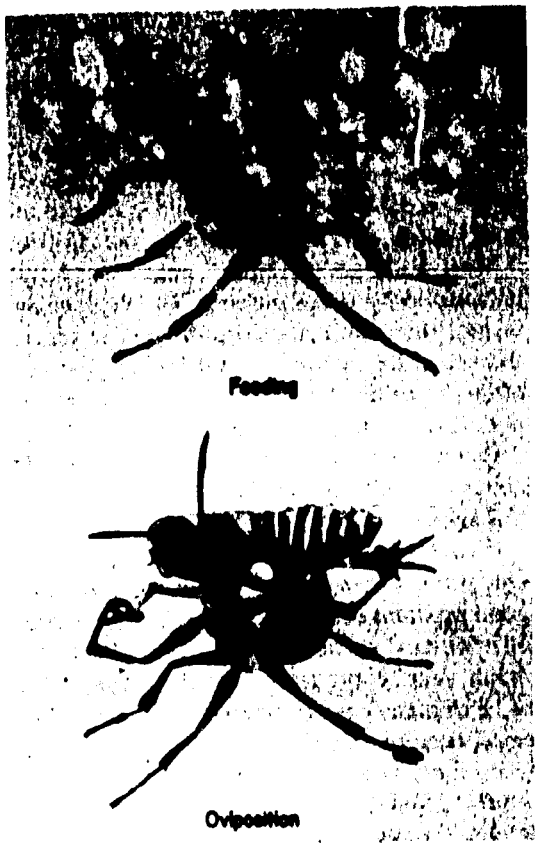
All parasite species were equally active in the three sites, indicating that they were not restricted to a particular habitat. BPH eggs were exclusively parasitized by *Anagrus* and *Oligosita*. A third parasite, *Gonatocerus* sp. (Mymaridae), also attacked *Nephotettix* spp. Only *Anagrus* attacked WBPH. Over the year both *Anagrus* and *Oligosita* parasitized BPH eggs to about the same extent, but *Oligosita* was dominant during the dry season and *Anagrus* in the wet. Usually either *Anagrus* (especially in the wet season) or *Gonatocerus* was the most common parasite of GLH eggs.

Parasites of nymphs and adults. A major parasite of hopper nymphs and adults at IRRI was *Pseudogonatopus nudus* (Dryinidae). Adult females, ant-like in appearance, lived in the laboratory about 12 days, during which they attacked hoppers, primarily planthoppers, by feeding on and ovipositing in them. Females derived from field collections in August 1977 fed on three and oviposited in five fourth-instar BPH nymphs daily, but females from collections made in January 1978 fed on only two and oviposited in one daily.

In the insectary *P. nudus* eggs hatched in 4 days, and the larvae developed in larval sacs (bulges between 2 host tergites) in another 4.5 days. The fifth-instar larvae emerged after killing the hopper, and then spun a cocoon on the plant. The pupal period lasted about 15 days. The sex ratio of laboratory-reared parasites was about 1:1, but males were almost twice as common as females in field-collected material. Mating occurred rarely. Adults lived only 2 to 5 days on water or 30% honey solution.

Female parasites catch host insects (especially those that move) with their forelegs, sting them, and start feeding or egg laying. The wasp's position with respect to that of its host is an indicator of the wasp's activity (Fig. 15). After feeding, the wasp drops the hopper but after egg laying, the wasp places the hopper back on the plant.

Several cages were developed for rearing and observing dryinids. All were made with clear plastic walls, and contained hoppers on a plant with its roots in water outside the cage. Moist filter paper was placed on the bottom of rearing cages to maintain humidity and absorb honeydew. The cages minimized moisture accumulation on the walls, simplified plant changing, and eliminated soil contact.



15. Dryinid parasite *Pseudogonatopus nudus* feeding on and ovipositing in a brown planthopper nymph. IRRI, 1978.

Three 1977–78 crops were sampled for hoppers and a variable number of hoppers were collected each week. The hoppers were reared in an insectary for 1 week and parasitism was determined. Five species of Dryinidae, including *Haplogonatopus* spp., and three species each of Strepsiptera and Pipunculidae were found. Nematode and fungal-infected hoppers were rare. The percentage of parasitism of hoppers in dryland and wetland fields was much the same; it ranged from 0 to 50% and averaged 14%. On the average the WBPH tended to have slightly less parasitism (10%) than BPH (15%) or GLH (18%). A pattern of parasitism within a crop period or year was not discernible; parasitism and host density showed little correlation.

BPH, WBPH, and GLH were all attacked by dryinids and strepsipterans, but during peak periods of parasitism, dryinids often predominated in WBPH and strepsipterans in BPH. Dryinid parasitism of planthoppers averaged 7%; strepsipteran parasitism averaged 8% for BPH and 3% for WBPH. Pipunculids were the dominant parasites of GLH (12% parasitism).

More BPH adults than nymphs were found parasitized by strepsipterans; WBPH developmental stages and parasitism by certain species showed little interaction. GLH nymphs were often parasitized by dryinids, but adults by pipunculids and strepsipterans.

Dryinid pupal hyperparasitism was 30–50%, limiting the effectiveness of this biological control agent.

Predators of hoppers. *Bugs.* The mirid bug *Cyrtorhinus lividipennis* is only a moderately good predator of BPH adults and nymphs but is an important predator of BPH eggs (Table 30). Adult female predators attacked more than twice as many eggs as males did (4.3 versus 1.6 eggs/predator daily). Oviposition was highest when the predator was fed BPH eggs or gravid female adults. When fed GLH nymphs or adults, the predator laid only about 1 egg/day. The protein in the egg prey may be needed for predator egg production.

The age of BPH eggs did not affect the predation rate. Egg predation slightly increased with increasing egg densities in rice plants. When caged with varying numbers of BPH eggs reconstituted daily for 5 days, a pair of predators attacked from 2 out of 23 eggs to 17 out of 119 eggs daily. The percentage of eggs attacked remained rather constant.

Cyrtorhinus also attacks GLH eggs. It pierces hopper eggs and sucks out part or all of the contents, causing the eggs to collapse.

Cyrtorhinus survived poorly on water or rice plants alone, but survival improved when the predator was provided with 10% sucrose solution. High survival and substantial oviposition evidently required insect prey.

The small brown or black ripple bug (Veliidae) *Microvelia atrolineata* lives on the water in wetland rice fields. It attacks hoppers and other small animals on the water, stinging them, and sucking out their body fluids. The predators may aggregate in spots with high hopper densities, an important characteristic with respect to biological control. In each of 4-hill field cages, which had large openings near the bottom, there were 34 predators (mainly *Microvelia*); only 2 were found in closed cages. This difference in predator density led to a highly significant reduction of BPH nymph density — 86 to 36 nymphs/cage over an 18-day period.

The life history of *Microvelia* was observed in petri dishes containing water, bits of floating rice leaves, and prey. White eggs are laid, singly or in batches, and glued to some object near the water surface. Red-eyed nymphs hatch (even if the eggs are under water) after 5 days and undergo 5 instars in about 20 days. Either macropterous or brachypterous adults develop at about a 1:1 sex ratio, and live about 23 days.

Table 30. Mortality of brown planthopper (BPH) and fecundity of a pair of adult *Cyrtorhinus lividipennis* (predator) when caged together on potted rice plants.[a] IRRI insectary, 1978.

BPH stage	BPH mortality experiment		Predator fecundity experiments	
	Predator longevity (days)	BPH mortality (no./day)	Predator longevity (days)	Predator fecundity (no. eggs/day)
Egg	20	4.1 a	19	12.9 a
1st-instar nymph	12	0.4 c	28	1.1 b
2d-instar nymph	7	0.4 bc	28	1.0 b
3d-instar nymph	9	0.5 bc	27	1.8 b
4th-instar nymph	12	0.5 bc	26	2.9 b
5th-instar nymph	9	0.5 bc	18	2.1 b
Adult (♂ + ♀)	10	0.6 bc	19	11.0 a
Adult ♂	24	0.6 bc	25	1.2 c
Adult nongravid ♀	26	0.4 bc	30	4.8 b
Adult gravid ♀	23	0.8 b	28	7.8 a

[a]One hundred seventy-five BPH eggs in rice plants or 20 nymphs or adults were provided daily. In a column, means followed by a common letter are not significantly different at 5% level.

Females lay between 4 and 20 eggs. The adults fly and are attracted to lights at night.

A large prey is attacked by several *Microvelia* at one time, but a smaller hopper can be killed by a single predator. The predator inserts its proboscis into the prey, lifts it, and starts feeding. Starvation due to few or no prey leads to cannibalism of young nymphs or old adults. In one experiment, cannibalism of first-instar nymphs reached 50%.

When 1 predator adult was provided daily with 20 BPH first-instar or second-instar nymphs for a 20-day period, 4.5 of the first-instar nymphs were killed daily. This was significantly more than the 2.8 second-instar nymphs killed each day. But 10 predators together, when offered 100–200 first-instar nymphs, daily killed 8 nymphs/predator. Thus, *Microvelia* is an important predator of BPH.

Microvelia adults preferred to attack first-instar nymphs of BPH and GLH, and least preferred adult prey (Table 31). The attack rate by starved predators usually was highest within the first 30 minutes the prey and the predators were caged together. No major difference in predation on the two hopper species was observed. But when 50 first-instar nymphs of each of BPH and GLH were caged in a petri dish together with 5 pairs of *Microvelia* adults, the 13 GLH killed in 30 minutes were significantly more than the 10 BPH. By the end of 1 day, however, significantly more BPH (42) than GLH (32) were dead, suggesting some preference for BPH if a long-term choice is available.

Spiders. Adults of several spider species were collected from wetland rice fields and caged separately with BPH nymphs in an insectary. *Tetragnatha* sp. and *Argiope* sp. had no apparent effect on the prey, and *Callitrichia* sp. killed only a few (0.5 nymph/day). But in 1 experiment, 1 individual of *Oxyopes* sp. killed 6 nymphs out of 10 available/day for 7 days. In another experiment *Oxyopes* killed 3 nymphs out of 15 daily for 7 days and *Lycosa pseudoannulata* killed 8 nymphs/day.

Spiders are general predators. One *Lycosa* caged with 15 *Cyrtorhinus* on each of 5 days killed 11 *Cyrtorhinus*/day. When *Lycosa* was caged with *Cyrtorhinus* and BPH adults, both species suffered the same mortality rate; for 8 days a total of 22 insects/day died. In the presence of *Lycosa*, therefore, the value of *Cyrtorhinus* as a predator is limited.

Because spiders inhabit levees and the levees at IRRI are periodically sprayed with herbicide, the toxicity of gramoxone at 0.2% active ingredient to *Lycosa* adults and juveniles was evaluated. Herbicide sprays directly on spiders or on plants with spiders were not toxic to the predators.

Spider density in the field fluctuated widely during a cropping period. During land preparation, especially harrowing, density decreased in the field and increased on the levees. After transplanting spider density on the levees decreased. Spider number increased both in the field and on levees, but sometimes declined as the crop matured. *Callitrichia* sp. was usually the most common spider on levees except around transplanting time when *L. pseudoannulata* was abundant. Both species were abundant in the field for most of the cropping period.

Ducks. The practicality of using ducks for controlling BPH in wetland rice was investigated. Important hopper pests and natural enemies were counted before and after ducks were herded in small fenced plots for 4 hours. In an experiment where BPH nymph density was high, the ducks eliminated about 90% of the hoppers (Table 32). The actual mechanism by which ducks achieve such remarkable pest suppression is not clear. Even when the BPH was not abundant, significant pest reduction occurred. Evaluation of ducks in an insect and weed management system will continue.

Ducks sometimes greatly reduced the

Table 31. Prey-stage preference of 5 pairs of *Microvelia atrolineata* adults caged for 1 day with the brown planthopper (BPH) or the green leafhopper (GLH) in a petri dish. IRRI, 1977.

Prey		Prey mortality (no./predator)	
Stage	No.	BPH experiment	GLH experiment
1st-instar nymphs	20	1.4	1.7
2d-instar nymphs	15	0.7	0.7
3d- + 4th-instar nymphs	10	0.6	0.6
5th-instar nymphs	10	0.4	0.2
Adults	10	0.2	0.2
Total	65	3.2	3.4

Table 32. Reduction of brown planthopper density by duckling (DD) and adult ducks (AD) herded into 100-m² plots of transplanted rice (15 hills/m²) and feeding for 4 hours. IRRI, 1978 dry season.

Treatment	Brown planthopper density (no./hill)			Reduction in density (%)
	Before herding	After herding	Difference	
Field 1 (36–43 days after transplanting)				
Ducklings	534	54	480*	90
Adult ducks	499	63	396*	86
Control	336	319	16	—
Field 2 (49–53 days after transplanting)				
Ducklings	15	7	8*	53
Adult ducks	21	13	6*	38
Control	20	22	-2*	—

Table 33. Survival of brown planthoppers (BPH) on BPH-susceptible transplanted rice with no pesticide applied. IRRI, 1977 wet and 1978 dry seasons, and Bay, Philippines, 1978 wet season.

Insect stage	Generations (no.)	Survival rate	
		Range	Av
Young egg	6	0.36–0.80	0.67
Medium-age egg	6	0.45–0.77	0.64
Old egg	6	0.13–0.60	0.46
Egg	6	0.06–0.31	0.19
1st-instar nymph	9	0.16–0.81	0.53
2d-instar nymph	9	0.30–0.75	0.48
1st + 2d instars	11	0.06–0.79	0.32
3d-instar nymph	9	0.36–0.65	0.54
4th-instar nymph	9	0.44–0.65	0.55
3d + 4th instars	11	0.15–0.58	0.36
5th-instar nymph	9	0.24–0.80	0.52
Nymph	9	0.01–0.20	0.08
Egg + nymph	5	0.01–0.03	0.02

number of *Cyrtorhinus* and spiders, but *Microvelia* density always declined significantly. Therefore, duck herding for hopper control may be appropriate only when pest densities urgently require suppression. Duck use is also restricted to the period before flowering because adult ducks damaged emerging rice panicles.

Other predators. Coccinellid larvae and adults of the species *Coccinella arcuata* were field collected and caged separately with BPH nymphs in an insectary. One predator from each stage killed about 1 BPH out of 10 prey daily for 10 days. Two species of ants, tested for predacious behavior, did not appear to prey on BPH or GLH nymphs or adults. Frogs did not kill BPH in cages.

ECOLOGY OF BROWN PLANTHOPPER

Entomology Department

Survival of natural field populations of BPH at each developmental stage was measured for three seasons at IRRI and in a nearby farmer's field. Frequent sampling with the Farmcop insect suction device provided BPH data never before available in the tropics. Egg survival (19%) was low, especially in the farmer's field at the early egg stages, largely because of parasitism and sometimes predation. Mortality due to predation reached 15%. The effect of these mortality factors tended to rise following a peak in egg density. Egg densities were usually 100 or less/hill, but sometimes reached a maximum of 1,200/hill.

The density of first-instar nymphs ranged from 7 to 968/hill. Nymph survival was about 50% for each instar, with only 8% survival for the nymph stage as a whole (Table 33). Predation appeared to be the major cause of nymph mortality, because higher predator densities were often associated with lower pest survival rates. A somewhat lower mortality in the farmer's field than in IRRI fields suggested less predator activity in the farmer's field.

The average survival of BPH from the egg through the nymphal stages was only 2%. Reproduction did not appear to compensate for such high death rates, and the population density declined. Natural control factors without human intervention suppressed the pest population during the period studied.

In dryland rice fields the BPH population was not high, and during the wet season parasites and predators killed about 50% of the eggs laid. But when rice was grown with irrigation in the dry season, extremely high egg predation occurred. The density of the egg predator *Cyrtorhinus* at that time was also high. Almost no BPH nymphs were found in the crop, suggesting that egg predation alone almost eliminated the population.

The ragged stunt virus disease was common at IRRI in 1977. Because it is transmitted by the BPH, the possible effect of diseased plants on the BPH was investigated. When the insect pest

Table 34. Catch of brown planthoppers, predacious bugs *Microvelia atrolineata* and spiders *Lycosa pseudoannulata* by different sampling techniques in transplanted rice.* IRRI, 1978.

Sampling technique	Brown planthoppers (no./5 hills)			*Microvelia* (no./5 hills)		Spiders (no./5 hills)	
	Nymphs	Adults		Nymphs	Adults	Juveniles	Adults
	34 DT	34 DT	55 DT	63 DT	63 DT	63 DT	63 DT
Visual	1 c	14 b	8 a	32 bc	32 c	9 bc	4 b
Farmcop	22 a	24 b	13 a	216 a	224 a	68 a	8 a
D-Vac	8 b	48 a	6 a	51 b	184 ab	28 b	4 b
Univac	2 c	25 b	9 a	20 c	64 bc	19 b	8 a
Sweep net	2 c	1 c	6 a	0 d	3 d	2 c	0 c
Mouth aspirator	2 c	17 b	6 a	0 d	0 d	15 b	5 b

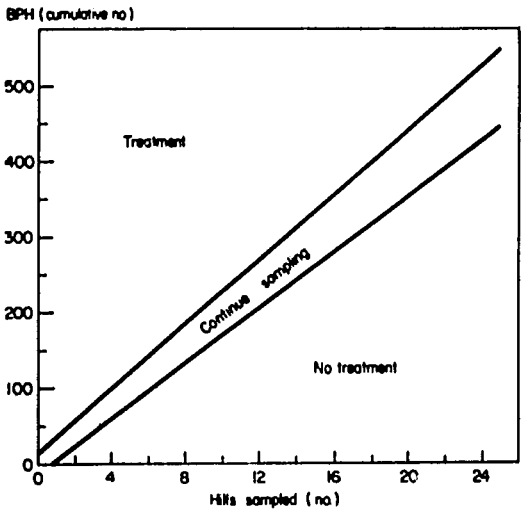
*In a column, means followed by the same letter are not significantly different at the 5% level. DT = days after transplanting.

was reared on diseased plants for three generations, the population became just as large as if it had been reared on healthy plants, and once even became larger. Thus the disease was not detrimental to the insect.

SAMPLING HOPPERS AND PREDATORS

Entomology Department

A sampling device developed earlier (1977 Annual Report) was improved and named the Farmcop suction sampler. It is portable, lightweight, battery-operated, and ideal for intensive insect collecting in flooded rice fields. It costs about US$100 and requires frequent recharging of the batteries. Two persons are usually needed to operate it in the field, and the technique is time-consuming.



16. Sequential sampling plan for brown planthopper (BPH) assuming an economic threshold of 20 BPH/hill. Based on BPH distribution data obtained with a Farmcop insect suction sampler at IRRI, 1977.

The accuracy of the Farmcop device for absolute sampling purposes was compared with that of other sampling techniques. Farmcop was better than or as good as others tested, especially for collecting nonadult insects and spiders (Table 34). The commercially available D-Vac sampler was sometimes better than Farmcop for collecting adult insects. Results similar to those for BPH were obtained for WBPH, GLH, and *Cyrtorhinus*. The Farmcop device was excellent for collecting nymphs of all instars of the hoppers.

Several methods of collecting adult hoppers from seedbeds were tested. Sweeping the seedlings with a net was easy and collected the largest number of hoppers per unit of time.

In sampling BPH in farmers' fields, a sequential sampling plan can greatly reduce the number of sample units required for a given level of precision. Only enough hills are sampled to determine if the pest population requires the application of a control measure or not. A sampling plan based on insect distribution data collected at IRRI was developed. It assumes an economic threshold of 20 BPH/hill (Fig. 16).

Weeds

Agronomy Department

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WEED CONTROL IN RICE

Transplanted rice. In the dry season, 14 granular herbicides were evaluated for weed control in irrigated transplanted rice at IRRI. Eight herbicides in advanced testing were further evaluated at the Maligaya and Bicol research stations of the Philippine Bureau of Plant Industry.

The major weeds at all sites were *Echinochloa* sp., *Cyperus difformis*, and *Monochoria vaginalis*. *Sphenoclea zeylanica* was common in Bicol; growth of *Scirpus maritimus* was patchy at IRRI.

All herbicides except Benzglycereth adequately controlled the weeds at all locations. All herbicide-treated plots, except those treated with Benzglycereth, yielded significantly higher than the untreated check (Table 1). At Maligaya, the yields of herbicide-treated plots and hand-weeded plots were comparable. Plots treated with naproanilide – thiobencarb at IRRI and with CGA 26423 and 2,4-D IPE at Bicol yielded significantly less than the hand-weeded checks.

Rat damage caused Maligaya yields to be about 2 t/ha lower than IRRI and Bicol yields.

In the wet season, the same herbicides were tested further at IRRI. In all herbicide-treated plots, except those treated with Benzglycereth, the weight of weeds sampled at heading stage of grasses was reduced by at least 50% (Table 2). Pendimethalin gave the best control. Crop damage from three typhoons caused extremely low yields. Only plots treated with oxyfluorfen, 2,4-D IPE, molinate – simetryn – MCPB, and X-52 – 2,4-D IPE yielded significantly higher than the untreated check. The hand-weeded check did not significantly differ in yield from the untreated check.

Wet-seeded rice. In the dry season at IRRI all herbicide-treated plots, except those treated with fluridone and R-40244, yielded significantly higher than the untreated check (Table 3). Weed control was poorer at Bicol. Only four treatments gave significantly higher yields than the untreated check. At Bicol, only 1 herbicide treatment (molinate – simetryn – MCPB) yielded as well as the standard herbicide check (thiobencarb – 2,4-D); at IRRI only 4 of the 15 test compounds were inferior to thiobencarb – 2,4-D.

At IRRI, fluridone and R-40244 caused moderate crop injury; at Bicol, pendimethalin was toxic.

In the wet season, strong winds caused the crop to lodge; only plots treated with butachlor + 2,4-D IPE and X-52 – 2,4-D IPE yielded significantly higher than the untreated check (Table 4).

On the basis of dry weed weight at the heading stage of the grassy weeds, Drepamon +

Table 1. Effect of granular herbicides applied before weed emergence (4 days after transplanting) on yield of IR42 rice at IRRI, the Maligaya Rice Research and Training Center, and the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1977 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)		
		IRRI	Maligaya	Bicol
Hand-weeded[d] check	—	7.5 a	4.8 a	7.6 a
Butachlor + 2,4-D IPE	0.75 + 0.5	7.1 ab	5.3 a	7.0 abc
Pendimethalin	0.75	6.7 ab	5.1 a	7.6 a
Molinate – simetryn – MCPB	1.8–0.1–0.1	6.8 ab	4.6 a	7.7 a
Piperophos – 2,4-D IPE	0.33 + 0.17	6.8 ab	4.9 a	7.6 a
CGA 26423	0.5	7.3 ab	4.7 a	6.2 c
Naproanilide – thiobencarb	1.0–0.7	6.7 b	4.3 a	7.2 ab
2, 4-D IPE	0.8	7.0 ab	4.7 a	6.4 bc
Benzglycereth	0.75	5.9 c	2.9 b	5.2 d
EXP 3391	0.25	7.4 ab	—	—
X-52 – 2,4-D IPE	2.1–0.75	7.2 ab	—	—
Fluridone	0.04	7.0 ab	—	—
Bifenox – 2,4-D EE	2.0–0.66	7.0 ab	—	—
Oxyfluorfen	0.25	6.8 ab	—	—
R-40244	0.3	6.8 ab	—	—
Untreated check	—	3.5 c	2.9 b	5.0 d

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture; + means that the herbicides were applied separately at about the same time. IPE = isopropyl ester, EE = ethyl ester. [b]a.i. = active ingredient. [c]Av of 4 replications/site. In each column, means followed by the same letter are not significantly different at the 5% level. [d]20 and 35 days after transplanting.

Table 2. Effect of granular herbicides applied before weed emergence (4 days after transplanting) on weed control and yield of IR42 rice, IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Yield[d] (t/ha)
		Broadleaf weeds	Grasses	Sedges	
Oxyfluorfen	0.25	7	20	2	2.7 a
2,4-D IPE	0.8	1	45	5	2.8 ab
Molinate – simetryn – MCPB	1.8–0.1–0.1	18	41	1	2.8 ab
X-52 – 2,4-D IPE	2.1–0.75	0	58	0	2.8 ab
Butachlor + 2,4-D IPE	0.75 + 0.5	0	30	2	2.5 abc
CGA 26423	0.5	8	77	0	2.4 abc
Pendimethalin	0.75	2	7	9	2.4 abc
Fluridone	0.04	11	47	7	2.5 abc
EXP 3391	0.25	12	31	1	2.4 abc
R-40244	0.3	2	20	1	2.3 abc
Naproanilide – thiobencarb	1.0–0.7	8	22	0	2.3 abc
Hand-weeded[e] check	—	6	3	0	2.1 abc
Piperophos – 2,4-D IPE	0.33–0.17	11	19	2	2.1 abc
Bifenox – 2,4-D EE	2.0–0.66	1	39	0	2.1 abc
Benzylcereth	0.75	41	137	2	1.5 bc
Untreated check	—	44	131	7	1.4 c

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture; + means that the herbicides were applied separately at about the same time. IPE = isopropyl ester, EE = ethyl ester. [b]a.i. = active ingredient. [c]Sampled at heading stage of grasses. [d]Av of 4 replications. Means followed by the same letter are not significantly different at the 5% level. [e]20 and 35 days after transplanting.

2,4-D IPE and molinate – simetryn – MCPB gave good control of the three groups based on morphological characters. Naproanilide – thiobencarb, thiobencarb – 2,4-D, and pendimethalin controlled grasses and sedges well, but not broadleaf weeds.

Pendimethalin, oxyfluorfen, R-40244, and fluridone were moderately toxic to the crop.

Upland rice. At IRRI, the major weeds were *Digitaria ciliaris, Eleusine indica, Echinochloa colona, Commelina benghalensis, Cleome rutidosperma, Calopogonium mucunoides,* and *Cyperus rotundus.* Seven preemergence and two postemergence herbicides were compared with the hand-weeded and untreated checks at IRRI and in a farmer's field in Batangas province, Philippines. The preemergence herbicides were applied 1 day after seeding; 4 days later, the crop and weeds emerged. Most of the preemergence herbicides adequately controlled the first flush of annual weeds. Grass control with oxadiazon and piperophos – dimethamet-

Table 3. Effect of granular herbicides applied at early postemergence of weeds (8 days after seeding) on yield of IR42 rice at IRRI and the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1978 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)	
		IRRI	Bicol
Molinate – simetryn – MCPB	1.8–0.1–0.1	5.8 abc	7.0 a
Thiobencarb – 2,4-D IPE	1.0–0.5	6.4 ab	5.9 ab
CGA 26423	0.5	5.8 abc	4.8 bc
Naproanilide – thiobencarb	1.0–0.7	6.0 ab	4.6 bcd
Butachlor + 2,4-D IPE	0.75 + 0.5	6.9 a	3.6 cde
Drepamon + 2,4-D IPE	3.0 + 0.5	6.0 ab	3.2 cde
Pendimethalin	0.75	5.6 abc	2.7 de
Piperophos – 2,4-D IPE	0.33–0.17	6.3 ab	1.9 e
Benzylcereth	0.75	4.3 bcd	3.5 cde
Oxyfluorfen	0.25	5.5 abc	—
Bifenox – 2,4-D EE	2.0–0.66	4.8 abcd	—
X-52 – 2,4-D IPE	2.1–0.75	4.8 abcd	—
EXP 3391	0.25	4.6 bcd	—
Fluridone	0.04	3.7 cde	—
R-40244	0.3	3.4 de	—
Untreated check	—	2.2 e	2.0 e

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture; + means that the herbicides were applied separately at about the same time. IPE = isopropyl ester, EE = ethyl ester. [b]a.i. = active ingredient. [c]Av of 4 replications/site. In each column, means followed by the same letter are not significantly different at the 5% level.

Table 4. Effect of granular herbicides applied at the 1- to 2- leaf stage of the grassy weeds (8 days after seeding) on weed control, crop tolerance, and yield of IR22 rice. IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[e] (t/ha)
		Broadleaf weeds	Grasses	Sedges		
Butachlor + 2,4-D IPE	0.75 + 0.5	2	77	0	0	2.8 a
X-82 – 2,4-D IPE	2.1–0.75	0	71	2	0	2.3 ab
EXP 3251	0.25	30	36	12	0	2.2 abc
Dropemon + 2,4-D IPE	3.0 + 0.5	0	13	0	0	2.1 abc
Bilenox – 2,4-D EE	2.0–0.66	0	60	1	0	2.1 abc
Piperophos – 2,4-D IPE	0.33–0.17	10	37	1	0	2.1 abc
Thiobencarb – 2,4-D IPE	1.0–0.5	43	7	3	0	2.0 abc
Oxyfluorfen	0.25	113	40	10	6	2.0 abc
Naproanilide – thiobencarb	1.0–0.7	11	1	0	0	1.9 abc
Molinate – simetryn – MCPB	1.8–0.1–0.1	3	1	3	0	1.9 abc
Pendimethalin	0.75	20	5	10	5	1.9 abc
Fluridone	0.04	16	31	17	4	1.9 abc
CGA 20423	0.5	11	40	0	0	1.6 bc
Benoglycereth	0.75	36	33	9	0	1.6 bc
R-40244	0.3	42	95	24	6	1.6 bc
Untreated check	—	13	150	44	0	1.3 c

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture; + means that the herbicides were applied seperately at about the same time. IPE = isopropyl ester, EE = ethyl ester. [b]a.i. = active ingredient. [c]Sampled at heading stage of grasses. [d]Taken at 16 days after seeding on a scale of 0–10:0 = no toxicity, 10 = complete kill. [e]Av of 4 replications. Means followed by the same letter are not significantly different at the 5% level.

ryn was outstanding (Table 5). Dinitramine gave the poorest broadleaf-weed control. No herbicide controlled *C. rotundus*. The intensity of *C. rotundus* infestation was dependent on the degree of control of the annual weeds (the better the control the greater the infestation). The postemergence herbicides gave poor control of all weeds.

At rice flowering, *C. mucunoides* and *Ipomoea triloba* invaded all plots and reduced yields greatly. Possible yield differences between treatments from initial weed control were lessened.

The crop was injured by oxyfluorfen, oxadiazon, X-150, propanil, and dichlofop-methyl, but it recovered rapidly.

In a farmer's field in Batangas, the major weeds were *E. colona, D. ciliaris, Cyperus compressus, Cyperus iria, Commelina diffusa, Ageratum conyzoides,* and *Bidens pilosa.* The preemergence herbicides were applied 3 days after seeding but drought delayed rice and weed

Table 5. Effect of liquid herbicides applied before crop and weed emergence (1 day after seeding) on weed control, crop tolerance, and yield of IR5575 rice grown in an upland trial. IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[e] (t/ha)
		Broadleaf weeds	Grasses	Sedges		
X-150	4.0	6	5	30	4	1.7 a
Oxyfluorfen	0.25	2	15	46	6	1.5 ab
Hand-weeded[f] twice	—	3	50	7	—	1.5 ab
Pendimethalin	2.0	13	45	51	0	1.4 ab
Oxadiazon	1.0	5	0	56	5	1.4 ab
Butachlor	2.0	11	17	24	0	1.1 ab
Propanil[g]	2.0	6	111	27	6	1.1 ab
Butralin	2.0	25	9	47	0	1.0 ab
Piperophos – dimethametryn	1.6–0.4	20	0	44	0	0.8 ab
Dinitramine	1.5	68	16	52	0	0.8 bc
Dichlofop-methyl[g]	0.6	110	102	28	4	0.6 bc
Untreated check	—	100	317	6	—	0.0 c

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Sampled at heading stage of grasses. [d]Taken 12 days after rice emergence (DE), on a scale of 0–10:0 = no toxicity, 10 = complete K.K. [e]Av of 4 replications. Means followed by the same letter are not significantly different at the 5% level. [f]12 and 22 DE. [g]Applied 10 DE.

Table 6. Effect of liquid herbicides applied before crop and weed emergence (3 days after seeding) on weed control and yield of IR[illegible] rice grown in upland conditions in a farmer's field, Batangas province, Philippines, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Yield[d] (t/ha)
		Broadleaf weeds	Grasses	Sedges	
Pendimethalin	2.0	101	0	46	2.5 a
Oxadiazon	1.0	4	146	0	2.3 ab
Butralin	2.0	12	10	112	2.0 ab
Hand-weeded twice[e]	—	0	33	7	1.8 abc
Dinitramine	1.5	97	17	61	1.4 abc
X-150	4.0	5	321	0	1.1 abc
Piperophos – dimethametryn	1.6–0.4	11	421	2	0.9 abc
Propanil[f]	2.0	6	188	21	0.9 abc
Butachlor	2.0	7	355	0	0.7 abc
Oxyfluorfen	0.25	14	298	11	0.5 bc
Untreated check	—	10	362	13	0.3 bc
Dichlofop-methyl[f]	0.8	24	141	102	0.2 c

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Sampled at heading stage of grasses. [d]Av of 3 replications. Means followed by the same letter are not significantly different at the 5% level. [e]28 and 39 days after rice emergence (DE). [f]Applied 25 DE.

emergence for 1 month. Another 20-day drought period after crop emergence depressed initial crop and weed growth. The slow weed growth delayed the application of the postemergence herbicides until 25 days after rice emergence (DE). Most herbicides gave poor weed control because of drought. Plots treated with pendimethalin, oxadiazon, and butralin yielded significantly higher than the untreated check (Table 6). The standard herbicide treatments, butachlor and piperophos – dimethametryn, gave the poorest control of the grassy weeds.

Dry-seeded, rainfed, bunded rice. At IRRI, 12 preemergence and 2 postemergence herbicides failed to control luxuriant weed growth — no plot produced yields. Initially, oxadiazon, fluorodifen, thiobencarb – prometryn, and GCP 6137 gave the best weed control. But the second weed flush was so profuse that at harvest the weed weight of plots with single herbicide applications did not differ.

Although a single herbicide application did not control the weeds, a follow-up postemergence treatment with propanil looked promising in this trial. The best preemergence herbicides for this type of treatment were oxadiazon, fluorodifen, and GCP 6137.

The more promising herbicides from the IRRI trial were tested further in Pangasinan and Iloilo, Philippines. In Pangasinan, weed growth was so heavy in all plots except those treated with dinitramine and thiobencarb that half of each plot was weeded 28 DE. When the herbicide-treated plots were hand weeded at 28 DE, the yields from most plots were not significantly higher than those from the plot that was weeded only once at 28 DE (Table 7). Plots treated with fluorodifen, molinate, and R-40244 yielded less than the plot that was hand weeded once. The time required for hand weeding ranged from 477 man-hours/ha in the dinitramine-treated plots to 2,164 man-hours/ha in the unweeded checks. Thus, the only advantage of the herbicide application was

Table 7. Effect of herbicides on yield and time required for weeding rainfed, bunded dry-seeded IR36 rice plots 28 days after rice emergence (DE). Farmers' fields, Pangasinan province, Philippines, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Time required for weeding (h/ha)	Yield[c] (t/ha)
Propanil – fenoprop	0.7–1.3	1480	4.4 a
Dinitramine	1.5	477	4.2 ab
GCP 6137	3.0	649	4.0 abc
Oxadiazon	1.5	491	3.7 abc
Propanil – fenoprop	1.1–1.9	646	3.6 abc
Thiobencarb	3.0	899	3.5 abc
Hand-weeded once at 28 DE	—	2164	3.1 abc
Butachlor	2.0	1138	3.0 abc
Thiobencarb – prometryn	2.5–0.5	948	2.9 abc
Fluorodifen	3.0	1201	2.7 bc
Molinate	2.0	1891	2.6 c
R-40244	0.5	1434	2.5 c

[a]All herbicide-treated plots were weeded 28 DE. A spaced dash(–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level.

Table 8. Effect of various weed control treatments on the yield of dry-seeded, rainfed, bunded IR20 rice. Farmer's field, Iloilo province, Philippines, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)
Twice hand-weeded[d] check	—	4.3 a
Thiobencarb	3.0	3.4 ab
Oxadiazon	1.5	3.2 bc
Fluorodifen	3.0	2.9 bcd
Thiobencarb – prometryn	2.5–0.5	2.7 bcd
Butachlor	2.0	2.6 bcd
Molinate	3.0	2.6 bcd
R-40244	0.5	2.6 bcd
Propanil – fenoprop	1.1–1.9	2.6 bcd
GCP 6137	3.0	2.2 cd
Dinitramine	1.5	2.2 cd
Untreated check	—	1.9 d

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Av of 3 replications. Means followed by the same letter are not significantly different at the 5% level. [d]14 and 35 days after rice emergence.

the reduction in time required to weed at 28 DE. With no weeding at 28 DE, only dinitramine- and thiobencarb-treated plots gave yields equivalent to those of plots that were later hand weeded. Plots treated with GCP 6137, propanil — fenoprop, and fluorodifen yielded much lower; no yield was obtained from the other plots.

In Iloilo, all plots except those treated with thiobencarb yielded significantly differently from the hand-weeded check (Table 8). None of the other herbicide-treated plots, except those treated with oxadiazon, yielded significantly differently from the untreated check. The oxadiazon-treated plots yielded significantly more than the untreated plots, but significantly less than the twice hand-weeded plot. Based on weed weight taken at 56 DE, the best control with a herbicide was obtained with R-40244; the poorest, with dinitramine.

The herbicides performed differently at the three sites not only because of soil and climate, but also because of the major weeds in each area.

In an experiment at IRRI, the weed flora growing in association with dry-seeded rice changed dramatically in four plots that differed only in ponding potential. At maximum flowering of weeds, there were 13 weed species in a well-drained upland, 15 in land with a very low ponding potential, 12 in land with a low ponding potential, and 9 in land with a high ponding potential. Only *E. colona* and *C. mucunoides* were common to the four plots. The major weed species and their relative importance varied among plots (Table 9). There was little similarity between the weed communities except in the plots with low and high ponding potential (Table 10). Therefore, recommending a single herbicide for all dry-seeding situations would be difficult.

SCREENING NEW HERBICIDES

In the 1978 wet season, herbicides not previously tested at IRRI were evaluated for weed control and selectivity in transplanted, wet-seeded, and upland rice grown in rainfed conditions. Treatments with the new herbicides were compared with standard chemical and hand-weeding treatments and untreated checks.

Only promising new herbicides that did not damage the crop are reported.

Transplanted rice. The major weed species at the test site were *Echinochloa* sp., *C. difformis*, and *M. vaginalis*.

Of the 11 herbicides evaluated, only about half adequately controlled weeds. The yields of

Table 9. Major weed species and their importance, based on weed weight at maximum flowering of the weeds in unweeded check plots of a dry-seeded rice crop grown in plots with different ponding potentials.[a] IRRI, 1978 wet season.

WDUL[b]	I.V.[c]	VLPP[d]	I.V.[c]	LPP[e]	I.V.[c]	HPP[f]	I.V.[c]
Digitaria ciliaris	50.5	*Echinochloa colona*	28.3	*Echinochloa colona*	76.4	*Echinochloa colona*	59.3
Amaranthus spinosus	20.7	*Eleusine indica*	21.9	*Leptochloa chinensis*	11.1	*Cyper. iria*	18.1
Commelina benghalensis	9.0	*Digitaria ciliaris*	21.7	*Cyperus iria*	6.0	*Paspalum distichum*	18.1
Cyperus rotundus	5.7	*Cyperus rotundus*	12.8	*Calopogonium mucunoides*	3.5	*Leptochloa chinensis*	1.8

[a]Av of 3 samples/plot and 3 replications. [b]WDUL = well-drained upland. [c]I.V. = importance value. [d]VLPP = land with very low ponding potential. [e]LPP = land with low ponding potential. [f]HPP = land with high ponding potential.

Table 10. Coefficient of similarity of the weed communities growing in association with dry-seeded rice grown in plots with different ponding potentials.[a] IRRI, 1978 wet season.

Land type	Coefficient of similarity (%) of weeds in		
	VLPP	LPP	HPP
WDUL	38.0	5.6	0.8
VLPP	—	34.3	28.5
LPP	—	—	67.7

[a]Determined on the basis of the importance value of species common to each crop. WDUL = well-drained upland, VLPP = land with very low ponding potential, LPP = land with low ponding potential, HPP = land with high ponding potential.

treated plots were not significantly different from that of the hand-weeded check, but were five to eight times as high as that of the untreated check (Table 11).

EF 5004 and thiobencarb – prometryn were comparable with hand weeding and the standard treatment thiobencarb – 2,4-D in controlling weeds. But initially, thiobencarb – prometryn was toxic. Herbicides such as R-22523, DPX 4432, and oxyfluorfen failed to adequately control the grasses.

Wet-seeded rice. The principal weeds in the test area were *Echinochloa* sp., *C. difformis*, and *M. vaginalis*.

Yields from plots treated with the most promising new herbicides did not differ statistically from yields from the plot treated with thiobencarb – 2,4-D, the standard herbicide check; however, they were significantly higher than yields from the unweeded check, which had no yield (Table 12). Weed control with EF 5004,

Table 11. Effects of promising new granular herbicides applied before weed emergence (4 days after transplanting) on weed control, crop tolerance, and yield of IR36 rice grown under rainfed conditions. IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[e] (t/ha)
		Broadleaf weeds	Grasses	Sedges		
EF 5004[f]	3.5	2	32	4	2	4.6 a
Thiobencarb – 2,4-D IPE	1.0–0.5	0	6	2	0	4.4 a
DPX 4432	0.075	0	128	6	2	4.0 a
R-22523	2.0	1	61	13	0	3.8 a
Thiobencarb – prometryn	2.0–0.16	0	4	22	6	3.8 a
NCL 2,4-D	3.0	0	52	2	4	3.6 a
EF 5004	3.5	0	22	3	2	3.6 a
Hand-weeded twice[g]	—	1	22	2	0	3.5 ab
Oxyfluorfen	0.1	1	229	0	4	3.2 ab
Untreated check	—	1	416	0	0	0.6 b

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]Sampled at heading stage of grasses. [d]Taken at 13 days after transplanting (DT) on a scale of 0–10:0 = no toxicity, 10 = complete kill. [e]Av of 2 replications. Means followed by the same letter are not significantly different at the 5% level. [f]Applied 8 DT. [g]18 and 28 DT.

Table 12. Effects of promising new granular herbicides applied 8 days after wet seeding on weed control, crop tolerance, and yield of IR36 rice grown under rainfed conditions. IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[e] (t/ha)
		Broadleaf weeds	Grasses	Sedges		
EF 5004[f]	3.5	1	52	12	2	2.7 a
Thiobencarb – 2,4-D IPE	1.0–0.5	0	110	39	0	2.4 a
R-42416	2.0	0	89	20	0	2.2 a
DPX 4432	0.150	0	52	16	6	2.2 a
EF 5004	3.5	0	30	7	5	2.0 a
R-34018	1.5	0	78	6	0	1.8 a
Oxyfluorfen	0.2	0	153	7	4	1.8 a
NCL 2,4-D	3.0	0	289	7	4	1.6 a
Untreated	—	0	259	7	0	0 b

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]Taken at heading stage of grasses. [d]Taken at 28 days after seeding (DS), on a scale of 0–10:0 = no toxicity, 10 = complete kill. [e]Av of 2 replications. Means followed by the same letter are not significantly different at the 5% level. [f]Applied 8 DS.

Table 13. Effects of promising new liquid herbicides applied 10 days after crop and weed emergence on weed control, crop tolerance, and yield of IR36 rice grown under upland conditions. IRRI, 1978 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[e] (t/ha)
		Broadleaf weeds	Grasses	Sedges		
Hand-weeded check[f]	—	0	11	1	0	3.5 a
Propanil LV-10 (Brazil)	2.0	18	15	14	5	2.4 b
Propanil LV-10 (USA)	2.0	10	52	8	5	1.9 bc
Propanil (Stam F-34)	2.0	156	36	6	5	1.7 bc
HOE 29152	1.5	80	0	15	6	1.4 c
Butachlor	2.0	150	52	7	3	0 d
Untreated check	—	347	64	0	0	0 d

[a]LV = low volume. [b]a.i. = active ingredient. [c]Sampled at heading of grasses. [d]Taken 13 days after rice emergence (DE) on a scale of 0–10:0 = no toxicity, 10 = complete chlorosis. [e]Av of 2 replications. Means followed by the same letter are not significantly different at the 5% level. [f]15 and 30 DE.

DPX 4432, R-34018, and R-42416 was superior to that with thiobencarb – 2,4-D.

The overall performance of the new herbicides, however, was not impressive. Good weed control was always accompanied by severe initial crop injury; herbicides that did not damage the crop controlled weeds poorly.

Upland rice. The major weeds in the upland rice trial were *Amaranthus spinosus, C. rutidosperma, D. ciliaris, C. rotundus,* and *Trianthema portulacastrum.*

When applied at preemergence, herbicides such as thiobencarb, CGA 26423, thiobencarb – prometryn, X-150, RH 6201, and butachlor (the standard herbicide check) failed to adequately control the weeds, particularly *A. spinosus* and *T. portulacastrum.* Plots treated with those herbicides and the untreated check plot gave no yield.

Only the postemergence herbicide treatments controlled *A. spinosus* and *T. portulacastrum.* The treated plots yielded significantly higher than the unweeded check, but significantly lower than the hand-weeded check (Table 13). Propanil did not adequately control *D. ciliaris.*

INTEGRATED WEED CONTROL

Transplanted rice. The effect of the degree of tillage combined with posttransplanting weed-control treatments on weed growth and yield of IR36 was examined in an IRRI trial.

At 50 days after transplanting (DT), the weight of broadleaf weeds was significantly less in the zero-tillage plots (paraquat applied 2 days before transplanting) than in the minimum-tillage (1 plowing and 1 harrowing) and in the maximum-tillage (2 plowings, 3 harrowings) plots. The weights of broadleaf weeds in the minimum- and maximum-tillage plots did not differ. At sampling time, the grasses in the maximum-tillage plots weighed significantly less than those in the minimum- and zero-tillage plots (which did not differ significantly from each other). The test site had no sedges.

In the zero-tillage plots, yields were significantly higher in the plot that was weeded twice than in those treated with herbicides and the unweeded check, which did not differ significantly from each other (Table 14). All the minimum-tillage plots, except those treated with 2,4-D, yielded significantly higher than the unweeded check. In the maximum-tillage plots, all treatments yielded significantly higher than the unweeded check. Thus, the number of possible weed control treatments that could be

Table 14. Effect of different methods of land preparation and weed control on yield of transplanted IR36 rice. IRRI, 1978 wet season.

Treatment	Rate[a] (kg a.i./ha)	Yield[b] (t/ha) in plots with		
		Zero tillage	Minimum tillage	Maximum tillage
Weeded twice[c]	—	4.9 a	4.2 a	4.2 a
Pendimethalin	2	2.0 b	3.5 a	3.6 a
Butachlor	2	0.4 b	3.9 a	3.5 a
2,4-D	0.8	0.4 b	2.0 b	3.2 a
Unweeded	—	0.9 b	2.1 b	2.0 b

[a]a.i. = active ingredient. [b]In a column, means followed by the same letter are not significantly different at the 5% level. [c]15 and 35 days after transplanting.

Table 15. Total dry weed weight 45 days after wet seeding of IR42 rice, as influenced by planting method and weeding regime. IRRI, 1977–78 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Total dry weed wt[c] (g/0.5 m²) when rice was			
		Broadcast	Sown in row spaced		
			20 cm	25 cm	30 cm
Hand-weeded twice[d]	—	5.3 a	8.6 a	3.8 a	18.6 a
Hand-weeded once[e]	—	38.4 b	24.5 b	14.6 b	60.1 b
Thiobencarb – 2,4-D	1.0–0.5	26.7 b	29.8 b	126.4 c	139.2 cd
Butachlor	2	34.7 b	27.1 b	95.4 c	91.8 bc
Two rotary weedings	—	40.2 b	46.5 b	96.6 c	134.1 cd
Unweeded	—	229.2 c	142.5 c	192.8 c	230.0 d

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]In a column, means followed by the same letter are not significantly different at the 5% level. [d]21 and 35 days after seeding (DS). [e]21 DS.

selected increased with increased tillage. Except in the plots that were weeded twice, the degree of weed control achieved with a particular treatment also increased.

Wet-seeded rice. The effect of planting method on weed growth and yield of wet-seeded IR42 was examined in an IRRI trial in the 1977–78 dry season. Three row spacings were compared with broadcasting for weed-competition ability and yield potential. Five weed-control methods were compared with the unweeded check in each planting method to determine the best way to control weeds for each planting method.

Weed weights were generally lower 45 days after seeding (DS) in the broadcast-seeded plots and where rice was sown in rows spaced 20 cm apart than were it was sown in rows spaced 25 and 30 cm apart (Table 15).

When herbicides were applied, weeds were significantly fewer when the rice was broadcast or sown in 20-cm-spaced rows than when it was sown in rows spaced 25 or 30 cm apart. Weed weights did not differ significantly between the narrowest row spacing and the broadcast-seeded plot nor between the two widest spacings. In the unweeded plots, weed weights did not differ significantly between planting methods.

In all planting methods, the plots that were hand-weeded twice had significantly fewer weeds than the other treatments. When the rice was broadcast or sown in 20-cm-spaced rows, there was no significant difference in weed weights among all weeding treatments other than the two hand weedings. But all treatments were superior to the unweeded check and inferior to the plot that was hand-weeded twice.

At the 25-cm spacing, the herbicide treatments and the two rotary weedings were inferior in weed control to two hand weedings and one hand weeding and did not differ significantly from the unweeded check.

At the widest row spacing, the weight of harvested weeds in the butachlor-treated plots did not differ significantly from that in the twice-weeded plot, but was significantly lower than that in the unweeded check. Other weeding treatments did not differ from the unweeded check.

The plots that were weeded twice yielded highest (Table 16). In them, rice sown at 25- and 30-cm row spacings yielded higher than rice sown at 20-cm spacing and broadcast rice.

In the unweeded plots, rice sown at 20-cm row spacing yielded significantly higher than rice planted by other methods. The yield depression due to weeds was lowest (46%) in the rice spaced at 20 cm and highest (73%) in the rice spaced at 30 cm.

In the broadcast-seeded plots and in those sown at 20- and 25-cm row spacings, the treated plots yielded significantly higher than the unweeded check. But at the 30-cm spacing, only the hand-weeding treatments yielded significantly higher than the unweeded check.

In all planting methods, the herbicide-treated plots yielded significantly lower than the plots that were hand weeded twice, but differences at the 30-cm spacing were far greater than those at the other spacings.

Upland rice. The effects of cultivar, tillage,

Table 18. Effect of planting method and weeding regime on the yield of wet-seeded IR42 rice. IRRI, 1977–78 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha) of IR42			
		Broadcast	Sown in rows spaced		
			20 cm	25 cm	30 cm
Hand-weeded twice[d]	—	5.4 a	6.3 a	7.1 a	7.2 a
Hand-weeded once[d]	—	3.9 b	5.8 ab	6.2 b	3.9 b
Thiobencarb – 2,4-D	1.5 - 0.5	3.9 b	5.3 b	4.9 c	2.1 c
Butachlor	2	3.8 b	5.4 b	4.8 c	1.9 c
Two rotary weedings	—	3.7 b	3.5 c	3.5 d	1.6 c
Unweeded	—	2.2 c	3.4 c	2.6 e	1.9 c

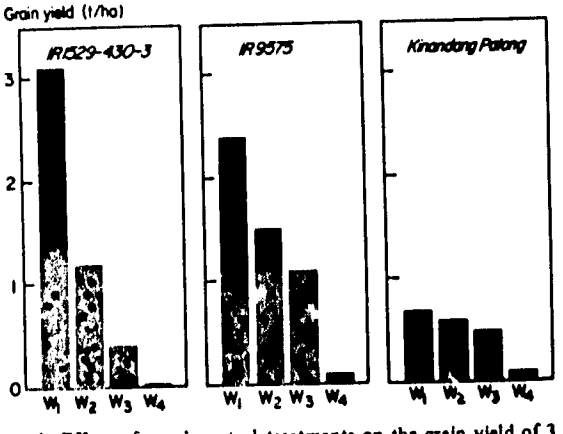
[a]A space dash (–) means that the herbicides were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]In a column, means followed by the same letter are not significantly different at the 5% level. LSD for comparison among planting method means = 0.73 (5%), 1.00 (1%). [d]21 and 35 days after sneding (DS). [e]21 DS.

and weeding method in upland rice were studied in the 1977 wet and 1978 dry seasons with IR1529-430-3 (semidwarf, high-tillering), IR9575 (intermediate-statured, high-tillering), and Kinandang Patong (tall, leafy, low-tillering). In the 1977 wet-season trial, the number of rotovations used before planting varied. These were 1 rotovation immediately before planting, 2 rotovations 15 days before planting (DBP) and immediately before planting, and 3 rotovations 15 DBP, 7 DBP, and immediately before planting. Four weed-control treatments were superimposed on the tillage treatments: dinitramine at 2.0 kg/ha; dinitramine at 2.0 kg/ha followed by (fb) propanil at 2.0 kg/ha; weeding 3 times, at 15, 30, and 60 DE; and an untreated check.

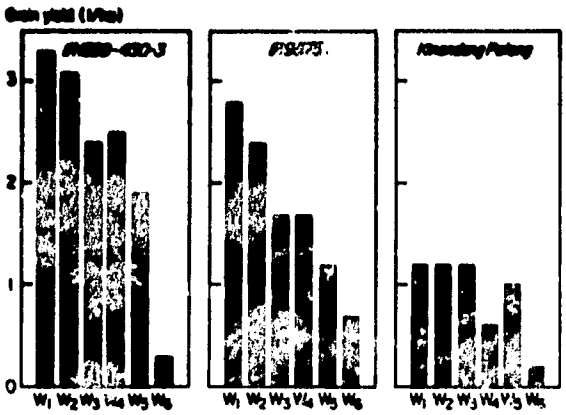
The weeds in the experimental area were *E. indica, Digitaria* sp., *E. colona, Dactyloctenium aegyptium, Rottboellia exaltata, C. benghalensis, Centrosema pubescens, I. triloba, A. spinosus, C. iria,* and *C. rotundus.* There were no significant differences between the weed populations, the weed biomasses, the time required for weeding, or the grain yield among land-preparation methods or cultivars — except that IR1529-430-3 and IR9575 yielded significantly higher than Kinandang Patong.

The correlation coefficients between weed weight and grain yield of the cultivars were highly significant. With appropriate weed-control practices (three hand weedings), the highest yielder was IR1529-430-3. But under partial weed control provided by herbicides, the grain yields decreased sharply and were lower than those of IR9575, indicating IR9575's better competitive ability (Fig. 1). The yields of Kinandang Patong were extremely low but stable, which indicates its weed-competition ability and its poor response to weed control measures (because of its low yield potential).

In the 1978 dry season experiment, the tillage treatments were dinitramine at 2.0 kg/ha 7 DBP fb rotovation immediately before planting, 2 rotovations 7 DBP and immediately before planting, and 2 rotovations immediately before planting. The same rice cultivars as those in the previous trial were used. The postplanting weeding treatments were dinitramine at 2.0 kg/ha, dinitramine at 1 kg/ha fb 1 hand weeding 30 DE, propanil at 2 kg/ha or 2,4-D amine at 0.5 kg/ha, hand weeding twice at 30 and 60 DE, and the untreated check.



1. Effect of weed control treatments on the grain yield of 3 upland rice cultivars. IRRI, 1977 wet season. W_1 = hand-weeded 3 times, W_2 = dinitramine fb propanil, W_3 = dinitramine, W_4 = untreated.



2. Grain yield of 3 upland rice cultivars as affected by weed control treatments in simulated upland conditions. IRRI, 1978 dry season. W_1 = hand-weeded twice, W_2 = dinitramine followed by (fb) one hand weeding, W_3 = dinitramine fb propanil, W_4 = dinitramine, W_5 = dinitramine fb 2,4-D, W_6 = untreated.

Results were similar to those obtained in the 1977 wet season, except that IR1529-430-3 yielded significantly higher than IR9575 and the herbicide treatments controlled weeds better (Fig. 2). IR1529-430-3 outyielded IR9575 in all treatments except in the unweeded check. Dinitramine applied at 7 DBP was extremely phytotoxic to all cultivars.

Dry-seeded, rainfed, bunded rice. In three farmers' fields in Iloilo, the combination of a preemergence herbicide with a hand weeding controlled weeds successfully in dry-seeded rice plots. The plots yielded as well as or better than those that were hand weeded twice. In two fields where weed growth was heavy, interrow cultivation gave only about 50% weed control. Yields in these plots were not significantly different from the yield of the untreated check. In a third field with light weed growth, interrow cultivation controlled most weeds. The yield was better than that in the untreated check, but not significantly different from that in the weed-free check.

Yields generally were much higher with hand weeding combined with interrow cultivation than with interrow cultivation alone (Table 17). In a farmer's field in Pangasinan the use of interrow cultivation to replace 1 hand weeding reduced the time for weeding dry-seeded rice from 1,067 to 537 man-hours/ha.

At IRRI, yields from plots treated with preemergence butachlor fb a hand weeding were not significantly different from those obtained from plots that received an interrow cultivation fb a hand weeding. But yields from those treatments were significantly higher than yields from plots with preemergence herbicide alone, with interrow cultivation alone, with preemergence herbicide fb interrow cultivation, and with preemergence herbicide fb 2,4-D (which did not differ significantly from the unweeded check). In a farmer's field in Pangasinan, a dry-seeded rice plot that was weeded by interrow cultivation yielded significantly less than plots that were weeded by other means, but not significantly more than the unweeded check.

In two fields in Iloilo and Pangasinan, inter-

Table 17. Effect of various weed control methods used in combination on the yield of dry-seeded, rainfed, bunded IR9 rice. Three farmers' fields, Iloilo province, Philippines, 1978 wet season.

Treatment[a]	Yield[b] (t/ha)		
	Field A	Field B	Field C
Butachlor fb hand weeding[c]	6.1 a	3.8 ab	3.5 a
Thiobencarb fb hand weeding[c]	5.8 ab	4.5 a	3.1 ab
Butachlor fb interrow cultivation[c]	5.4 abc	4.7 a	2.8 abc
Weeded twice[d]	5.0 bcd	5.1 a	2.5 bcd
Weed-free[e]	5.4 abc	4.9 a	1.9 cde
Butachlor fb hand weeding[c]	4.7 cd	4.4 a	2.9 ab
Interrow cultivation[c] fb hand weeding[c]	4.3 d	5.1 a	2.6 abcd
Thiobencarb fb interrow cultivation[c]	4.4 d	3.9 ab	3.0 ab
Butralin fb interrow cultivation[c]	2.6 e	4.8 a	1.7 de
Interrow cultivation[c]	0.8 f	4.5 a	1.1 ef
Untreated	0.5 f	2.3 b	0.5 f

[a]fb = followed by. [b]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level. [c]28 days after rice emergence (DE). [d]Until 56 DE. [e]14 and 35 DE. [f]42 DE.

Table 18. Effect of various weed control practices on time required for weeding and yield of dry-seeded, rainfed, bunded IR36 rice. Farmers' fields, Iloilo and Pangasinan provinces, Philippines, 1978 wet season.

Treatment[a]	Herbicide rate[b] (kg a.i./ha)	Time required for weeding in Pangasinan (h/ha)	Yield[c] (t/ha)	
			Iloilo	Pangasinan
Butralin fb hand weeding[d]	2.0	—	6.4 a	—
Butachlor fb hand weeding[d]	2.0	1141	5.9 ab	2.7 abc
Weed-free check[e]	—	—	5.6 ab	—
Thiobencarb fb hand weeding[d]	3.0	436	4.8 bc	4.1 a
Weeded twice[f]	—	2587	3.7 c	2.3 bcd
Dinitramine fb hand weeding[d]	1.5	402	—	3.5 ab
Pendimethalin fb hand weeding[d]	2.0	507	—	3.1 abc
Weeded once[g]	—	1881	—	2.7 abc
Butralin	2.0	—	2.3 d	—
Pendimethalin	2.0	—	—	2.1 cd
Thiobencarb	3.0	—	0.4 e	1.3 d
Dinitramine	1.5	—	—	1.3 d
Butachlor	2.0	—	0.7 e	0.3 e
Untreated check	—	—	0.2 e	0.1 e

[a]fb = followed by. [b]a.i. = active ingredient. [c]Av of 3 replications. In a column means followed by the same letter are not significantly different at the 5% level. [d]21 days after rice emergence (DE) in Pangasinan, 28 DE in Iloilo. [e]Until 56 DE. [f]21 and 35 DE in Pangasinan, 14 and 35 DE in Iloilo. [g]21 DE.

row cultivation could not be practiced because soil conditions were unsuitable. Yields were relatively low when the preemergence herbicide was applied alone (Table 18). A follow-up hand weeding increased the yield substantially in all herbicide-treated plots. In Pangasinan, however, such yields were not significantly higher than yields from a plot that was weeded once. But the time required for the hand weeding after use of a preemergence herbicide was at least 700 man-hours/ha less than the time needed without the use of preemergence herbicides. The low yields in the plots that were only hand weeded were caused by crop damage during weeding (Pangasinan) and by luxurious weed growth after the second weeding at 35 DE (Iloilo).

Table 19. Effect of different types of spray equipment on weed control and yield of dry-seeded IR36 rice grown in rainfed, bunded fields. IRRI, 1978 wet season.

Spraying equipment used	Weed wt[a,b] (g/m^2)	Yield[c] (t/ha)
CDA[d] (0.5 m/s[e])	18.5 b	2.5 a
Twin nozzle (2 passes[f])	31.2 ab	1.7 ab
Boom sprayer	36.0 ab	1.5 b
CDA (1 m/s)	33.6 ab	1.4 b
Twin nozzle (1 pass[f])	47.5 ab	1.1 bc
Single nozzle (2 passes[f])	54.3 ab	0.8 bc
Single nozzle (1 pass[f])	55.8 ab	0.4 c
None	68.1 a	0.4 c

[a]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level. [b]Sampled 49 days after rice emergence. [c]CDA = controlled droplet application. [d]Walking speed. [e]Number of times field was sprayed.

In Iloilo farmers' fields, propanil applied at the two- to three-leaf stage of grassy weeds either as a follow-up to, or in combination with, the preemergence residual herbicide butachlor or butralin, improved the spectrum of weed control obtained with propanil alone. Results were inconsistent, but butachlor applied in combination with or fb propanil was generally superior to butralin plus propanil. Postemergence propanil was inferior to a combination of preemergence and postemergence herbicides.

EFFECT OF APPLICATION METHOD AND VOLUME ON HERBICIDE PERFORMANCE

Dry-seeded, rainfed, bunded rice. The major weed species in the trial area, in order of importance, were *Echinochloa glabrescens*, *Echinochloa crus-galli* spp. *hispidula*, *Melochia corchorifolia*, and *E. colona*.

Butachlor was applied to all plots at 2 kg/ha. The controlled droplet application (CDA) equipment most effectively controlled weeds. The weight of weeds harvested from the plots sprayed with the CDA system at a walking speed of 0.5 m/second was significantly lower than that of weeds from the unweeded check (Table 19). Other treatments did not differ significantly in weed weight.

The CDA plot sprayed at a walking speed of 0.5 m/second gave the highest yield (Table 19)

— significantly higher than yields from all other treatments except one sprayed twice with a sprayer that had twin nozzles on the lance. Plots sprayed with the CDA system at a walking speed of 1 m/second and those sprayed with a boom sprayer gave similar yields. Yields from plots treated with a single knapsack-sprayer pass with one or two nozzles on the lance — or two passes with a single nozzle — did not differ significantly from yields from the untreated check.

In a similar farmers' field trial in Pangasinan, the growth of the dominant weed *E. colona* was so heavy that no yield was harvested. But at 4 weeks after emergence, weeds harvested from plots sprayed with 1 or 2 passes of a knapsack sprayer using single or twin nozzles on the lance weighed significantly less than weeds from the unweeded check. The weights of weeds harvested from the CDA system and the boom-sprayed plots were not significantly lower than those from the unweeded check.

A similar trial was conducted in four farmers' fields in Iloilo. In two fields the major weeds were *E. colona* and *C. iria*. In the third field, *E. colona*, *C. iria*, and *Ischaemum rugosum* predominated. The fourth field had few weeds. Butachlor controlled weeds poorly in all fields and a supplementary hand weeding was done at 45 DE. In the first field, there were no significant yield differences between plots treated with different sprayers. But fields treated with the CDA and the twin-nozzle systems yielded significantly higher than the untreated check. In the second field, boom sprayer-treated plots had significantly higher yields than the plot treated with the twin-nozzle sprayer. The latter did not differ significantly from the unweeded check. The yields from the herbicide-treated plots were not significantly different from that of the check in the third field, where the hand-weeded check yielded significantly more than all herbicide-treated plots except that sprayed with the CDA system. Because weed growth was light in the fourth field, yield differences between plots were not significant.

Upland rice. In the upland trial oxadiazon, pendimethalin, and butachlor were applied at the recommended and at half the recommended rates using the CDA system (8 liters/ha) and the boom sprayer (300 liters/ha). During its early growth, the crop was heavily infested with *C. rotundus* and *E. colona*. At the rice flowering stage, the most important weeds were *C. benghalensis*, *I. triloba*, and *Phaseolus lathyroides*.

Herbicide performance differed only slightly regardless of application method or rate. Oxadiazon was generally superior to the other herbicides (Table 20). Yields of plots treated with oxadiazon at 1 kg/ha and of the hand-weeded check were not significantly different. At 0.5 kg/ha, oxadiazon plots yielded sig-

Table 20. Effect of volume and rate of herbicide spray applied before emergence of crop and weeds (4 days after seeding) on weed control and yield of IR8575 rice grown under upland conditions. IRRI, 1978 wet season.

Treatment	Application		Weed wt[b] (g/m²)	Yield[c] (t/ha)
	Vol (liters/ha)	Rate[a] (kg a.i./ha)		
Hand-weeded twice	—	—	19 a	3.18 a
Oxadiazon	8	1.0	60 bc	2.27 ab
Oxadiazon	300	1.0	52. ab	2.00 abc
Oxadiazon	8	0.5	154 de	1.50 bcd
Oxadiazon	300	0.5	130 cde	1.37 bcde
Butachlor	8	2.0	149 cd	1.25 bcde
Pendimethalin	300	2.0	186 de	0.96 cde
Pendimethalin	8	2.0	164 cde	0.96 cde
Pendimethalin	8	1.0	144 cde	0.80 cdef
Butachlor	300	1.0	218 de	0.72 cdef
Pendimethalin	300	1.0	117 cde	0.65 def
Untreated	—	—	329 e	0.32 def
Butachlor	8	1.0	160 cde	0.28 def
Butachlor	300	2.0	173 de	0.00 f

[a]a.i. = active ingredient. [b]Sampled at heading of grasses. [c]Av of 3 replications. Means followed by the same letter are not significantly different at the 5% level.

Table 21. Effect of herbicides on control of *Scirpus maritimus* and yield of transplanted IR36 rice. IRRI, 1978 dry season.

Treatment used for control of *Scirpus maritimus*[a]	Application		Weed wt[d] (g/m²)		Yield[d] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c]	*Scirpus maritimus*	Annual weeds[e]	
Hand weeding	—	20 & 35 DT	1 a	4 a	5.0 a
Bentazon	1.0	20 DT	4 ab	12 a	4.8 a
2,4-D amine	1.0	20 DT	5 b	17 a	4.8 a
Fenoprop	1.0	20 DT	5 b	7 a	4.7 a
2,4-D amine	1.5	20 DT	3 ab	16 a	4.0 ab
Fosamine	4.0	27 BT	100 c	9 a	3.5 bc
Fosamine	8.0	27 BT	179 cd	12 a	3.0 bcd
None	0	7 DT	281 d	8 a	2.6 cd
Untreated check	—	—	162 cd	178 b	2.1 d

[a]To control annual weeds, thiobencarb – 2,4-D was applied at 1.5 – 0.05 kg/ha to all plots except the hand-weeded and untreated check plots. [b]a.i. = active ingredients. [c]DT = days after transplanting, BT = foliar application of chemical to *S. maritimus* before initial tillage. [d]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level. [e]Primarily *Echinochloa* sp., *Monochoria vaginalis*, and *Cyperus difformis*.

nificantly less than the hand-weeded check but, generally, significantly more than the other herbicide-treated plots.

Further trials to clarify if weed control with various herbicides differs with changes in application equipment are planned.

CONTROL OF *SCIRPUS MARITIMUS*

The herbicide 2,4-D applied at 20 DT at 1.0 and 1.5 kg/ha controlled *S. maritimus* as effectively as bentazon and fenoprop (Table 21). When applied 27 days before the first tillage, fosamine, which supposedly reduces tuber formation, had little effect on *S. maritimus*. Plots where *S. maritimus* was controlled yielded significantly more than the plots where it was not. Generally, yields in plots where the weed was poorly controlled did not differ significantly from that in the unweeded check. Application of thiobencarb – 2,4-D to all herbicide-treated plots adequately controlled the annual weeds.

Table 22. Effect of rate and time of 2,4-D application on control of *Scirpus maritimus* and yield of transplanted IR42 rice. IRRI, 1978 wet season.

Treatment[a]	2,4-D application		Dry wt of *S. maritimus*[d,e] (g/m²)	Yield[e,f] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c] (DT)		
Thiobencarb - 2,4-D IPE fb bentazon	1.0 - 0.5 fb 1.0	5 20	12 a	4.0 a
Thiobencarb - 2,4-D IPE fb 2,4-D amine	1.0 - 0.5 fb 0.5	5 15	108 b	3.3 ab
Thiobencarb - 2,4-D IPE fb 2,4-D amine	1.0 - 0.5 fb 0.5	5 20	93 b	3.3 ab
Thiobencarb - 2,4-D IPE fb 2,4-D amine	1.0 - 0.5 fb 1.0	5 20	9 a	3.0 ab
Hand-weeded twice[g]	—	—	8 a	3.0 ab
Thiobencarb - 2,4-D fb 2,4-D amine	1.0 - 0.5 fb 1.0	5 15	52 b	2.6 b
Thiobencarb - 2,4-D IPE	1.0 - 0.5	5	477 c	0.0 c
Untreated check	—	—	535 c	0.0 c

[a]A spaced dash (–) means that the herbicides were formulated as a proprietary mixture. IPE = isopropyl ester. fb = followed by. [b]a.i. = active ingredient. [c]DT = days after transplanting. [d]Sampled 58 DT. [e]Means followed by the same letter are not significantly different at the 5% level. [f]Av of 3 replications. [g]15 and 26 DT.

In another experiment, 2,4-D was applied at 0.5 and 1.0 kg/ha at 15 and 20 DT. Bentazon applied at 20 DT at 1.0 kg/ha was the standard herbicide treatment.

S. maritimus infestation was so heavy that no yield was obtained from the unweeded check or the plot treated with thiobencarb – 2,4-D (the standard herbicide treatment for transplanted rice, which does not control *S. maritimus*). Regardless of the rate and time of application, 2,4-D greatly reduced the *S. maritimus* stand (Table 22); 2,4-D applied 20 DT at 1.0 kg/ha controlled *S. maritimus* as effectively as bentazon, and better than the other 2,4-D treatments. Plots treated with 2,4-D generally yielded comparably with the hand-weeded check and the bentazon-treated plots.

In a third experiment, the interrelated effects of land preparation, cultivar, and herbicide on *S. maritimus* control were examined. Increasing from one to two the number of harrowings before planting did not contribute to *S. maritimus* control. *S. maritimus* growth was unaffected by IR42, a medium-statured cultivar, and IR36, a semidwarf. Only 2,4-D applied 24 DT caused a significant decrease in the weight of *S. maritimus* harvested shortly before senescence.

A trial begun in 1974 to study the effect of different cropping systems on the population density of *S. maritimus* and other weeds in upland and lowland fields was continued in 1978 with the three cropping patterns used in 1977.

In the continuous transplanted rice pattern in the 1978 dry season, the rotary-weeded plots yielded significantly more than the bentazon-treated plot. Bentazon controlled *S. maritimus* and the annual sedges, but not the grasses. However, the bentazon plot yielded significantly higher than the unweeded check (which produced no yield) (Table 23).

In the upland crop-dry seeded rice pattern, corn was planted during the 1978 dry season. The butachlor- and bentazon-treated plots yielded significantly more than the untreated check. The yield differences among the other treatments were not significant.

In the upland crop-transplanted rice pattern, corn-soybean was grown in the 1978 dry season. Plots that were hand weeded twice yielded significantly more than the plots treated with butachlor and bentazon, and the unweeded check.

As in previous years, this cropping pattern had more annual grasses and fewer *S. maritimus* than the continuous transplanted rice pattern. It also had less *S. maritimus* and more *C. rotundus* than the upland crop-dry seeded rice pattern.

In the 1978 wet season, the unweeded plots

Table 23. Effect of weeding methods and cropping pattern on crop yield and population density of *Scirpus maritimus* and other weeds. IRRI, 1978 dry season.

Cropping pattern, weeding treatment[a]	Yield[b]/ha	Weeds (no./m²)				
		Annuals			Perennials	
		Broadleaf weeds	Grasses	Sedges	*S. maritimus*	*Cyperus rotundus*
Continuous transplanted rice	*Rice (t)*					
Rotary weeding[c]	4.2 a	18	135	14	14	0
Bentazon 2 kg a.i./ha	2.2 b	11	19	13	19	0
No weeding	0 c	24	70	171	395	0
Upland crop-transplanted rice	*Corn (ears) + soybean (kg)*					
Hand weeding[c]	41,000 a + 632 a	1	226	9	5	0
Butachlor 2 kg a.i./ha fb bentazon 1 kg a.i./ha	37,000 b + 309 b	5	106	5	3	1
No weeding	23,000 c + 243 b	1	412	67	26	3
Upland crop-dry seeded rice	*Corn (ears)*					
Butachlor 2 kg a.i./ha fb bentazon 1 kg a.i./ha	44,500 a	6	388	30	5	24
Hand weeding[c]	38,500 ab	0	104	9	3	11
No weeding	22,500 b	94	562	100	4	11

[a]fb = followed by. a.i. = active ingredient. [b]Av of 2 replications. For each crop in each cropping pattern, means followed by the same letter are not significantly different at the 5% level. [c]17 and 29 days after rice emergence or days after transplanting.

Table 24. Effect of weeding methods and cropping pattern on crop yield and population density of *Scirpus maritimus* and other weeds. IRRI, 1978 wet season.

Cropping pattern, weeding treatment[a]	Yield[b] (t/ha)	Weeds (no./m²)				
		Annuals			Perennials	
		Broadleaf weeds	Grasses	Sedges	*S. maritimus*	*Cyperus rotundus*
Continuous transplanted rice						
Bentazon, 2 kg a.i./ha	3.4 a	15	38	69	22	0
Rotary weeding	3.2 a	21	12	67	53	0
No weeding	0.7 b	43	4	273	177	0
Upland crop-transplanted rice						
Rotary weeding	3.8 a	36	25	52	14	0
Bentazon, 2 kg a.i./ha	3.3 b	54	14	183	5	0
No weeding	1.8 c	82	1	299	53	0
Upland crop-dry seeded rainfed bunded rice						
Hand weeding	3.7 a	23	14	73	2	1
Dinitramine, 1.75 kg a.i./ha	2.7 b	29	12	48	5	7
No weeding	0 b	45	71	70	6	7

[a]a.i. = active ingredient. [b]Av of 2 replications. Within each cropping pattern, means followed by the same letter are not significantly different at the 5% level.

of the continuous transplanted rice pattern had less than half as many *S. maritimus* as in the 1977 wet and 1978 dry seasons. Because *S. maritimus* was few, the unweeded check plot gave some yield (Table 24). The weeded plots yielded significantly more than the unweeded check.

In the upland crop-transplanted rice pattern, as in previous years, *S. maritimus* increased while *C. rotundus* disappeared from the weed flora in the transplanted rice. The *S. maritimus* population was far lower than in the continuous transplanted rice pattern but higher than in the upland crop-dry seeded rice pattern.

The unweeded plot of the 3 patterns gave yields ranging from 1.8 t/ha to 0.

In the upland crop-transplanted rice and the upland crop-dry seeded rice patterns, the hand- or rotary-weeded plots yielded significantly more than the herbicide-treated plots.

Table 25. Response to herbicides and mesocotyl length of rice cultivars at various planting depths. IRRI, 1978.

Cultivar	Visual rating[a] (24 DS)			Mesocotyl length (mm) of rice plants	
	Pendimethalin	Butachlor	Thiobencarb	2 cm deep	4 cm deep
Tolerant of all herbicides					
BKN6986-45-1	2	3	3	4	9
BKN6986-147-2	2	2	3	2	5
BR188-3B-17	3	2	2	2	4
Yodaya	3	3	3	4	11
Kurkaruppan	3	3	3	4	4
Nam Sagui 19	3	3	3	4	16
Tolerant of at least 1 herbicide					
IR5825-41-2-P2	5	3	5	4	17
IR5825-41-2-D4	4	2	4	3	16
IR5853-189-2P7	3	4	5	9	19
Pelita I-1	3	6	4	3	6
PG 56	3	4	6	5	18
Susceptible to all herbicides					
BR223-B-3	6	6	9	7	28
Balebish	7	7	8	16	29
CN539	8	5	6	14	29
Sulpen	8	6	8	10	31
Sungawala	7	7	8	12	26

[a]DS = days after seeding. Rating scale: 1 = no injury, 9 = all plants killed.

Effect of time of herbicide application on damage to dry-seeded, rainfed, bunded rice. At IRRI, stands were reduced when pendimethalin and dinitramine were applied immediately after seeding and immediately after the germinating rain but not when the herbicides were applied 4 days after the germinating rain or 4 DE. Butachlor applied at any one of those times did not reduce stands. No herbicide applied alone controlled weeds regardless of application time. Except in plots where herbicide was applied 4 DE, a follow-up hand weeding at 28 DE was always needed to obtain yields comparable with those from the plots that were weeded twice. When the herbicides were applied at 4 DE, weed growth was so profuse that by 28 DE, when hand weeding was done, so much competition had taken place that the plots yielded significantly less than the plots hand weeded twice.

In a similar trial in an Iloilo farmer's field, pendimethalin and dinitramine did not reduce stands at any application time, but piperophos – dimethametryn and butachlor applied at 4 DE reduced stands. Thiobencarb – prometryn reduced stands when applied immediately after the germinating rain and at 4 DE, but not when applied immediately after seeding.

Cultivar herbicide tolerance. The entries in the 1978 International Rice Deepwater Observational Nursery were tested in the greenhouse for tolerance for pendimethalin, butachlor, and thiobencarb applied preemergence.

BKN6986-45-1, BKN6986-147-2, BR188-3B-17, Yodaya, Kurkaruppan, and Nam Sagui 19 were tolerant of the herbicides at double the recommended rate (Table 25). Other cultivars such as BR223-B-3, Baisbish, CN539, Sulpan, and Sungwala were susceptible.

Herbicide injury was influenced by the location of the first node in relation to the treated soil surface. Cultivars with their first nodes near the soil surface (those with long mesocotyls) tended to be susceptible to herbicides; those with short mesocotyls tended to be tolerant.

Irrigation and water management

Irrigation and Water Management Department

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IRRIGATION WATER MANAGEMENT RESEARCH

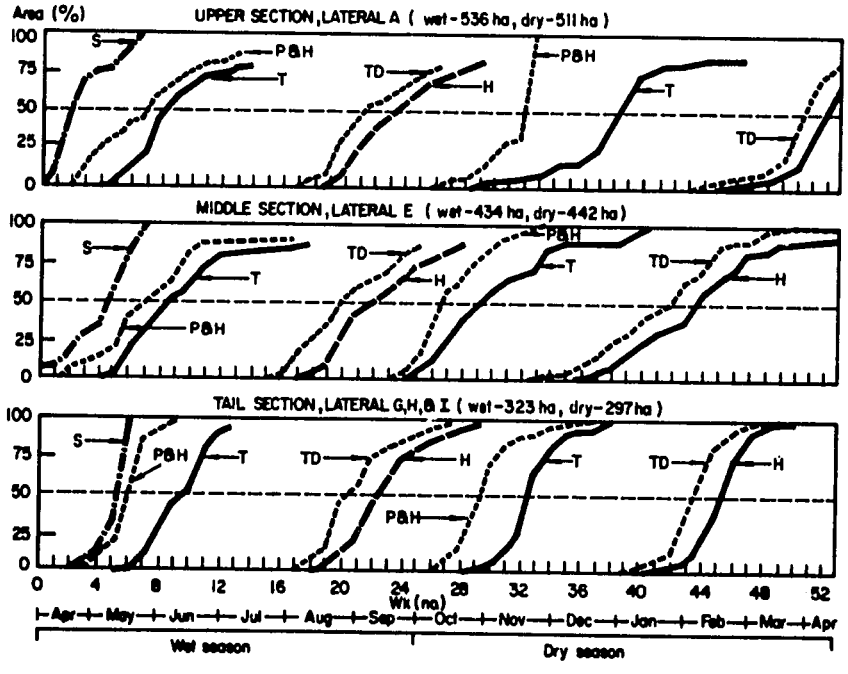
Previous research had documented the maldistribution of water and unequal availability of water over the length of a main distributory of large irrigation systems. In 1978, studies included a method to remedy inequality of water distribution in a gravity system, water-use patterns in a communal irrigation system, and reuse of drainage water from an irrigated watershed.

Integrated approach to irrigation system management. A joint study with the National Irrigation Administration (NIA) in the 2,500-ha Lower Talavera River Irrigation System (LTRIS) in Nueva Ecija province applied a 3-step method of system management to efficiently and equitably distribute water throughout the system. The study had a sociological component to determine farmers' attitude toward system performance, irrigation fee collection and water conflict resolution, and it documented farmers' irrigation problems and behavior related to interference in system operations.

Three major elements were used in the system management method:

- *Measurement* of the magnitude of water supplies, areas in various farming activities and crop growth stages, and irrigation water requirements.
- *Control* based on the calculation of target water discharges needed for crop and land requirements, irrespective of expected rainfall, and imposing a water flow using available structures and measuring devices. Actual water flow allowed considered measured rainfall in the service area.
- *Monitoring* to provide a rapid feedback of field problems to LTRIS managers and maintenance of a record of system performance.

In the 1977 wet season, about 45% of the total rainfall was used in lieu of irrigation releases. The equitable distribution of water from head to middle and tail of the system resulted in a remarkably similar progression of



1. Percentage of area soaked (S), plowed and harrowed (P&H), transplanted (T), terminally drained (TD), and harvested (H) for Laterals A (upstream section), E (midstream section), G, H, I (downstream section). Lower Talavera River Irrigation System, District II, Upper Pampanga River Integrated Irrigation System, 1977 wet season and 1977–78 dry season.

Table 1. Mean crop-cut grain yields[a] in consecutive sections of Lower Talavera River Irrigation System, District II, Upper Pampanga River Integrated Irrigation System, Nueva Ecija, 1976 and 1977 wet seasons, and 1977–78 dry season.

Section	Lateral canal	1976 wet season		1977 wet season		1977–78 dry season	
		Samples (no.)	Yield (t/ha)	Samples (no.)	Yield (t/ha)	Samples (no.)	Yield (t/ha)
1	A	9	2.16 ac	26	4.20 ab	28	2.50 a
2	B	10	2.62 ac	30	4.26 ab	28	2.40 a
3	D, F	7	3.71 bb	27	4.30 ab	27	3.10 a
4	E	9	4.10 bb	31	4.50 bb	31	3.30 a
5	G, H, I	13	2.40 ac	23	4.90 ab	32	3.20 a
Weighted av			2.90		4.40		2.90

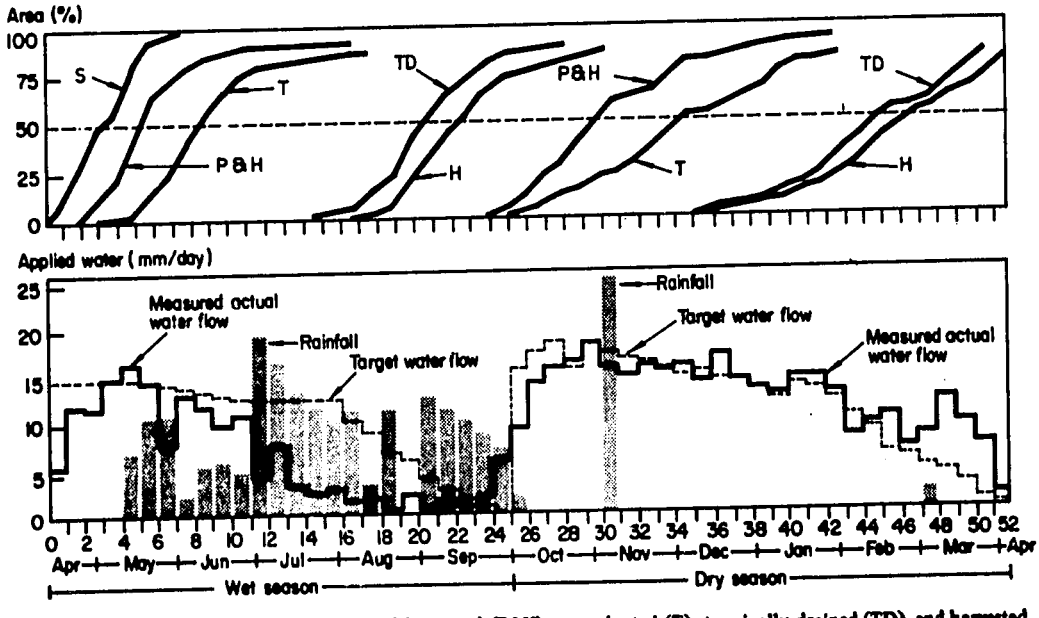
[a]The statistical significance (p = .05) of differences in mean yields from section to section in a given season is denoted by the first letter in the pair by difference compared vertically down the column. The statistical significance of differences in yields within a section between the two wet seasons is denoted by the second of paired letters compared horizontally across the page.

farming activities (Fig. 1). Yields based on crop-cut samples from 189 paddies in the system averaged 4.4 t/ha, notably higher than the 1976 wet season benchmark crop-cut yield average of 2.9 t/ha (Table 1).

During the 1977–78 dry season, the target flow and measured flow showed excellent agreement because of a strictly imposed system management technique and the lack of rainfall interference (Fig. 2). Cropping activities from head to tail of the system were, however, markedly nonuniform for reasons unrelated to water supply. The dry season yields averaged 2.9 t/ha (Table 1) because of increased bird, insect, and disease damage.

When most of the 2,500-ha rice crop was in the vegetative stage, water-use efficiency was determined for selected weeks in both seasons. A preexperimental wet-season water-use efficiency of 43% increased to 60% with improved system management. Likewise, dry season efficiency increased from 51 to 60%.

Farmer response to management improvement. Farmer behavior patterns with respect to



2. Percentage of area soaked (S), plowed and harrowed (P&H), transplanted (T), terminally drained (TD), and harvested (H), average daily target water flow, measured actual flow and rainfall in millimeters per day. Lower Talavera River Irrigation System, District II, Upper Pampanga River Integrated Irrigation System, Nueva Ecija, 1977 wet season and 1977–78 dry season.

Table 2. Mean weekly manifestation of negative irrigation behavior observed, Lower Talavera River Irrigation System, Nueva Ecija, Philippines, 1977–78.

Season	Incidents (no.)					
	Checking canal	Illegal turnout	Opening and closing gates	Breaking embankment	Others	Total
1977 wet	17.3	12.7	7.7	2.6	0.6	40.9
1977–78 dry	8.8	0.7	6.8	0.2	0.5	16.9

intervention in system operations, water conflict relationships among farmers and their resolution by NIA officials, perception of changes in system performance, reasons for low fee payment, and expectations from the system were determined.

As the study progressed, farmers interfered less in systems operations (Table 2), suggesting that they had become more convinced of the system's ability to deliver required amounts of water on time.

With improved system management, 83% of farmers at the head and 84% at the middle portion of the system reported no conflicts over use of water during the 1977–78 dry season; 32% at the tail portion reported conflicts. Sixty-one percent of all farmers reported conflicts that were settled by the LTRIS water tenders and water management technologists; only 5% of the conflicts were settled by the farmers themselves.

Farmers' ability to follow the LTRIS planting schedule given for each lateral service area, a major consideration in better management of the system, varied significantly with position in the system. Two-thirds of the farmers at upper and tail portions reported they would be able to follow the schedule. That ability, however, was different from willingness to follow, as demonstrated in the 1977–78 dry season by farmers in the upper portion who delayed planting to suit themselves (Fig. 1).

The belief that water supply was insufficient for all farmers was the reason farmers most frequently gave for inability to follow the planting schedule given by the system. Other reasons given were lack of capital and unavailability of cash for transplanting labor and farm machinery (Table 3). Among the farmers who followed the LTRIS planting schedule, those at the tail portion of the system expressed the greatest concern for water conservation and avoidance of waste (Table 4).

More than 60% of the farmers expressed satisfaction with the 1977–78 dry season performance of the system (Table 5). Despite the system-wide average yield of more than 7 t/ha per year, more than 50% were dissatisfied with the 1977–78 dry season returns. The fact that only 6% of the farmers fully paid the irrigation fees apparently corroborates the dissatisfaction. Most farmers believed that payment of irrigation fees affected irrigation service but rejected nonpayment as a means of forcing better water service (Table 6).

Irrigation system management markedly improved with the application of simple and rational techniques of measurement, control, and monitoring during the 1977 wet and

Table 3. Reasons farmers gave for not following the schedule to plant simultaneously in 1 lateral with respect to location, Lower Talavera River Irrigation System, Nueva Ecija, Philippines, 1977–78 dry season.

Reason	Farmers							
	Upper		Middle		End		Total	
	No.	%	No.	%	No.	%	No.	%
Insufficient rotation water if fields are planted at the same time[a]	4	22	18	43	4	33	26	35
Lack of capital	5	28	5	12	2	17	12	16
No available cash for labor and farm machinery	2	11	6	14	3	25	11	15
Willingness to plant ahead of schedule	2	11	4	10	0	0	6	8
Different rice varieties	1	6	2	5	0	0	3	4
No answer	1	6	0	0	1	8	2	3
Others	3	16	8	16	2	17	13	19
Total	18		43		12		73	

[a]χ^2 at $p = 0.05$ significant for position.

Table 4. Reasons given by farmers for following the schedule to plant simultaneously in a lateral service area. Lower Talavera River Irrigation System, 1977–78 dry season.

Reason	Farmers[a] (%)			
	Upper (36)	Middle (30)	End (22)	Total (88)
To avoid water wastage	19	13	41	23
To follow LTRIS schedule or orders	25	23	14	22
Water is sufficient	17	27	18	20
Afraid of water cutoff	19	17	14	17
To harvest at the same time	14	17	9	13
Other reasons	6	3	4	5
Total	100	100	100	100

[a]Figures in parentheses indicate number of farmers in the section.

1977–78 dry season experiments.

Water-use patterns in a communal irrigation system. About 49% of the total irrigated land in the Philippines was irrigated by communal systems in 1975 (1975 Annual Report), but little is known about the water-use patterns in such systems. A recent study, therefore, concentrated on the availability, distribution, allocation, and use of water in the Sagnay communal irrigation system in Camarines Sur Province.

The Sagnay system has 3 dams — 1 on a river and 2 on small creeks—that divert water into a canal that serves 506 ha. The service area is divided into five sectors on the basis of source of irrigation water, topography, and drainage waterways (Fig. 3). Three sectors receive water from the main canal and two receive the remaining flow of the canal supplemented by small-

Table 5. Farmers' satisfaction with the management aspect of the Lower Talavera River Irrigation System. 1977–78 dry season.

Factor	Farmers (%)			
	Not satisfied	Slightly satisfied	Satisfied	Very satisfied
Dry season water supply	13	21	62	4
Water tender performance	9	12	74	5
Water management technician performance	15	21	62	2
Current farming returns compared with those 1 year ago	54	24	16	6

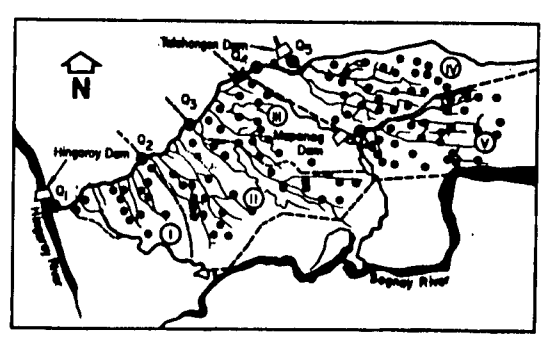
Table 6. Farmers' performance and opinions on payment of irrigation fees. Lower Talavera River Irrigation System, 1977–78 dry season.

Performance, attitude	Farmers (%)
Payment performance	
No payment	1
Partial payment	64
Full payment	6
No response	29
Opinion on payments' effect on water service	
Does not improve	38
Slightly improves	30
Improves	27
Highly improves	5
Opinion on withholding of payment to force better water service	
Does not improve	97
Slightly improves	2
Improves	1
Highly improves	0

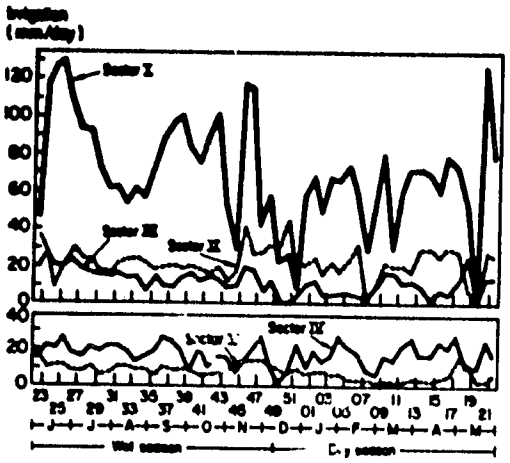
creek flow. The last two sectors are flat land with loamy soil, the rest of the area has a mild slope, sandy loam to loamy soil, and is on one side of the main canal.

Staff gauges and current meters were used to measure flow at six points (Fig. 3). Staff gauges were read at 0800 and 1700 hours daily, and rainfall and evaporation were measured daily. A total of 112 paddies distributed among the sectors proportionate to their service areas were observed daily for water adequacy status and farming activities.

Water availability and use. Availability of irrigation water from the river fluctuated, but most of the year the flow remained between 660



3. General layout showing water diversion and flow measurement points, sector boundaries, and observation paddies, Sagnay communal irrigation system, Camarines Sur, Philippines.



4. Average daily irrigation by week delivered to different sectors, Sagnay communal irrigation system, Camarines Sur, Philippines. 1976 wet and 1977 dry seasons.

and 1,100 liters/second (av 821 liters/second). The average flow into the service area from each of the 2 creeks was about 90 liters/second. Rainfall occurred throughout the year. The first season — week 23 to 49, 1976 — had 1,944 mm and the next season had 1,175 mm (Fig. 4).

The amounts of irrigation water delivered from the main canal to the different sectors were highly variable (Table 7). Irrigation water used per hectare decreased drastically with distance away from the dam. The total dry season irrigation flow from the river was about 23% lower than that in the wet season and the relative advantage of sector I over more distant sectors remained practically unchanged (Table 7).

The inequity in distribution of water from the main canal to the different sectors was attributed primarily to the nonimplementation of a rational water delivery schedule and uncontrolled diversion of water by farmers who had direct access to the canal. Farmers diverted water with pipe turnouts or through cuts in the canal bank. Because the main canal bed was higher than the adjacent farmland, water flowed continuously through the pipes; the rate of flow was higher when the canal water head was high. At times of low main canal flow, the downstream farmers were at a relative disadvantage.

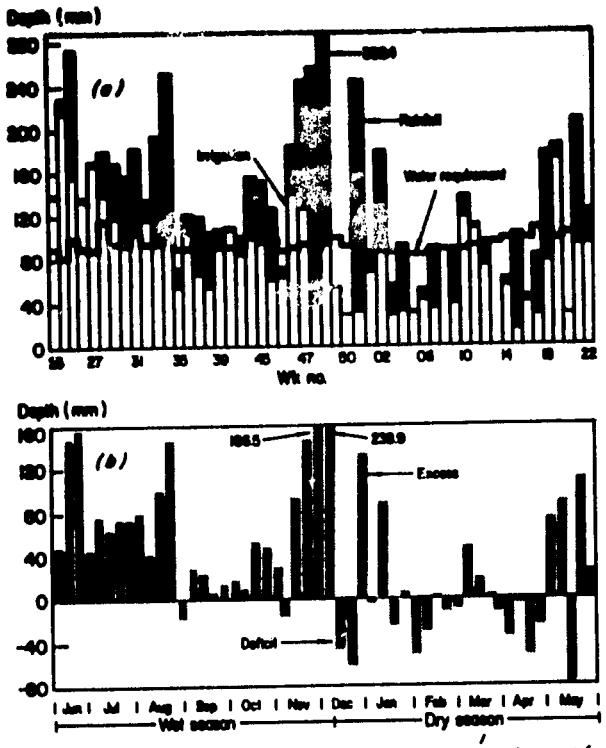
Haphazard individual or small group action in constructing farm ditches and sharing the water from a turnout contributed to a water distribution problem within different parts of the service area. The presence of a large number of turnouts in the main canal (the number increased from 58 in 1969 to 149 in 1976), accompanied by a lack of systematic layout and construction of farm ditches, resulted in a high farm ditch density (70 m/ha) in the service area.

The average seepage and percolation rates were 7.3 mm/day for the area covered by the first 3 sectors and 2.3 mm/day for the remaining area. The soils in the first 3 sectors were light textured, and had clay contents between 2.2 and 8.4%; the soils in the 2 other sectors had clay contents between 22.7 and 26.4%. Assuming the potential evapotranspiration (ET) to be equal to Class A pan evaporation, the average water requirement for both seasons was 12 mm/day for sectors I–III and 7 mm/day for sectors IV and V. The water requirements were about the same in both seasons mainly because of the occurrence of rainfall throughout the year (Fig. 5a).

Because sectors III and V received the least irrigation flow per hectare of service area (Table 7) the net weekly water availability and

Table 7. Area irrigated, farm ditch density, flow diverted per hectare, by sector. Sagnay communal irrigation system, Camarines Sur, Philippines, 1976 wet and 1977 dry seasons.

Sector	Area (ha)	Farm ditch density (m/ha)	Av flow diverted per ha			
			Wet season		Dry season	
			mm/day	% of total	mm/day	% of total
I	47.8	69	80.7	55	59.7	53
II	144.5	98	21.4	15	21.0	19
III	75.0	73	14.8	10	8.4	8
IV	112.0	62	18.3	13	17.1	15
V	127.2	44	10.6	7	5.7	5
Total	506.5					
Weighted av		70				



5. a) Total water applied (mm) from irrigation and rainfall; and water requirement (mm) for seepage and percolation plus evapotranspiration; b) weekly excess or deficit of water applied in millimeters (total water applied – water requirement), Sector III, Sagnay communal irrigation system, Camarines Sur, Philippines. 1976 wet and 1977 dry seasons.

requirement for both sectors were analyzed for the wet and dry seasons. Rainfall effectiveness was assumed as 60% for weekly amounts exceeding 80 mm, and 100% for weekly amounts less than 80 mm. It was also assumed that a paddy held a maximum of 80 mm of water.

In the wet season, sector III had high weekly water excesses, caused by the combined supply from irrigation and rainfall (Fig. 5b). Water stored before the start of the deficit period made up for the deficits of January and February and there was no significant stress of the rice crop. The first 3 weeks of storage in March also made up for the 3 weeks of deficit that followed. The 2 weeks of deficit in April caused no concern because most of the paddies were terminally drained for harvest, and only a small area required irrigation at that time.

Water deficit also occurred in sector V from March to early April but by then about 10% of the area had been harvested and 60% terminally drained. The excess water stored from end of February and the water supplied more than adequately met the water requirement of the 30% of the area that needed irrigation.

The observed occurrences of plant water stress in the different sectors reflected localized water distribution problems (Table 8).

System rules and farmer practices. The farmers' water allocation practices were compared with the rules set by the farmer association that governs the Sagnay system, to better understand the reasons for the farmers' water-use behavior.

The farmer association's formal rules are based on the NIA system rules for water distribution and allocation. Only the association's genuine members can use the system. The association determines turnout size on the basis of land area to be irrigated, controls the number of turnouts, and rotates water delivery to the

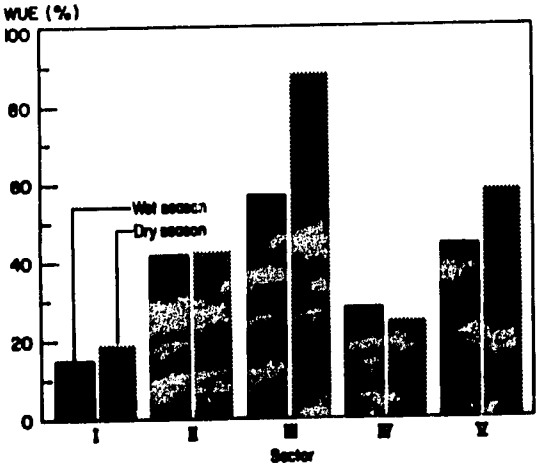
Table 6. Percentage of farms observed to have various degrees of water stress,[a] by sector. Sagnay communal irrigation system, Camarines Sur, Philippines, 1976 wet and 1977 dry seasons.

Sector	Farms (%)							
	Wet season				Dry season			
	Very light (0–2)	Light (3–7)	Moderate (8–15)	High (>15)	Very light (0–2)	Light (3–7)	Moderate (8–15)	High (>15)
I	100	0	0	0	85	15	0	0
II	86	14	0	0	82	11	3.5	3.5
III	64	29	7	0	91	9	0	0
IV	91	0	4.4	4.4	91	9	0	0
V	79	7	7	7	93	7	0	0

[a]Numbers in parentheses indicate stress days during the season.

different sectors. However, on-site observations of the daily water management activities in the system revealed the prevalence among the farmers of a *folk rule* that differed from the formal rule.

A major component of the *folk rule* is the notion that a farmer who has physical access to irrigation water can take as much water as he wishes as long as there is water in the system. The continuous-flow basis used in allocation and distribution gave farmers with lands close to the source and those adjacent to the main canal more irrigation water than distant farmers. In the wet season, farmer association personnel generally allowed the *folk rule* to govern the allocation-distribution system. In the dry season, the association personnel are expected to close upstream turnouts at regular intervals to make more water available downstream. The attempts to exercise authority were sometimes superficial and, on the average, unsuccessful as shown by the actual water allocation in the different sectors during the study period (Table 7).



6. Water-use efficiency (WUE) at the different sectors, Sagnay communal irrigation system, Camarines Sur, Philippines, 1976 wet and 1977 dry seasons.

Water-use efficiency. The performance of the Sagnay system was evaluated in terms of water-use efficiency (WUE), which is calculated as the ratio of the evapotranspiration plus seepage and percolation (S&P) requirements to the total water supplied from irrigation and rainfall. The test of performance in such a diversion-type system, in which there is no water storage provision and continuous flow is allowed in the main canal and service area, would be the ability to maintain a reasonably high WUE uniformly among different sections of the system.

The different sectors of the system differed greatly in WUE because allocations were highly disproportionate to actual requirements. Sector I had the lowest WUE because it used up about 6.5 times more water than it actually needed. Sectors III and V, which were supplied with the least irrigation water, had the highest WUE. WUE in sector III was 56% in the wet season and 88% in the dry season (Fig. 6). The high dry season efficiency in sector III was possible because of low irrigation water availability and relatively low but regular weekly rainfall.

The Sagnay communal system has good potential for increasing its service area beyond the 506 ha it irrigates. It is estimated that if the

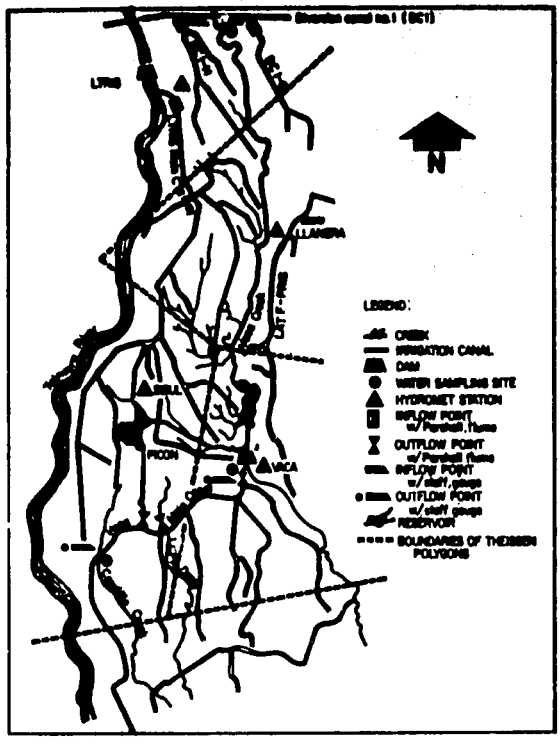
WUE of sectors I and II were increased to 60%, enough water would be saved to irrigate more than 150 additional ha.

Reuse of drainage water from an irrigated watershed. Drainage losses occur as surface or subsurface flow from an irrigated area. Recycling of the drainage water for irrigation is common in water-scarce situations. Where topographic features are suitable water draining from an irrigated watershed to an adjoining lower area can be recycled without the use of pumps. The Vaca Creek Irrigation System (VCIS, about 1,740 ha), which uses drainage water from an upper 3,183-ha watershed, was studied jointly with NIA. About 60% of the watershed consists of the service area of the LTRIS. VCIS receives, in addition to the drainage water from the watershed, fresh irrigation water from a diversion canal (DC1) from the Pampanga River. Both the irrigation and drainage water discharge into the Vaca Creek, which has a concrete dam and serves as the reservoir for the main canal serving VCIS (Fig. 7).

The study was done in two consecutive seasons, beginning in the 1977 wet season, to determine the extent of the watershed drainage delivered into VCIS and the suitability of the water for further irrigation.

Drainage outflow computations. The inflow consisted of local inflow from Vaca Creek (Q_{rlf}), irrigation sources from two laterals of DC1 (Q_{dc1}), drainage from 13 rotational areas and 7 laterals served from the main canal of LTRIS, and water from lateral F of the Pampanga River Irrigation System. The Vaca spillway flow (Q'_{rs}), the Caudillo Creek flow (Q'_{cc}), and the land consolidation pilot project drain (Q'_{lcp}) did not contribute to the Vaca main canal flow at the reservoir diversion point (Q'_{rmc}), but some minor drainage from part of the watershed (Q'_{dm}) directly contributed to it after the diversion point (Fig. 7).

Appropriate Parshall flumes and staff gauges calibrated with current meters were installed in the inflow-outflow points (Fig. 7) and gauge readings taken daily at 0800 and 1700 hours. The water balance method was used to determine the total drainage from the watershed that flowed into the Vaca Creek (Q'_{rc}). That is,



7. The area north of the Vaca Main Canal is the irrigated watershed. The Vaca Creek Irrigation System is located south of the canal. The figure shows important flow and water quality monitoring points and other relevant features.

$$Q'_{rc} = Q'_{rmc} + Q'_{rs} - (Q_{dc1} + Q_{rlf})$$

The total drainage from the watershed (Q'_{md}), which included those flows not contributing to the Vaca Creek, was computed by the equation

$$Q'_{md} = Q'_{rc} + Q'_{rc} + Q'_{lcp} + Q'_{dm}$$

The potential drainage from the watershed (Q'_{pd}), defined as the maximum amount of drainage flow that could take place during each season, was calculated using

$$Q'_{pd} = Ir + Rn - P_{et} - S\&P^*$$

where Ir and Rn are the irrigation and rainfall supply, P_{et} is the mean potential evapotranspiration, assumed to be equal to mean Class A pan evaporation, and $S\&P^*$ is the part of seepage and percolation in the watershed that did not contribute to drainage flow in the creeks. The equation assumes that there was no change

Table 9. Total watershed drainage determined by the water balance technique. Vaca Creek watershed, Nueva Ecija, Philippines, 1977–78.

Item	Watershed drainage (million m³)		
	1977 wet season	1977–78 dry season	Both seasons
Inflow from irrigation sources			
(1) Vaca creek flow, Q_{vtf}	1.93	0.22	2.15
(2) Diversion canal flow, Q_{dc1}	20.44	19.48	39.92
Outflow through			
(3) Vaca main canal, Q'_{vmc}	23.19	32.00	55.19
(4) Vaca Dam spillway, Q'_{vs}	32.65	19.76	52.41
Watershed drainage to Vaca creek, Q'_{vc} (5) = [(3) + (4)] − [(1) + (2)]	33.47	32.06	65.53
Total watershed drainage outside Vaca Creek (6) = $Q'_{vc} + Q'_{icp} + Q'_{dm}$	7.26	4.37	11.63
Total drainage from watershed, Q'_{wd} (7) = (5) + (6)	40.74	36.43	77.16

Table 10. Measured total and potential drainage, and drainage reuse by 3 different models. Vaca Creek watershed, Nueva Ecija, Philippines, 1977–78.

Season	Water (million m³)			Drainage reuse (million m³)		
	Delivered to VCIS[a] area	Measured total drainage from watershed	Potential drainage from watershed	Irrigation model	Drainage model	Proportionality model
Wet	23.19	40.74	49.74	8.21	17.55	12.84
Dry	32.00	36.42	27.42	13.62	26.96	19.69
Both wet and dry	55.19	77.16	77.16	21.83	44.51	32.53

[a]Vaca Creek Irrigation System.

in the soil-water or underground reservoir status.

The rainfall and evaporation values were measured at four hydrometeorological stations within the watershed and their weighted average values, obtained by the Thiessen polygon method, were used.

The total drainage outflow from the watershed was 40.7 million m³ in the 1977 wet season and 36.4 million m³ in the 1977–78 dry season (Table 9). The values represented about 49% of the total water applied from irrigation and rainfall in the wet season, and 54% in the dry season. The watershed's potential drainage was about 22% higher than measured total drainage in the wet season (Table 10). That was attributed to the contribution of the drainage to the dry Picon and Vaca reservoirs and low soil moisture and groundwater storage at the beginning of the wet season in April 1977, which followed about a month of drought after the end of the previous irrigation schedule.

The dry season potential drainage was about 25% less than the measured drainage (Table 10) probably because the water stored in the reservoirs from the previous wet season, and that in groundwater and soil-moisture storage were lost from the watershed through supply to VCIS, the Vaca Dam spillway, and crop use.

Drainage reuse. Drainage reuse (DR) is the proportion of the watershed drainage delivered to the Vaca main canal for use in VCIS. Because the water in the Vaca Creek reservoir, from which almost all delivery into Vaca main canal took place, consisted of both the watershed drainage and water from two irrigation sources (Q_{dc1} and Q_{vtf}), three models were developed and used to obtain the effects of different possible patterns of contribution from these sources to the Vaca main canal flow. In the use of the

models, it is assumed that the VCIS requirement of reservoir water is always met through the Vaca main canal flow (Q'_{rmc}), which was found to be true during the study period.

1. *The irrigation model.* The assumption is that the water used for VCIS is from the irrigation sources, i.e. Q_{dc1} and Q_{rlf}, as long as the sum of these two sources is enough to meet the Vaca main canal flow requirement, and the watershed drainage water (DR_i) is used only when the supply from the irrigation sources is less than the requirement. Thus,

   $$DR_i = 0,$$

   when $(Q_{dc1} + Q_{rlf}) \geqq Q'_{rmc}$; and

   $$DR_i = Q'_{rmc} - (Q_{dc1} + Q_{rlf}),$$

   when $(Q_{dc1} + Q_{rlf}) < Q'_{rmc}$

   This model gives a measure of how much water from the irrigation source has been saved due to the practiced schedule of water release from the diversion canal, DC1.
2. *The drainage model.* The drainage from the watershed is assumed to be the main source of VCIS water and only supplemental water, if needed, is released from the irrigation source. Thus,

   $$DR_d = Q'_{rc},$$

   when $Q'_{rc} < Q'_{rmc}$; and

   $$DR_d = Q'_{rmc},$$

   when $Q'_{rc} \geqq Q'_{rmc}$

   The model gives a measure of how much water from the irrigation source could be saved if all of watershed drainage could be delivered to the Vaca main canal.
3. *The proportionality model.* The drainage from the watershed and the flows from the irrigation sources are assumed to have proportional shares in the total Vaca main canal flow. In terms of the practical aspect of the phenomenon this assumption is more realistic than the two others, which have their own purposes, as explained previously. The proportionality model permits evaluations of the efficiency of the present system in scheduling irrigation water releases and use of drainage flow for delivery to the Vaca main canal.

As expected, the drainage reuse values differed between the models because of the assumptions involved. The wet season drainage reuse computed using the irrigation model was 8.2 million m³ or 35% of the total water delivered to VCIS, and 20% of the total measured drainage from the watershed. In the dry season, 13.6 million m³ or 37% of the measured drainage was reused. The amount represented about 42% of the total water delivered to VCIS during the season (Table 10). For the 2 seasons combined, the total drainage reuse using the irrigation model was about 40% of the total water delivered to VCIS and 28% of the total measured drainage from the watershed.

The drainage reuse computed by the drainage model in the wet season was about 17.6 million m³ or 76% of the total water delivered to VCIS compared with about 27.0 million m³ or 84% in the dry season (Table 10). Thus, 74% of the total measured drainage from the watershed was reused for VCIS in the dry season and 43% in the wet season. There were much fewer occasions in the dry season than in the wet season when drainage water could not be used for VCIS. Combining the data for the two seasons, the total drainage reuse as obtained by the drainage model was 58% of the total measured watershed drainage (Table 10).

The drainage model gave far greater reuse of drainage water than the irrigation model. That indicates that the irrigation water from DC1 could have been reduced to allow more drainage water to be used in VCIS. The values computed for the drainage model would, however, be impossible to attain fully because the reservoir has a limited capacity. Another limitation is the need for a continuous spill of more than 300 liters/second from the reservoir to fulfill the water rights of a farmer downstream. That accounts for about 4.5 million m³ of water spilled during a growing season.

The assumption made in the proportionality model permits comparison of the proportion of the water actually used from irrigation and watershed drainage. The 12.84 million m³

drainage reuse in the wet season computed by this model is about 35% of the measured watershed drainage; the corresponding value for the dry season is 19.7 million m^3 or about 61% of the watershed drainage. For the year, about 42% of the measured watershed drainage, which was 59% of the total water delivered from the Vaca reservoir to the Vaca main canal, was reused for VCIS. Water released to Vaca Creek from the irrigation source was more efficiently used in the dry season than in the wet season. That made possible the reuse of a larger proportion of the dry season watershed drainage for VCIS.

Water quality analysis. Water samples were collected once every week from sites (Fig. 7) that represented drainage outflow from the watershed, irrigation water mixed with drainage, and water from irrigation source alone.

The water was analyzed at the Soil and Water Laboratory of the NIA at Muñoz. The drainage water was found suitable for irrigation. The mean pH values for the 3 sources were between 7.0 and 7.1.

The electrical conductivity (EC) of drainage water was significantly higher ($p = 0.05$) than that of water from the two other sources. The highest recorded EC was 496 μmho/cm, which is well below any problem level for irrigation water.

The sodium adsorption ratio (SAR) values were not significantly different among the 3 sources and the highest recorded SAR was 2.12. Drainage water had a significantly higher ($p = 0.05$) total dissolved solids (TDS) value but the highest TDS concentration of 367 ppm was well below the allowable limit.

Concentrations of calcium and combined calcium and magnesium ions were in most cases significantly higher ($p = 0.05$) in the drainage water than in the mixed drainage and irrigation, or irrigation water. The highest observed values in the drainage water were 1.42 meq calcium/liter and 2.91 meq of combined calcium and magnesium/liter.

Other cation and anion tests showed no significant differences in concentration among the different sources of water or values near the allowable limit.

Water management training. In 1978 an irrigation water management training course had 22 participants from 6 countries. All participants, except one, were irrigation engineers from their national agencies and were responsible for operation and maintenance, planning, research, or training.

The primary purpose of the training was to enhance the participants' understanding of important concepts and theories related to efficient irrigation water management, to provide them alternative approaches to solving field operational problems, and to enable them to better appreciate the complex relationships between engineering, agronomic, and socioeconomic aspects that influence the use of irrigation water in a given environment.

The 5-week training course included 2 weeks of rice production training, 2 weeks of lecture-group discussion activities on selected engineering, economic and social-institutional aspects, and 1 week of practical work in the Lower Talavera River Irrigation System where the participants applied an improved method of irrigation system management.

Soil and crop management

Soil characterization

Soil Chemistry Department

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The main activities in 1978 were characterization of problem rice lands in the Philippines, soil nitrogen studies, and improvement of soil tests for nitrogen, zinc, and copper.

PHILIPPINE PROBLEM RICE LANDS

In 1978 the survey of problem rice lands in the Philippines was continued, and field and laboratory studies of soils at 26 sites in 12 Philippine provinces were made. Field experiments were conducted on 14 of the sites.

Maps and field observations give the estimated problem rice lands (current and potential) of the Philippines as follows: 400,000 ha of saline soils, 5,000 ha of alkali soils, >20,000 ha of acid sulfate soils, >15,000 ha of peat soils, and >1,000,000 ha of zinc-deficient soils.

Saline soils. Philippine coastal saline soils vary widely in hydrology, salt source, salt concentration, salt distribution, salt dynamics, toxicities, nutrient availability, and productivity. Some of their characteristics are in Table 1.

Four main types with different varietal requirements were identified. Three are shown in Figure 1. Type 1 (not shown in figure) is wet throughout the year, is not excessively saline, and can grow two salt-tolerant rice crops a year. Type 2 is flooded with fresh water during the wet season and is saline during the dry season because of the intrusion of brackish creek water. It needs flood-tolerant varieties in the wet season and short-duration, salt-tolerant varieties in the dry season. Type 3 is saline in the wet season because of the upwelling or seepage of brackish water. The present salt-tolerant varieties will do well on type 3 soils. Type 4 derives its salinity directly from tides. Salt injury can be severe on this soil type.

Field experiments on salt tolerance are of little value unless salt concentration dynamics during the season are known. The curves in Figures 2 and 3 were from data obtained with perforated polyvinyl-tube piezometers.

But the type of piezometer used required time to construct and install. Besides, the solutions were turbid, oxidized, and derived from too wide a soil depth. To simplify and improve the measurement, piezometers made by sealing 1-bar porous ceramic cups in narrow polyvinyl tubes (Fig. 4) were tested. The tubes were pushed into the mud to the desired depth, and the solutions that collected were either pipetted out and brought to the laboratory for electrical conductivity (EC) measurement or measured in situ with a portable conductivity bridge. The piezometers gave sufficient solution (about 25 ml) for measuring pH, EC, and Eh, and for chemical analysis, within 12 hours of installation. EC values obtained with the porous-cup piezometers were higher than those obtained with the perforated tube piezometers or the mud extract, but were closer to the EC value of the saturation extract (Table 2). The porous-cup piezometer is inexpensive, simple, and convenient for sampling interstitial solutions from flooded fields for chemical and physicochemical measurements.

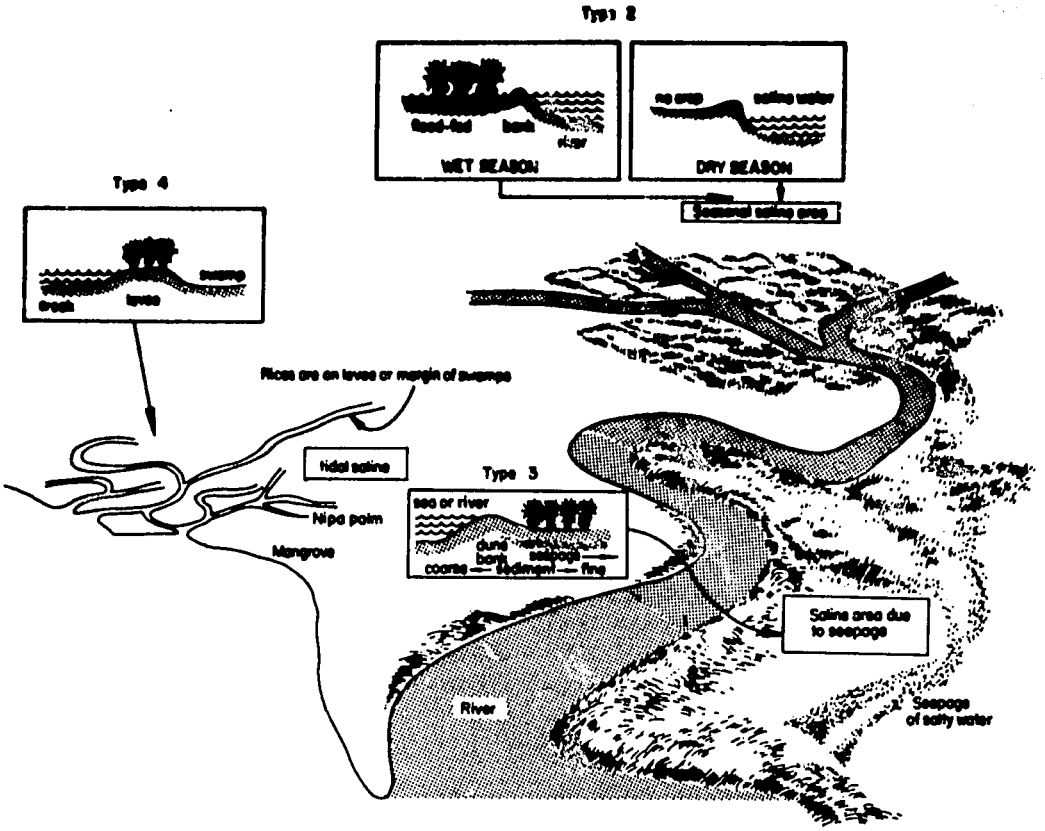
Acid sulfate soils. Acid sulfate soils or potential acid sulfate soils were recognized at Aparri, Cagayan; Sinacaban, Misamis Occidental; Butuan, Agusan del Norte; Puerto Princesa, Palawan; and Leganes, Iloilo.

The largest area (about 6,000 ha) is at Aparri. Here the soils occupy a swampy lowland protected from the sea by a wide beach ridge. Brackish water enters the area through a network of creeks. Both the surface and ground water are

Table 1. Some characteristics of 6 coastal saline soils in the Philippines.

Location	Salt source	Deep flooding	EC[a] (mmho/cm)	pH	Organic matter (%)	Iron toxicity	Zinc deficiency	Highest yield (t/ha)
Sinacaban, Misamis Occidental	Seawater seepage	No	2–8	4.4	15.4	Yes	No	5.6
Calapan, Mindoro	Seawater	No	1–12	6.8	6.9	No	Yes	4.0
Lubao, Pampanga	Creek	Yes	6–12	6.9	2.0	No	No	1.0
Tayi, Batangas	Creek	No	1–5	7.8	2.4	No	Yes	2.5
Aparri, Cagayan	Seawater	Yes	6	3.9	7.5	Yes	No	No experiment
Sabang, Camarines Sur	Groundwater	No	5–8	7.4	3.2	No	Yes	3.8

[a]Electrical conductivity.



1. Three types of coastal saline soils. IRRI, 1978.

saline. The soils are Sulfic Tropaquepts with a pH of 3.5–4.0. They are suitable for rice if they are kept submerged and fertilized. Soil EC was 6 mmho/cm.

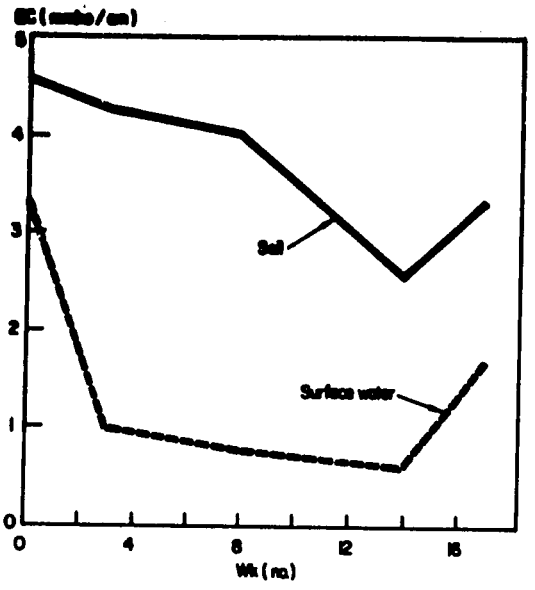
The soil at Sinacaban is a Typic Sulfaquent covering a narrow coastal swamp. It has a pH of 3.2–4.1 and an organic matter content of 15.4%. In spite of strong potential acidity, mild salinity, and patchy iron toxicity, the area is suitable for rice because saltwater intrusion is excluded by dikes, and freshwater for irrigation is available to keep the soil continuously submerged. Yields of 4.1–5.6 t/ha were obtained in 1978, a year after the area was reclaimed. Rice varieties for the area need tolerance for salt and for iron toxicity.

Table 2. Electrical conductivity (EC) values of a saline soil in the field determined by 3 methods at 2 sites. IRRI, 1978.

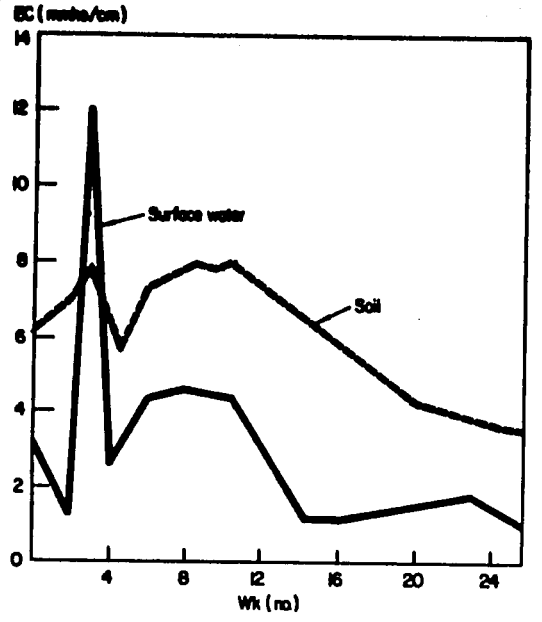
Method	EC (mmho/cm)
Site 1	
Porous-cup piezometer	3.31
Perforated tube piezometer	2.64
Mud extract	2.62
Site 2	
Porous-cup piezometer	2.98
Mud extract	2.79
Saturated extract of dry soil	3.00

Peat soils. Peat soils identified by inspection or chemical analysis cover more than 16,000 ha in the Philippines.

Peat soils occupy about 1,000 ha in places scattered over Laguna. Most of the peats are hanging mires occurring just below springs at the transition of steeply rising land and a lower alluvial or colluvial plain. They are fed by both surface and underground water. The chemical analyses of some peats are given in Table 3. They reveal a high nitrogen content, a moderate



2. Trend of electrical conductivity (EC) values in the experimental field, Sinacaban, Misamis Occidental, Philippines, 1978 dry season.



3. Trend of electrical conductivity (EC) values in the experimental field, Lubao, Pampanga, Philippines, starting 14 February 1978.

potassium content, and low phosphorus and zinc contents. But because up to 90% of a submerged peat soil is water, the nutrient supply on a volume basis is lower than is indicated by chemical analysis of the dry soil. Besides , in permanently wet fields nutrients are not readily available.

Rice on the peat soils of Laguna responded to applications of nitrogen, phosphorus, potassium, copper, molybdenum, and zinc (1977 Annual Report).

Peat soils cover about 10,000 ha at Santa Fe, Leyte. The formation is associated with a physiographic depression and high, evenly distributed rainfall. The peat is 0.5 to 8 m deep and is fed by surface runoff from surrounding hills. It is a Hydric Tropohemist.

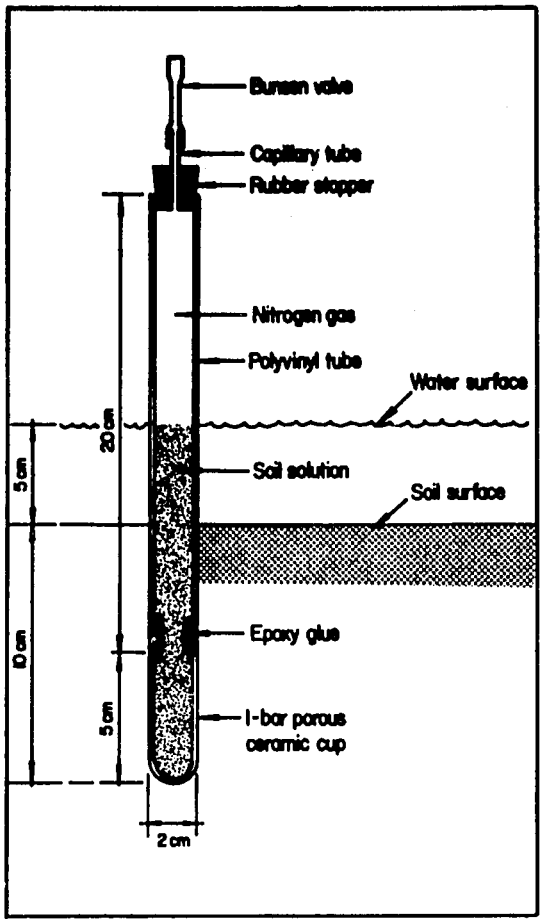
The National Grains Authority has cleared and drained 500 ha. Because of drainage, the peat has subsided more than 2 m in some places, the groundwater has been lowered to 20–60 cm below the surface, and the upper 15 cm of the soil has become compacted.

Rice is grown as a dryland crop on the drained peat and as a wetland crop on the undrained peat. Rice grown on peat soil suffers particularly from *Helminthosporium* and *Pyricularia*, and from deficiencies of zinc and copper. Wetland rice responded positively to copper, zinc, and silica in the presence of nitrogen, phosphorus, and potassium fertilizers.

Although peat soils contain more than 1% N,

Table 3. Chemical characteristics of some dry peat soils in the Philippines.

Location	pH (1:2)	Organic matter (%)	Cation exchange capacity (meq/100 g)	Total nitrogen (%)	Available phosphorus (ppm)	Exchangeable potassium (meq/100 g)	Available zinc (ppm)
Calauan, Laguna	6.9	48	80	1.44	3.1	.35	.16
Pangil, Laguna	5.8	52	68	1.96	6.0	.67	.76
Famy, Laguna	5.7	53	80	1.86	7.0	.40	.24
Pola, Mindoro	5.1	59	65	1.87	5.0	.24	.31
Santa Fe, Leyte	4.7	66	68	2.79	3.0	.21	1.6



4. Porous-cup piezometer for collecting interstitial solutions of flooded soils. IRRI, 1978.

rice on undrained peats suffers from nitrogen deficiency. In pots, peat soil that is drained (and thus aerated) and then flooded showed marked increases in water-soluble nitrogen, phosphorus, and potassium over the undrained soil (Table 4). Lowering the water table in peat lands shortly before submergence and replanting should increase the availability of both native and added nitrogen, phosphorus, and potassium.

Zinc-deficient soils. Zinc deficiency is perhaps the most widespread nutritional disorder of wetland rice in the Philippines. It has been recognized at 66 sites in 31 Philippine provinces.

Zinc-deficient soils cover a wide range of texture, pH, and organic matter content, and they

Table 4. Effect of draining a peat soil before reflooding on the concentration of nutrients in the soil solution at transplanting. IRRI, 1978.

Soil treatment	Nutrients (ppm)				
	Ammonium nitrogen	Potassium	Phosphorus	Iron	Manganese
Drained	57	133	31	2.8	0.0
Not drained	6	12	3.0	7.0	0.0

have one or more of the following characteristics:

1. pH >7;
2. prolonged waterlogging;
3. high organic matter content;
4. low available zinc content;
5. a Mg-Ca ratio >1;
6. strong zinc adsorption.

A combination of all of these factors is lethal to rice. In a varietal test at Tiaong, Quezon, on such a soil (Lipa clay loam, a Hydraquent; pH 8.2, O.M. content: 17.5%, Mg-Ca ratio: 1.54, zinc adsorption capacity: 99.0%, and available zinc content: 0.04 ppm), only 2 out of 698 varieties survived.

Because phosphate fertilizers are said to aggravate zinc deficiency, a factorial experiment was set in Pangasinan in the 1978 wet season on a Tropaquent (pH 7.4, Olsen P:9.8 ppm) and on another Tropaquent (pH 7.7, Olsen P: 4.0 ppm) to detect, among other effects, a possible zinc-phosphorus interaction. Table 5 reveals a marked response to zinc in IR26 and IR36. IR34's yield was low because of typhoon damage.

To ascertain the contribution of zinc fixation by soil materials to zinc deficiency in rice, the nonspecific fixing capacity of 68 soils was determined using ^{65}Zn. The soils used were

Table 5. Influence of zinc and phosphorus on the yield of 3 rices at 2 sites in Pangasinan, Philippines, 1978.

Treatment (kg N-P-K-Zn/ha)	Grain yield (t/ha)					
	Natividad			Bugallon		
	IR26	IR34	IR36	IR26	IR34	IR36
100-30-30-0	0	0	0	0.2	1.7	1.8
100-30-30-8	2.7	2.8	2.4	3.5	1.9	4.4
100-0-30-8	3.8	2.9	3.0	3.6	2.2	3.7

Tropaquents and Tropohemists. The nonspecific fixing capacity of the surface soil ranged from 12,450 to 21,320 μg/g for the Tropaquents and 14,100 to 59,300 μg/g for the Tropohemists. There was no correlation between fixing capacity and total or available zinc.

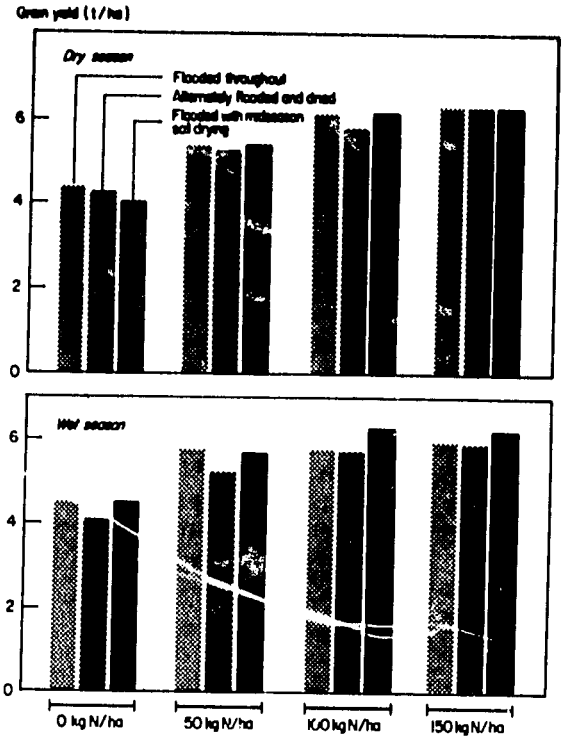
Because the unavailability of zinc in peat soils is ascribed to zinc fixation, the specific zinc-fixing capacity of five peat soils was compared with that of a mineral soil, Maahas clay (pH 6.6, O.M.: 2.0%). The specific adsorption capacity of the peat soils ranged from 94 to 213 mg/100 g and showed a significant negative correlation with available zinc. The mineral soil had a specific adsorption capacity of 185 mg/100 g. The bonding energy K was of the same order ($2.6–6.5 \times 10^4$) for both Maahas clay and the organic soils.

SOIL NITROGEN

Water regime and nitrogen supply. Rice fields undergo alternate oxidation and reduction from voluntary or involuntary drying and flooding. The process is believed to lead to a heavy loss of nitrogen by nitrification-denitrification.

A greenhouse study revealed that the effect on yield of soil drying followed by resubmergence depended on the nitrogen-supplying capacity of the soil and the growth stage at which soil drying was imposed (Table 6).

Yield loss occurred in Pangasinan silt loam (available N:39 ppm) regardless of the time stress was imposed, but in Maahas clay (available N:252 ppm) and Bulacan loam (available N:95 ppm) it occurred only when stress was imposed in the early stages. In Lumban clay (available N:32 ppm) yield was not reduced at any stage of soil drying.



5. Effect of 3 water regimes on yield of IR36 at 4 levels of nitrogen fertilizer. IRRI, 1978 dry and wet seasons.

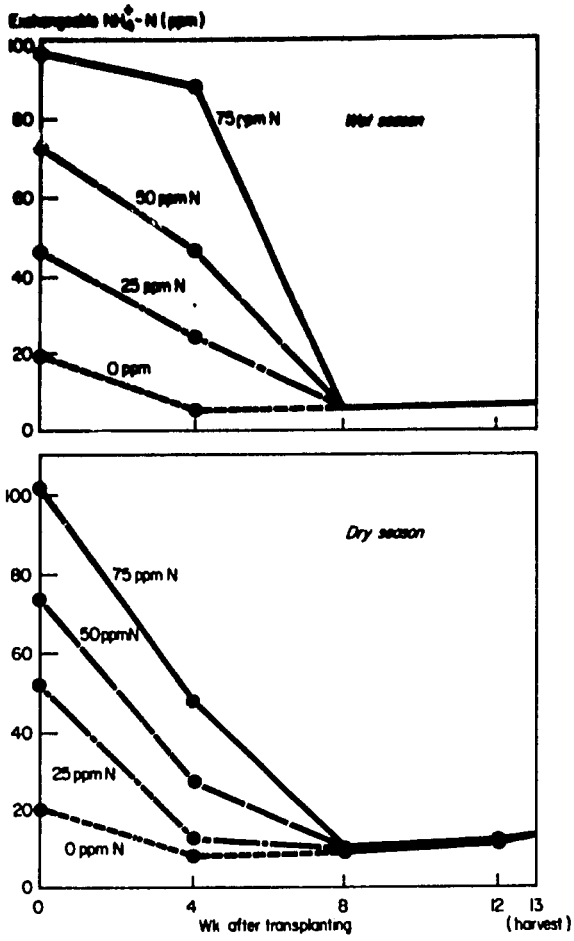
Two field experiments indicated that drying and reflooding Maahas clay (pH 6.7, total N: 0.24%, nitrogen-supplying capacity: 285 ppm) carrying a rice crop did not depress yield or nitrogen uptake (Fig. 5). Apparently there was little nitrogen loss even in the fertilized plots. Regardless of the amount of nitrogen applied, the concentration of exchangeable ammonium 8 weeks after planting was less than 10 ppm (Fig. 6). Soil analyses after the drying period revealed no nitrate.

Alternate wetting and drying may not cause appreciable nitrogen losses in fields carrying a

Table 6. Influence of 4 water regimes on the grain yield of IR26 on 4 soils. IRRI, 1978

Water regime	Grain yield[a] (g/pot)			
	Pangasinan silt loam	Bulacan loam	Maahas clay	Lumban clay
Continuous submergence	33.6 a	42.4 a	78.9 a	80.8 a
Soil drying at 2 wk after transplanting	25.8 c	37.2 b	67.3 b	76.2 a
Soil drying at 5 wk after transplanting	28.4 b	39.5 ab	68.0 b	75.0 a
Soil drying at 8 wk after transplanting	28.9 b	42.2 a	82.3 a	81.3 a

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



6. Kinetics of exchangeable ammonium (NH_4^+) in Maahas clay at 4 levels of nitrogen fertilizer. IRRI, 1978.

rice crop. On the contrary, drying a wet field may encourage mineralization of nitrogen and thereby increase its availability.

Effect of straw on the status of nitrogen and other nutrients. Leaving the straw in the field increased the total nitrogen, available phosphorus, and exchangeable potassium content of the soil. The mean increases after the 12th season, averaged for 3 water treatments (dry fallow, dry fallow with midseason soil drying, and flood fallow), are shown in Table 7. Returning the straw to the field either as long straw or as compost, increased the nitrogen content (Table 8). In 2 separate long-term experiments, it led to a nitrogen gain of 0.023% or 460 kg/ha in 6 years.

Table 7. Effect of straw on the nutrient status of Maahas clay after the 12th season. IRRI, 1978.

Treatment	Organic matter (%)	Nitrogen (%)	Exchangeable potassium (meq/100 g)	Olsen phosphorus (ppm)
Straw removed	3.00	0.196	1.24	8
Straw incorporated	3.50	0.218	1.41	10
Difference	0.50**	0.023**	0.17**	2**

Phototrophic nitrogen fixation. To ascertain the influence of lime and phosphate on phototrophic nitrogen fixation, Luisiana clay (pH 4.8, O.M.: 2.2%; total N: 0.160%) and Maahas clay (pH 7.0, O.M.: 1.4%; total N: 0.108%) were treated with the factorial combinations of 2 levels of phosphate and lime and then kept submerged in 4-liter pots in the greenhouse, with and without light.

Neither lime nor phosphorus produced a significant increase in nitrogen, but the net nitrogen gain in light and the net nitrogen loss in darkness were less in the acid-soil Luisiana clay than in the neutral-soil Maahas clay (Fig. 7). In 2 years, Luisiana clay gained 0.014% N or 280 kg/ha; Maahas clay gained 0.005% N or 100 kg/ha. Luisiana clay showed no appreciable gain beyond 6 months.

Contrary to expectation, net phototrophic nitrogen fixation was greater in the acid soil than in the neutral soil. Apparently nitrification-denitrification in the acid soil was less.

Gains in nitrogen by phototrophic fixation may be enhanced by using nitrification inhibitors in the surface water.

SOIL TESTING

Nitrogen-supplying capacity of soils. The incubation method is subject to two errors: 1) ni-

Table 8. Effects of 4 straw treatments on the nutrient status of Maahas clay after the 12th season. IRRI, 1978 wet season.

Treatment	Organic matter (%)	Nitrogen (%)	Exchange potassium (meq/100 g)	Olsen phosphorus (ppm)
Straw removed	3.26 b	.187 b	1.19 c	12 c
Straw burned	3.17 b	.187 b	1.35 ab	13 bc
Straw incorporated	3.73 a	.210 a	1.45 a	15 b
Straw composted	4.01 a	.211 a	1.27 c	20 a

Table 8. Effects of 3 treatments on the ammonium (NH_4^+) content of 10 soils submerged in 2 cm water in test tubes and incubated at 30°C for 2 weeks. IRRI, 1978.

Soil pH	NH_4^+ (ppm of dry soil)		
	Incubated in air	Incubated in nitrogen	Incubated in air with N-serve*
4.4	82 a	82 a	82 a
4.9	41 a	42 a	42 a
5.3	73 a	74 a	74 a
5.8	279 a	282 a	281 a
6.4	48 a	54 a	54 a
6.6	54 b	62 a	60 a
7.0	47 b	53 a	54 a
7.2	17 b	21 a	20 ab
7.5	17 b	24 a	26 a
7.9	20 b	36 a	32 a

*In supernatant water.

trification or denitrification losses at the soil-water interface; 2) loss of ammonia gas at the water-air interface.

Table 9 shows that exposure of the soil surface to air caused no loss of ammonium until soil pH was raised to 6.5, and that N-serve was as effective as nitrogen gas in reducing ammonium loss.

N-serve does not prevent loss of ammonia gas, but acidification retards both nitrification-denitrification and ammonia loss. The effect of adding 2 drops of N HCl to the surface water in the incubation tubes was studied. Results indicate that to avoid loss of ammonium by nitrification-denitrification and ammonia volatilization, both argon and HCl were necessary — argon to suppress nitrification and HCl to reduce loss of ammonia gas.

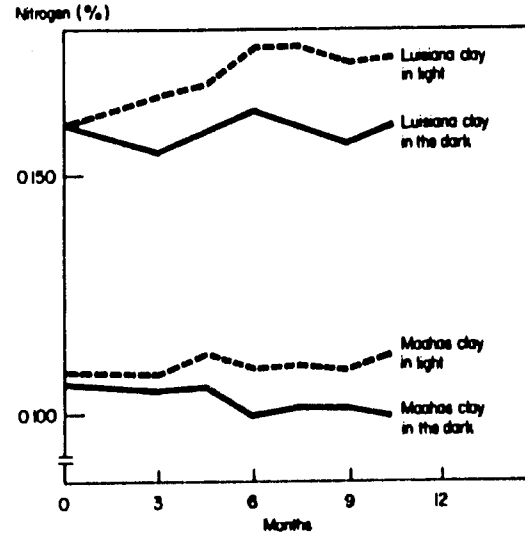
Available zinc and copper in rice soils. Zinc deficiency is a widespread nutritional disorder of wetland rice. It occurs on alkali soils, calcareous soils, poorly drained mineral soils, and peat soils. Copper deficiency limits rice yields on peat soils and perhaps also on other zinc-deficient soils. A simple, rapid, reliable method of estimating zinc and copper in soils used for wetland rice is a pressing need.

Because the widely used DTPA (diethylene triamine pentaacetic acid) and EDTA (ethylene diamine tetraacetic acid) methods consume much time and chemicals, they were compared with methods using 0.1 N HCl and 0.05 N HCl as extractants for available zinc and copper in a laboratory and greenhouse study of 32 soils with a wide range of pH and organic matter content.

The 0.1 N HCl method consisted of shaking 2 g of air-dry soil with 20 ml of 0.1 N HCl for 5 minutes. The 0.05 N HCl method used 10 g of air-dry soil shaken with 20 ml of 0.05 N HCl for 5 minutes. The extracts were filtered, and zinc and copper were determined by atomic absorption spectrophotometry, along with the DTPA-TEA and EDTA-$(NH_4)_2CO_3$ extracts obtained by shaking for 2 hours and 30 minutes, respectively. Rice plants grown on the flooded soils were wet-ashed, and the concentrations of zinc and copper were measured.

The 0.05 N HCl method gave the best correlation between extractable zinc and copper and their concentration in the plant, as shown below:

Method	Concn of element in extract vs concn in plant	
	Zinc	Copper
EDTA-$(NH_4)_2CO_3$	0.43**	0.28**
DTPA-TEA	0.31**	0.20**
0.1 N HCl	0.55**	0.64**
0.05 N HCl	0.88**	0.74**



7. Influence of soil type and light on phototrophic nitrogen fixation in 2 submerged soils. IRRI, 1978.

On 13 of the 16 soils that contained less than 1 ppm extractable zinc with 0.05 N HCl, plants showed zinc deficiency symptoms or contained <27 ppm zinc. Although no copper deficiency symptoms were observed, plants growing on 13 of the 15 soils with < 0.1 ppm copper by the 0.05 N HCl method contained < 5 ppm copper.

Available zinc (0.05 N HCl) correlated highly with available copper (0.05 N HCl), with r = 0.58**. So did plant zinc and copper, with r = 0.52**. Apparently because of similarities in their chemical behavior, copper deficiency may occur in zinc-deficient soils.

The 0.05 N HCl extraction appears to be an accurate, simple, rapid, and inexpensive method of measuring available zinc and copper in soils used for wetland rice.

Soil and crop management

Soil fertility management: microbiological studies

Soil Microbiology and Agronomy Departments

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MOLECULAR NITROGEN FIXATION ASSOCIATED WITH THE RICE PLANT

Soil Microbiology and Agronomy Departments

Nitrogen-balance studies. In cooperation with Boyce Thompson Institute and Cornell University, IRRI conducted nitrogen balance experiments on rice in pots in the greenhouse. Maligaya (Central Luzon) clay soil with 0.069 to 0.073% nitrogen was used. A summary of 3 nitrogen balance experiments containing data from about 2,650 Kjeldahl analyses is in Table 1. The data from experiment A show a highly significant increase in nitrogen in pots planted to rice, when the surface was exposed to light. Phototrophic organisms appear to actively fix nitrogen in the presence of light.

The data in experiments A and B indicate that nitrogen fixation by soil heterotrophic and phototrophic microorganisms depends on the rice plant. The mechanism of this association remains to be explored.

The effect of azolla and blue-green algae on nitrogen balance in flooded soil was studied (experiment C, Table 1). The addition of iron and phosphorus alone increased molecular nitrogen fixation, apparently by stimulating the indigenous population. Inoculation with blue-green algae did not significantly improve fixation. The incorporation of azolla and its growth significantly increased nitrogen fixation and the total nitrogen content of the crop. That suggests that a portion of nitrogen in azolla mineralized rapidly and became available to the associated rice crop.

^{15}N gas incorporation into wetland rice. In an attempt to obtain direct evidence of molecular nitrogen fixation associated with rice and the availability of the fixed nitrogen to the rice plant, rice plants were exposed to ^{15}N. The exposure chambers had controlled temperature and gas composition and, in certain cases, light.

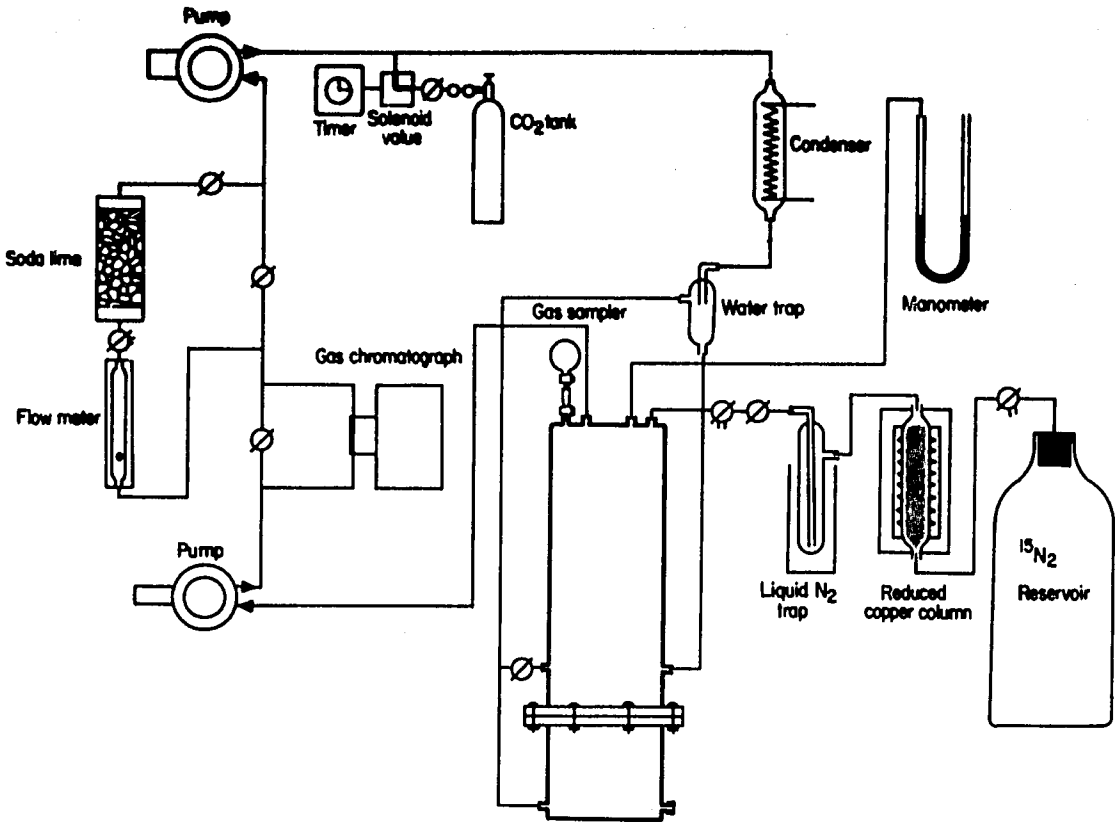
IR8 was grown in pots with flooded Maligaya soil, and 49-day-old plants were placed in a chamber with artificial lighting. The plants remained in the chamber for 7 days, and the ^{15}N content of the root and top portions was analyzed. Positive ^{15}N incorporation was found. The rhizospheric soil and roots had a high ^{15}N concentration. Low but significant enrichment of ^{15}N was detected in the upper leaves. That indicates that some of the fixed nitrogen is available to the aerial portion of the rice plant.

IR26 grown in unfertilized plots of IRRI's paddy field was transferred to a mineral-nitrogen-free liquid medium. The pots were then enclosed and fed with ^{15}N gas (Fig. 1). The gas was continuously circulated between the gas phase and the liquid phase to saturate the rooting medium. The result of 7-day exposure to ^{15}N is shown in Table 2. The greatest amount of ^{15}N was found in the roots in the first trial and in the

Table 1. Data from 3 nitrogen balance experiments. IRRI, 1978.

Pot treatment			Nitrogen[a] (mg)				
Planted to rice	Exposed to light	Supplemental	Plant (A)	Change in soil ± SE[b] (B)	Miscellaneous inputs (C)	Balance (A + B − C)	N gain (% of plant N)
				Experiment A (6 crops)			
+	+	None	1175 a	−604 ± 70 a	27	544** a	46
+	−	None	1148 b	−961 ± 50 b	27	160*	14
−	+	None	0 c	193 ± 82 c	24	169 n.s.	—
				Experiment B (4 crops)			
+	−	None	997 a	−795 ± 39 a	21	181** a	18
+	−	Stubble removed	1042 a	−875 ± 66 a	21	148* a	14
−	−	None	0 b	−243 ± 40 b	0	−243** b	—
				Experiment C (6 crops)			
+	+	None	1204 b	−789 ± 61 a	27	387** a	32
+	+	P, Fe	1211 b	−395 ± 77 b	92	723** b	60
+	+	P, Fe, algae	1273 b	−261 ± 80 b	98	914** bc	72
+	+	P, Fe, azolla	1681 a	−421 ± 67 b	106	1153** c	69

[a]Means followed by the same letter are not significantly different at the 5% level. [b]Standard error of mean.



1. Diagram of ^{15}N feeding device and enclosed chamber with rice plants. IRRI, 1978.

outer leaf sheaths in the second trial. Because blue-green algae sometimes grow on the outer leaf sheaths of plants dipped in the floodwater, a contribution from blue-green algae was suspected. In the second trial, the ^{15}N in the outer leaf sheaths was no higher in the exposed sheath than in the cover sheath. Thus, heterotrophic molecular nitrogen fixation appears to contribute ^{15}N enrichment of outer leaf sheaths. Enrichment was also found in the lower portion of the stems. As suggested by acetylene reduction assay (described in the following section) the outer leaf sheath, crowns, and nodes dipped in the soil and floodwater appear to contribute to molecular nitrogen fixation associated with rice.

Relative contributions of blue-green algae and bacteria. Propanil, a herbicide used for the postemergence control of barnyard grass and other annual weeds in rice cultivation, was tested in a series of experiments to determine its effect on blue-green algae, other soil microflora, and the rice plant. The chemical acted as a potent inhibitor of blue-green algae; but concentrations that severely inhibited blue-green algae were not toxic to rice or nontarget soil microorganisms. Ethanol-amended flooded soils treated with propanil (25 ppm) generally had higher rates of nitrogenase activity than those not treated with propanil. The flush of nitrogenase activity in propanil-treated soils was associated with a rise in the population of

Table 2. Fixation of ^{15}molecular nitrogen by the IR26 rice plant in 7 days. IRRI, 1978.

Plant part	^{15}N content (atom % excess)	^{15}N amount (mg/plant)
Root	0.783	1.00
Outer leaf sheath	2.035	0.866
Inner leaf sheath	0.066	0.241
Leaf blade	0.002	0.08
Young panicle	0.003	0.02

Table 3. Nitrogen fixation in uninoculated flooded soil planted to rice.[a] IRRI, 1978.

Hours	C_2H_4 (nmol/cm²)		
	Disk	Propanil	No propanil, no disk
6	2.4 ± 0.6	36.6 ± 2.2	4.5 ± 0.4
26	33 ± 8	174.4 ± 8.4	38.9 ± 4.3
30	44 ± 11	217.9 ± 13.7	54.8 ± 7
48	87 ± 18	404 ± 36.6	96.7 ± 7.9

[a]30-day-old IR32 plants. Values represent means of 4 replications ± standard deviation.

purple sulfur bacteria, especially of cells resembling *Chromatium*.

Propanil, as observations suggest, could be used in experiments to differentiate the nitrogenase activity of the blue-green algae from that of the photosynthetic bacteria in paddy soils. Its use with the polystyrene disk method of preventing the development of phototrophs at the soil-water surface in lowland rice culture made assessment of the relative activity of the blue-green algae, photosynthetic bacteria, and rhizosphere microflora possible (Table 3, 4). Table 3 shows that the activity obtained with light was not significantly different from that obtained using the disk method to eliminate phototrophic activity. Since the soil was well colonized with indigenous algae at the time of the acetylene-reduction assay, the low activity in light indicates the absence of highly active blue-green algae. The substantial flush of activity observed when indigenous algae were exposed to propanil suggests that the initiation of nitrogenase activity in photosynthetic bacteria requires the suppression of algae activity. Table 4 shows that both photosynthetic bacteria and blue-green algae have substantially higher activity than rhizosphere microflora. However, the highest value was associated with the activity of the blue-green algae. That is not surprising, since the soil had been inoculated with *Anabaena*. The results of both experiments suggest that the potential contributions of photosynthetic bacteria may be significantly higher than that of the rhizosphere microflora and may even approach that of active blue-green algae.

The role of varieties. Repeated comparisons of the nitrogenase (C_2H_2 reduction) activity of five test rice varieties, as well as of some associated variables, were made. The relative nitrogenase activities at different times were somewhat variable, but the most frequent values are represented by those in Table 5. Varietal differences in nitrogenase activity were correlated positively with root dry weight and with methane production but negatively with shoot dry weight. The differences within varieties were also correlated with methane production in some varieties (r = 0.94–0.98), but the correlation was very weak for others (r = 0.44–0.55). Moreover, plants that developed poorly generally had higher rates of nitrogenase activities than those that developed normally. The results suggest that data from varietal experiments involving nitrogenase activity should be interpreted carefully.

New types of molecular nitrogen-fixing bacteria isolated from rice roots. In the past, molecular nitrogen-fixing microorganisms were isolated and counted primarily through use of selective N-free media. Tests to determine the best culture media for most-probable-number counts of molecular nitrogen-fixing bacteria revealed that the addition of a small amount of yeast extract (0.1 g/liter) was effective in detecting nitrogenase.

Table 4. Nitrogen fixation in a flooded soil planted to rice[a] and inoculated with *Anabaena* sp. IRRI, 1978.

Hours	C_2H_4 (nmol/cm²)		
	Disk	Propanil	No propanil, no disk
24	9.7 ± 2.5	107.7 ± 24.9	291.6 ± 31
48	47.7 ± 10.3	431.8 ± 47	747 ± 108
72	121 ± 19.9	764.6 ± 96.6	1162 ± 195.7
96	237 ± 35.9	1123 ± 88.2	1690 ± 338

[a]55-day-old IR26 plants. Values represent means of 4 replicates ± standard deviation.

Table 5. Nitrogen fixation in the rhizosphere of 5 rice varieties. IRRI, 1978.

Variety	C_2H_4 (nmol/day)	
	Seedling stage[a]	Reproductive stage[b]
IR34	14 ± 6	776 ± 363
IR2037	11 ± 5	843 ± 643
IR2071	36 ± 11	1322 ± 910
Mahsuri	23 ± 3	1360 ± 683
IR2G	33 ± 8	1860 ± 808

[a]15-day-old seedlings. [b]65-day-old plants (r = 0.84).

Diluted samples were prepared from the soil around the roots of IR26 grown in paddy soil, from washing of the roots (outer rhizoplane), from macerated washed roots (inner rhizoplane), and from macerated stems. The preparations were inoculated on 0.1% tryptic soy broth plates. Colonies were selected, grown on semisolid glucose-yeast extract (0.1 g/liter) agar, and tested for molecular nitrogen-fixing activity.

Percentages of nitrogenase-positive bacteria were 2.4 (1/41) in rhizosphere soil, 37.5 (9/24) in stems, 76 (19/25) in the outer rhizosphere, and 81 (95/117) in the inner rhizoplane. Isolates from the inner rhizoplane showed the highest incidence of nitrogenase-positive bacteria. The bacteria were tested for their nutritional requirements. None could grow on nitrogen-free medium, but most grew better on casamino acid plus basal medium than on ammonium ion plus basal medium. The effects of ammonium ion (16 mg N/liter), casamino acids, each amino acid, and vitamin mixtures on bacterial growth and nitrogenase in a semisolid medium were tested. Ammonium depressed nitrogenase; casamino acid or each component amino acid was effective for nitrogenase induction.

An oxygen concentration of 1% or less was optimal for nitrogenase. ^{15}N-labeled molecular nitrogen feeding experiments on amino acid-supplemented medium confirmed nitrogen fixation. The bacteria resemble *Achromobacter*.

The experiments lead to the postulate that nitrogenase may be more widely distributed in the procaryotes than previously believed, provided that the nitrogenase test is performed with a small amount of combined nitrogen. Combined nitrogen for nitrogenase induction was also found necessary for nitrogen-fixing free-living rhizobia.

Inner rhizoplane heterotrophic bacteria isolated from the non-nodule-forming leguminous plant *Cassia tora* were all negative to nitrogenase.

The significance of these bacteria in nitrogen fixation in wetland rice is still unknown.

Relative contribution of roots to nitrogen fixation associated with wetland rice. Nitrogen fixation associated with rice is not confined to the roots or rhizosphere because rice plants from which roots were removed still exerted nitrogen-fixing activity. The relative contribution of the lower portion of stems may vary with growing conditions. To determine the relative contribution of roots and stems, the acetylene reduction activity (ARA) of rice plants with and without roots was assayed by the water culture technique.

IR26 and Latisail were grown in a new field. Plants were taken from the field, transferred to nitrogen-free mineral nutrient liquid medium, and grown for another day. ARA rates were assayed for 5 and 24 hours with rootless and intact plants. The ARA rates of rootless plants relative to intact plants were always higher in the 24-hour ARA assays than in the 5-hour assays. That suggests that ARA rates of rootless plants increased during growth after root cutting. The value for the 5-hour ARA may therefore be more realistic for evaluating the relative contribution of roots in nitrogen fixation.

Using 5-hour ARA rates, the relative contribution of stems ranged from 100 to 6%. The relative contribution of roots was less during early growth than during later growth, and greater in IR26 than in Latisail.

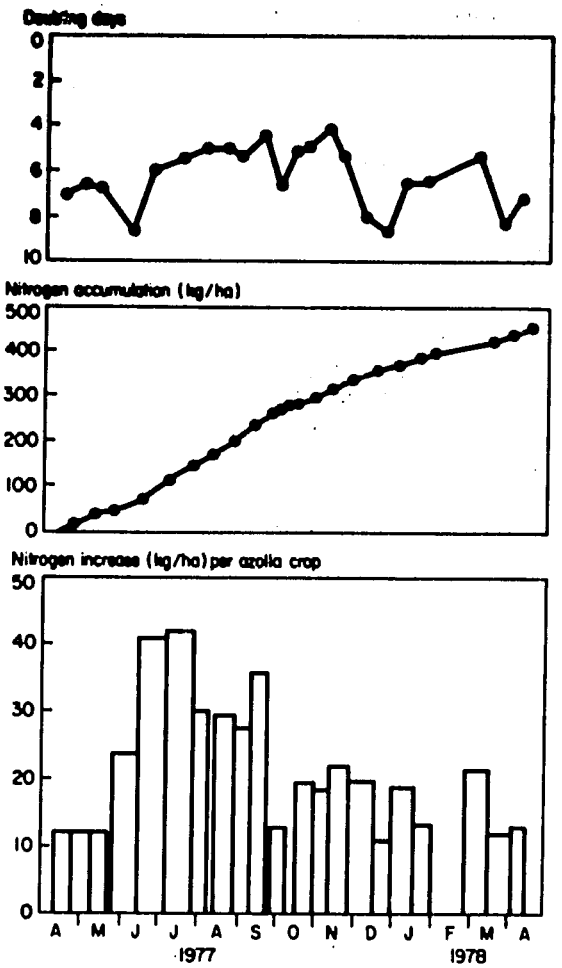
Heterotrophic nitrogen-fixing activity of blue-green algae attached to the lower portion of stems, and of heterotrophic bacteria on the leaf sheath surface and in the nodes may account for nitrogen fixation in the rootless rice plant.

Excised tissue showed that nodes from the lower portion (1–2 cm from the lower tip) had nitrogen-fixing activity. The levels of nitrogen-fixing bacteria in the nodes were similar to those in the roots.

NITROGEN FIXATION ASSOCIATED WITH AZOLLA

Soil Microbiology Department

Continuous growth of azolla. Twenty-two crops of azolla were harvested from open field plots at IRRI for a period of 335 days. The nitrogen increase from the crops totaled 465 kg/ha, an average of 1.4 kg/ha per day (Fig. 2), nearly comparable to the nitrogen fixation of forage legumes.



2. Nitrogen-fixing rates of azolla grown for a year in the field. IRRI, 1978.

Azolla species and clones collections. Clones of *A. pinnata* and *A. mexicana* were collected in 1978. The growth rates of the collections in various seasons, light intensities, and temperatures were compared.

Field trials. One-square-meter frames were set in open and 50% shaded plots. One hundred grams of fresh azolla with 3 kg a.i. carbofuran/ha was inoculated in each frame. Superphosphate at the rate of 1 kg P_2O_5/ha was applied every 3 days. Azolla was harvested every week to determine fresh weight up to the 6th week. Experiments were conducted from 15 May to 26 June and from 5 September to 17 October. Maximum fresh weight and nitrogen content during growth, final nitrogen content, and growth rates in open plots during the first 2 weeks are shown in Table 6.

In the first 2 weeks of the first season (hot and sunny), the growth of *Azolla pinnata* from Bangkok was the most rapid but final nitrogen gains were similar among clones, except those of *A. pinnata* from Bogor and *A. filiculoides*. *A. mexicana* could not grow. In the second season, *A. filiculoides* did not grow. Except for *A. mexicana*, there was little difference in maximum nitrogen gain and initial growth rates.

Fifty percent shading retarded growth, but the differences in growth rates among clones were nearly similar, whether in open or in shaded plots. The results indicate differences in azolla growth rates and nitrogen-fixing rates among clones and species and between seasons, and point up the importance of selecting the best clones.

Temperature requirement. Clones of *A. pinnata* (6), *A. filiculoides* (2), and *A. mexicana* (1) were grown in nitrogen-free water culture media kept at 37°/29°C day/night temperature (12 hours–12 hours) and at 26°/18°C. Light intensity

Table 6. Growth and molecular nitrogen fixation by various azolla species in 2 seasons.[a] IRRI, 1978.

Azolla species and clones	1st season (15 May–26 Jun)			2d season (5 Sep–17 Oct)		
	Max fresh wt (kg/m²)	N content at 6 wk (kg/ha)	Growth rate for the first 2 wk (doubling day)	Max fresh wt (kg/m²)	N content (kg/ha)	Growth rate for the first 2 wk (doubling day)
Ap Banaue	1.23 (3)	31.8 a	5.4	1.49	36.4 a (4)	4.0
Ap Bicol	1.54 (5)	38.7 a	4.7	1.50	43.6 a (4)	4.2
Ap Bangkok	1.80 (3)	34.2 a	3.6	2.38	44.8 a (8)	3.8
Ap Malaysia	1.52 (5)	36.5 a	5.3	1.83	42.0 a (6)	4.2
Ap Bogor	1.23 (2)	19.3 b	3.9	1.60	42.3 a (4)	3.9
Am California	n.g.			0.48	11.3 b (3)	6.6
Af Hawaii	0.76 (4)	17.4 b	20.0	n.g.		

[a]Ap = *Azolla pinnata*, Am = *A. mexicana*, Af = *A. filiculoides*. Each value in parentheses represents week when observation was made. Values followed by the same letter are not significantly different at the 5% level. n.g. = no growth.

Table 7. Clones of *Azolla pinnata*, *A. filiculoides*, and *A. mexicana* grown in nitrogen-free culture media with 2 temperature and light regimes. IRRI, 1979.

Species	Source	37°/29°C			29°/19°C		
		Nitrogen maximum (g/m²) (19 days)	Nitrogen (%)	Doubling days (1st week)	Nitrogen maximum[a] (g/m²)	Nitrogen (%)	Doubling days (1st week)
A. pinnata	Thailand	2.34	3.14	3.85	6.56 (33)	4.60	5.67
	Bogor	2.02	2.74	4.36	6.00 (42)	4.46	6.97
	Baneua	1.28	2.20	4.67	6.19 (33)	4.77	5.54
	Malaysia	1.14	1.94	5.31	6.61 (42)	4.41	7.10
	Bicol	1.13	1.96	5.45	6.40 (42)	5.26	7.09
	Bangkok	0.52	1.42	7.56	6.27 (42)	4.79	7.02
A. filiculoides	Hawaii	0.20	2.79	17.8	6.34 (42)	4.30	6.56
	Tiedale	0.14	2.98	22.0	6.75 (33)	5.30	5.38
A. mexicana	Graylodge	1.44	3.00	5.38	5.10 (42)	4.93	7.85

[a]Figures in parentheses represent days when observation was made.

was kept at 30 klux and relative humidity was 75%. Fresh weight was measured every 2 days, and nutrients were renewed. Plants were harvested at maximum growth; dry matter and nitrogen content were measured. Except for *A. filiculoides*, initial growth rates were higher at higher temperatures; however, maximum biomass and nitrogen content were much higher at lower temperatures.

A. pinnata from Bangkok showed a very different growth pattern. It was superior in the field but inferior at 37°/29°C. Maximum temperature never exceeded 33°C in both field trials (Table 7).

Phosphorus application. Phosphorus is essential for maximum yields of azolla. Because azolla absorbs phosphorus from the water, and applied water-soluble phosphate is quickly adsorbed into the soil, split application is expected to be more effective. The effects of basal and split applications on growth were studied in the field. The total amount of 15 kg P_2O_5/ha or 30 kg P_2O_5/ha was split into five portions and applied every 2 days until the 10th day. The fresh weight of azolla was measured every week and the final harvest was made at 27 days. Floodwater was taken every 2 days and analyzed for its phosphorus content.

Table 8 shows that the split application of 15 kg P_2O_5 gave higher azolla and total nitrogen yield than the basal application of 15 kg P_2O_5. It also approximated the 30-kg split yield. It is evident that the split application of phosphorus can reduce the phosphorus needed for azolla culture. In the 15-kg split application the ratio of nitrogen fixation to unit weight of phosphorus pentoxide applied was 1.9. Analysis of the phosphorus content of azolla revealed a phosphorus absorption efficiency of 37%.

Phosphorus analysis of paddy water indicates that 0.1 or 0.2 ppm phosphorus is probably the threshold of phosphorus deficiency in azolla.

Intervals and rates of split phosphorus application to azolla. The best interval and rate of split application were determined in another experiment. Two intervals (2 and 4 days) and

Table 8. Effects of basal and split applications of phosphorus on azolla growth, 27 days after inoculation.[a] IRRI, 1979.

Phosphorus pentoxide (kg/ha)	Application	Azolla fresh wt (g/m²)	Nitrogen content (%)	Total nitrogen (kg/ha)	Phosphorus content (kg P_2O_5/ha)
0		221 c	2.48	5.0 c	0.20
15	Basal	1030 b	3.09	20.6 b	2.36
15	Split	1450 a	3.48	33.1 a	5.80
30	Basal	1340 ab	3.99	31.7 a	8.03
30	Split	1430 a	4.29	34.4 a	8.98

[a]In any column, values followed by the same letter are not significantly different at the 5% level. Split applications were divided into 5 portions and applied every 2 days, from inoculation to the eighth day.

three levels of phosphorus (7.5, 10, 15 kg P_2O_5/ha) were tested.

Phosphorus was applied 12 times at 2-day intervals and 6 times at 4-day intervals. The first application was made at the time of inoculation, and azolla was harvested after 35 days. The intervals produced no difference in fresh weight and dry weight; however, the nitrogen content of azolla at both intervals was inferior at the low level of phosphorus application and application at 2-day intervals was slightly better than application at 4-day intervals. Application rates of 7.5 kg P_2O_5/ha per azolla crop split into twelve 2-day or six 4-day intervals are recommended as efficient.

The ratio of nitrogen fixed to unit weight of phosphorus pentoxide applied was about 1.9 in the highest case (10 kg, 2-day intervals). Probably because of the higher phosphorus content in the water, the growth of azolla was no better than that in the previous experiment.

Availability of azolla nitrogen to rice and its loss in soil. Greenhouse-grown *Azolla pinnata* from Malaysia was labeled with ^{15}N by growing it on a culture medium containing ammonium sulfate. The ^{15}N-labeled azolla was either incorporated into the soil, floated on the water, or placed on the surface of the soil. Then the fate of ^{15}N in the flooded soil was followed for 6 weeks. Azolla incorporated into the soil lost 33% of its ^{15}N; azolla placed on the surface of the soil lost 66%. Floating azolla, with some plants still alive after 6 weeks, lost 48% of its ^{15}N. That confirmed the high efficiency of azolla nitrogen after soil incorporation.

The uptake of ^{15}N in azolla by rice grown in pots was studied. When azolla was incorporated into the soil, 52, 50, and 53% of ^{15}N was absorbed by the rice plants at 42, 81, and 123 days after transplanting. When azolla was floated on the surface, only 3.9, 6.2, and 9.5% of the ^{15}N was taken up by the rice. That indicates the higher efficiency of azolla nitrogen incorporated into the soil.

In the field, nitrogen uptake from the ^{15}N-labeled azolla in 1-m^2 plots was studied. The field trial also showed the higher efficiency of incorporated azolla nitrogen.

Soil and crop management

Soil fertility and fertilizer management

Agronomy and Soil Chemistry Departments

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NITROGEN FERTILIZER EFFICIENCY

Agronomy and Soil Chemistry Departments

Research on ways of increasing the efficiency of nitrogen fertilizers for rice was intensified during 1978 through a collaborative project with the International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama. Two general approaches — deep placement and slow release — are being tested. Among the experimental fertilizers being considered, two — sulfur-coated supergranules and forestry-grade sulfur-coated urea (SCU) — were developed especially for rice and were first tested in the field in 1978. The forestry-grade SCU granules are approximately 10 times larger than regular SCU granules and are easier to incorporate into puddled soil.

Dry season. The second trial of the International Network on Fertilizer Efficiency in Rice (INFER) was continued at IRRI (Alfisol) and in two farmers' fields (Ultisol and Vertisol). The early-maturing varieties IR36 and the medium-maturing IR42 were used. Point placement (10-cm depth) of mudballs or urea briquets was compared with band placement (15–20 cm) of prilled urea by the plow sole applicator. Another treatment was regular SCU broadcast and incorporated at final harrowing. These fertilizer treatments were compared with split application, which is the best method presently available.

The first 52 kg N increased yields of both varieties by more than 2 t/ha. Except for SCU, higher rates of nitrogen did not further increase the yield of IR36 (Table 1). However, IR42 at IRRI gave significantly higher yields with 82 kg N/ha from methods other than split application. In fact, its highest yield from split application was obtained at 120 kg N/ha.

Yield response to SCU at 82 kg N/ha was consistently higher than that to split application. With SCU at that rate, IR42 gave a particularly high yield of 7.7 t/ha, suggesting that in the dry season, when demand for nitrogen is high, slow-release fertilizers may be especially effective with medium- to late-maturing rice varieties.

Wet season. At the International Rice Research Conference in April the current status of INFER was evaluated. The INFER participants decided to modify the list of treatments for the nitrogen efficiency trials. The liquid band placement and urea-in-mudball treatments

Table 1. Effect of sources and methods of nitrogen application on grain yield of rice at IRRI and in 2 farmers' fields in the Philippines. Second trial of the International Network on Fertilizer Efficiency in Rice, 1978 dry season.

Treatment	Yield[a] (t/ha)				
	Neutral Alfisol at IRRI		Acid Ultisol in Luisiana, Laguna	Neutral Vertisol in Teresa, Rizal	Mean
	IR36	IR42	IR36	IR36	
No fertilizer nitrogen	4.0 c	3.8 f	2.6 e	2.5 e	3.2
Urea – 52 kg N/ha					
Split application[b]	6.1 ab	6.1 de	4.8 bcd	4.5 bc	5.4
Plow sole placement	6.3 ab	6.2 de	4.4 d	4.0 d	5.2
Mudball placement	6.0 b	6.7 bcde	4.7 cd	4.7 bc	5.5
Briquet placement	6.4 ab	6.0 e	4.5 d	4.3 cd	5.3
Sulfur-coated urea	6.7 ab	6.4 cde	5.0 bcd	4.9 b	5.8
Urea – 82 kg N/ha					
Split application[b]	6.4 ab	6.2 de	5.4 ab	5.4 a	5.9
Plow sole placement	6.4 ab	7.1 abc	4.9 bcd	4.7 bc	5.8
Mudball placement	6.3 ab	7.2 ab	5.4 ab	5.3 a	6.1
Briquet placement	6.5 ab	6.8 bcd	5.3 abc	5.4 a	6.0
Sulfur-coated urea	6.8 a	7.7 a	6.0 a	5.7 a	6.6
Ammonium sulfate – 120 kg N/ha					
Split application[b]	6.6 ab	7.1 abc	5.4 ab	5.3 a	6.1

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Two-thirds basal + one-third 5–7 days before panicle initiation.

Table 2. Effect of sources and methods of nitrogen application on the grain yield of rice at IRRI and in 2 farmers' fields in the Philippines. Third trial of the International Network on Fertilizer Efficiency in Rice, 1978 wet season.

Treatment	Grain yield[a] (t/ha)				
	IRRI		Lucban, Quezon	Teresa, Rizal	Mean
	IR36	IR42	IR36	IR36	
No fertilizer nitrogen	3.2 c	3.4 a	1.7 h	3.0 c	2.8
Urea – 27 kg N/ha					
Split[b] application	4.7 ab	3.7 a	2.2 fg	3.1 bc	3.4
Plow sole placement	4.4 b	4.0 a	1.9 gh	3.3 abc	3.4
SCU[c] broadcast and incorporated	4.6 b	4.0 a	2.5 def	3.8 a	3.8
SCU plow sole placement	4.5 b	3.8 a	2.6 cde	3.9 a	3.7
SCU[d] broadcast and incorporated	4.6 b	3.8 a	2.2 fg	3.6 abc	3.6
Supergranule point placement	4.4 b	3.9 a	2.6 cde	3.6 abc	3.8
Urea – 54 kg N/ha					
Split[b] application	4.5 b	3.8 a	2.7 bcde	3.9 a	3.7
Plow sole placement	4.6 b	3.9 a	2.4 ef	3.5 abc	3.6
SCU[c] broadcast and incorporated	4.5 b	3.9 a	2.8 abcd	3.8 a	3.8
SCU plow sole placement	4.6 ab	3.8 a	2.9 abc	4.0 a	3.9
SCU[d] broadcast and incorporated	5.0 ab	3.9 a	2.6 cde	3.7 ab	3.8
Supergranule point placement	4.7 ab	3.4 a	2.7 bcde	3.7 ab	3.6
Urea – 80 kg N/ha					
Split[b] application	4.9 ab	2.8 b	3.0 ab	4.0 a	3.7
Ammonium sulfate – 80 kg N/ha					
Split application	5.3 a	3.8 a	3.2 a	4.0 a	4.1

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

were dropped: in their place the plow sole applicator (for applying prilled urea or SCU), and forestry-grade SCU, applied broadcast and incorporated, were used. The third international trial on nitrogen fertilizer efficiency consisted of 15 treatments. A simpler experiment for rainfed rice was also designed for use in some countries. The experiment was conducted at IRRI and on two field sites. Mean yield increases with the application of 27 kg N/ha and 54 kg N/ha were only 0.8 and 1.0 t/ha (Table 2). Lodging caused by typhoons was most severe on plots receiving the high rate of nitrogen and in those treatments in which the most efficient nitrogen fertilizers were used. Treatment differences were therefore only poorly expressed in grain yield.

Another wet-season experiment was designed to study experimental fertilizers that use deep placement or slow-release concepts, either alone or in combination. ^{15}N microplots were used in some plots. The ^{15}N balance data are still being processed, but data from the large plots are available (Table 3). Lodging from a typhoon again reduced differences in grain yield between treatments. However, N analysis of aboveground plant parts permitted calculation of the nitrogen apparently recovered from the different fertilizers. The plant recovered significantly more nitrogen from forestry-grade SCU. This high recovery may be caused by the peculiar release characteristics of the forestry-grade SCU — whose granule size and coating thickness are uniform — that allow eventual release of 100% of the urea from the granules. Regular SCU, on the other hand, may fail to release as much as 20% of its nitrogen during the growth of the rice crop.

Fertilizer placement depth. Although deep placement of nitrogen has been shown to increase fertilizer efficiency, the optimum depth for mudballs or urea briquets has not been determined. The effect of placement depth on fertilizer nitrogen efficiency was studied in the 1978 dry season.

The results (Table 4) show that deep placement of urea was more effective than split application. Placement at depths of 10 to 20 cm in general gave better yields than placement at 5 cm. At 5 cm, briquets were less efficient than

Table 3. Effect of sources and methods of nitrogen application on grain yield and apparent recovery of fertilizer nitrogen (N) by IR42 rice. IRRI, 1978 wet season.[a]

Treatment	Yield (t/ha)	Apparent recovery[b] (%)
No fertilizer nitrogen	2.3 b	
Urea - 58 kg N/ha		
Basal application	4.0 a	47 b
Split application[c]	3.8 a	45 b
Supergranule point placement	4.0 a	38 b
SC supergranule point placement	4.1 a	39 b
SCU[d] broadcast and incorporated	4.1 a	53 ab
SCU[e] broadcast and incorporated	4.3 a	74 a
Ammonium sulfate - 58 kg N/ha		
Split application[c]	4.3 a	34 b

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

$$\text{[b]N recovery} = \frac{(\text{N uptake in fertilized plants} - \text{N uptake in control})\ \text{kg} \times 100\%}{58\ \text{kg}}$$

[c]Two-thirds basal + one-third 5–7 days before panicle initiation. [d]Regular sulfur-coated urea. [e]Forestry-grade sulfur-coated urea.

mudballs, probably because the mudball combines some slow-release properties with the deep-placement effect. Results were essentially the same for IR36 and IR42.

NITROGEN FERTILITY OF SOILS

Agronomy Department

Field trials at IRRI and in the countries involved in INFER to evaluate experimental nitrogen fertilizers for rice can yield conflicting results. One way of resolving such conflicts is to examine in detail the chemical and biological transformations of the fertilizer nitrogen in different soils, with particular emphasis on loss mechanisms such as ammonia volatilization.

Ammonia volatilization. Alkaline conditions are generally considered necessary for occurrence of ammonia volatilization. Because volatilization is repressed by adsorption to soil colloids or by solution in soil moisture, the heaviest ammonia losses are found in light, sandy soils. It was recently reported that ammonia volatilization also occurs in acid clay soil, but the loss is lower than in neutral clay soil. An experiment using an acid sandy loam soil (Pangasinan soil, pH 5.0, total N: 0.08%, O.M.: 1.12%, CEC 7) and a neutral clay soil (Maahas soil, pH 6.9, total N: 0.17%, O.M.; 3.15%, CEC 43) in outdoor drums was conducted. It had two objectives:

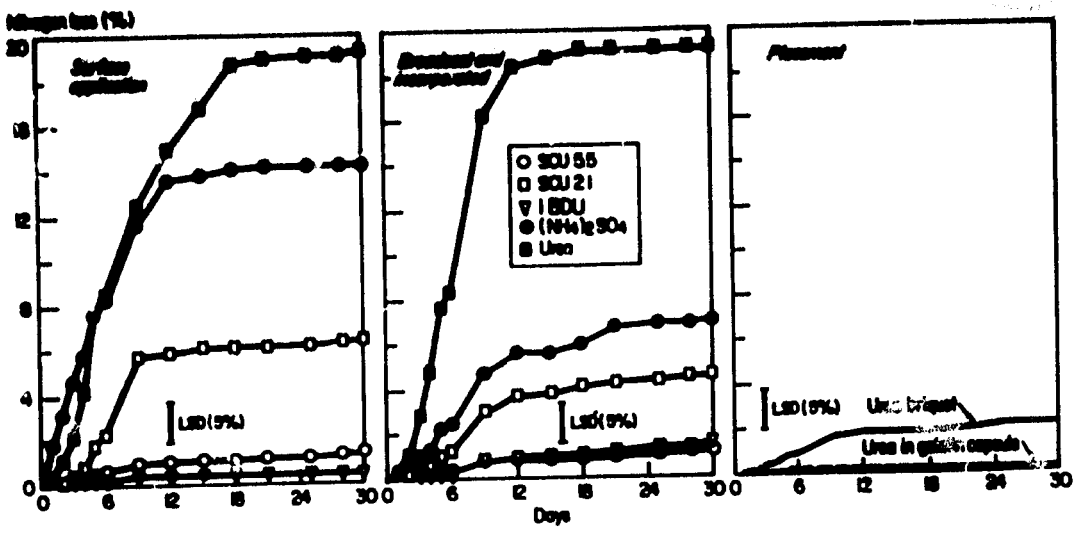
1) to quantify the ammonia volatilization losses from five nitrogen sources under two methods of application and two placement techniques in two different soils;
2) to evaluate the effectiveness of slow-release fertilizers and placement techniques in minimizing ammonia losses in a coarse-textured soil.

Ammonia volatilization losses were measured from two soluble nitrogen sources (urea and ammonium sulfate) and three slow-release fertilizers (SCU 21, SCU 5.5, and isobutylidene diurea [IBDU]). Two methods of application tested were broadcast and incorporation (basal) and topdressing or surface application. Two

Table 4. Effect of depth of urea placement[a] on grain yield of IR36 and IR42. IRRI, 1978 dry season.

Treatment	Grain yield[b] (t/ha)				
	IR36		IR42		T-mean
	Briquet	Mudball	Briquet	Mudball	
No nitrogen	2.7 d	3.0 c	3.4 d	3.1 c	3.0 d
Best split[c]	4.2 c	3.7 b	4.4 c	4.6 b	4.2 c
Deep placement					
5 cm	4.4 bc	4.9 a	5.2 b	5.4 a	4.9 b
10 cm	5.0 a	5.0 a	5.7 ab	5.4 a	5.3 a
15 cm	4.5 abc	5.2 a	5.7 ab	5.6 a	5.2 ab
20 cm	4.8 ab	4.7 a	5.8 a	5.8 a	5.2 ab
F-mean	4.2	4.4	5.0	5.0	

[a]At 58 kg N/ha. [b]Av of 4 replications. In a column, means followed by the same letter are not significantly different at the 5% level. [c]Two-thirds basal incorporated + one-third topdressed 5–7 days before panicle initiation.

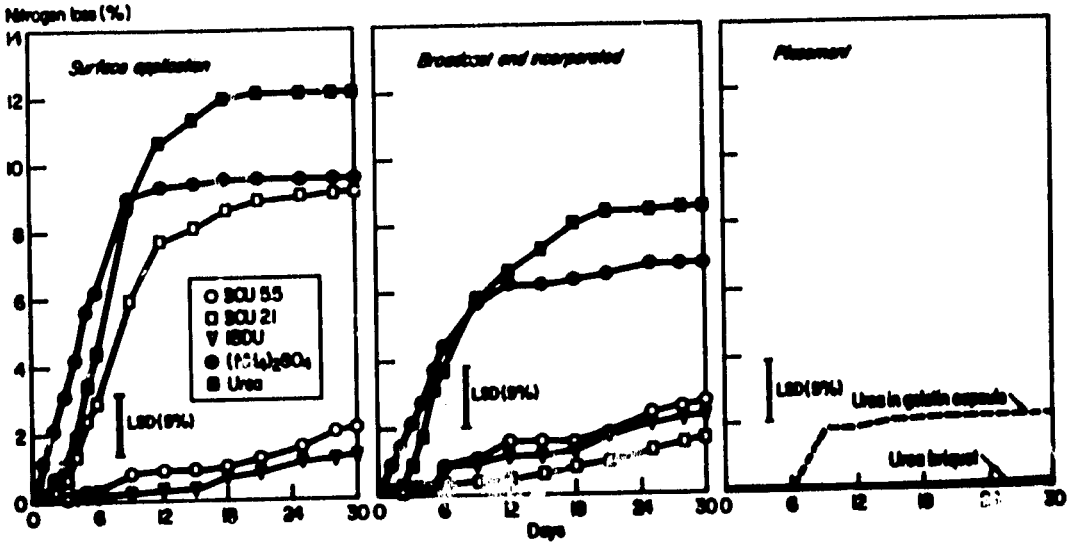


1. Effect of nitrogen sources and methods of application on ammonia volatilization loss in Pangasinan soil. Large-pot experiment, IRRI, 1978 dry season. SCU = sulfur-coated urea, IBDU = isobutylidene diurea.

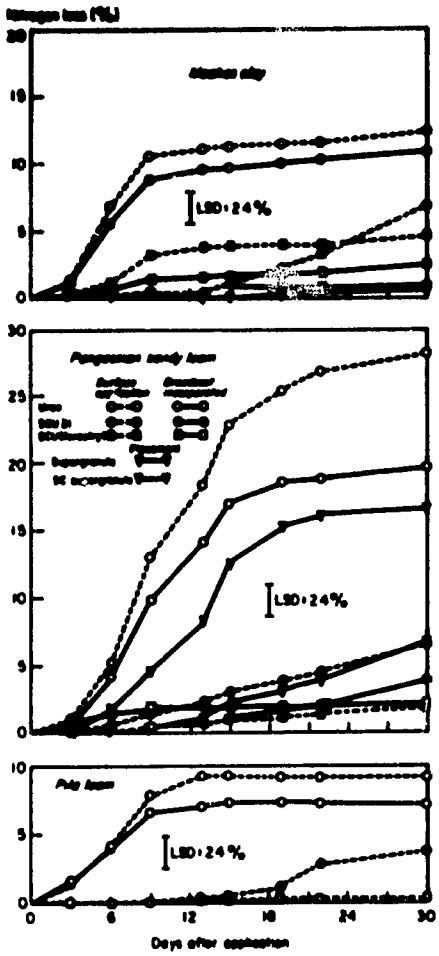
urea forms were compared: briquet and gelatin capsule.

In Pangasinan soil (coarse-textured, acid), urea, either broadcast and incorporated or surface applied, resulted in 19.2% nitrogen loss through ammonia volatilization (Fig. 1). Surface application of ammonium sulfate resulted in 14.2% loss, which was reduced to 7.0% when the fertilizer was incorporated. Although Pangasinan soil is acidic, the pH of floodwater ranged from 8.0–9.0 with urea and 7.7–8.5 with ammonium sulfate.

Placement of urea briquets and use of the slow-release fertilizers IBDU and SCU 5.5 resulted in low amounts of loss, and urea in gelatin capsules produced negligible loss by



2. Effect of nitrogen sources and methods of application on ammonia volatilization loss in Maahas clay soil. Large-pot experiment, IRRI, 1978 dry season. SCU = sulfur-coated urea, IBDU = isobutylidene diurea.



3. Effect of different forms of urea fertilizer on nitrogen loss through ammonia volatilization in 3 soils. Large-pot experiment. IRRI, 1978 wet season.

ammonia volatilization. SCU 21, surface applied, recorded 6.4% loss, and incorporation of the basal dose decreased the loss to 4.5%. Evidently, use of slow-release fertilizers like IBDU and SCU 5.5, or placement of urea in gelatin capsules minimizes losses in a coarse-textured soil. Incorporation of fertilizers like ammonium sulfate and SCU 21 reduced ammonia volatilization. Incorporation of urea did not improve fertilizer efficiency in the coarse-textured soil.

Surface application of urea, ammonium sulfate, and SCU 21 in Maahas clay resulted in 12.1, 9.5, and 9.1% N loss, respectively (Fig. 2). Urea broadcast and incorporated showed 8.5% N loss, while ammonium sulfate applied the same way showed 6.7% loss. The magnitude of nitrogen loss was significantly higher from urea than from ammonium sulfate with both methods of application. SCU 21, when broadcast and incorporated, had 1.6% N loss, which indicates that the material is suitable for minimizing ammonia loss in neutral clay soil. With both methods of application, SCU 5.5 and IBDU had similar values, ranging from 1.3–2.7% N loss. Use of urea briquets resulted in a negligible level of ammonia loss, but urea in gelatin capsules resulted in 2.0% N loss.

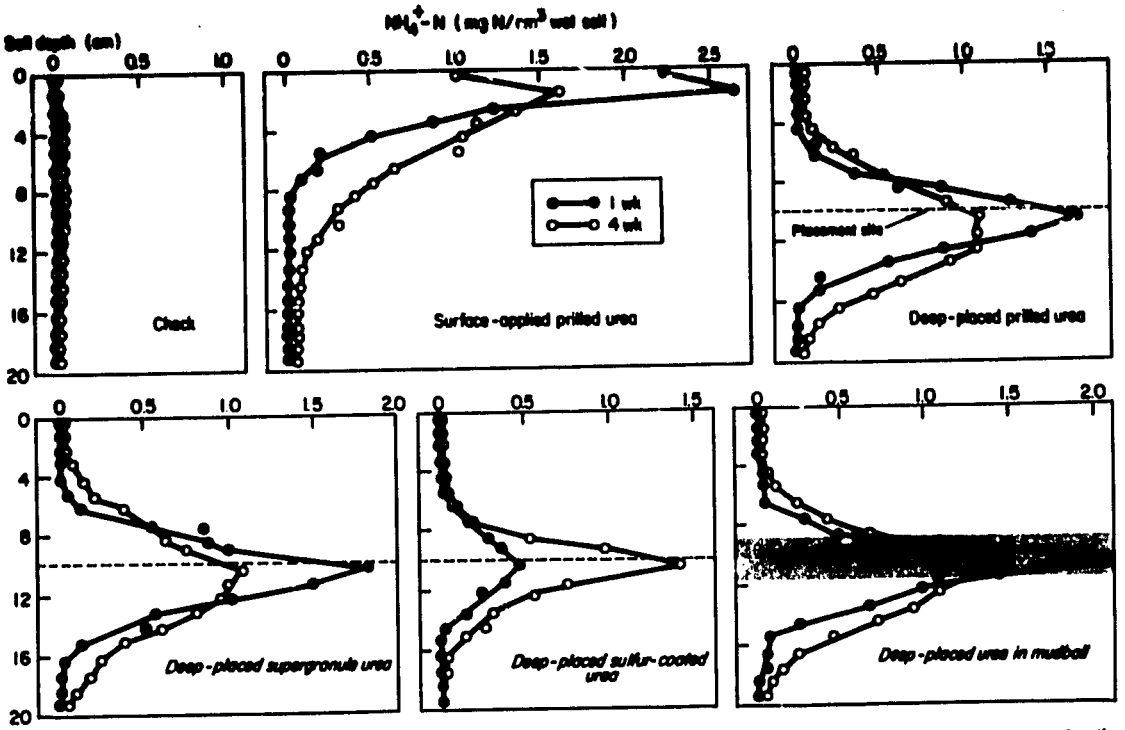
In the wet season, ammonia volatilization from regular and forestry-grade SCU, urea supergranules (SGU), and sulfur-coated supergranules of urea in three different types of soils was measured. Maahas and Pangasinan soils and Pila loam (pH 7.5, total N: 0.26, O.M.: 3.16, CEC: 25 meq/100 g, loam) were used.

Surface-applied urea had higher loss through ammonia volatilization than any other treatment (Fig. 3). This trend was shown in all three soils, but the total ammonia loss was always higher in Pangasinan sandy loam. Incorporating urea significantly reduced the loss.

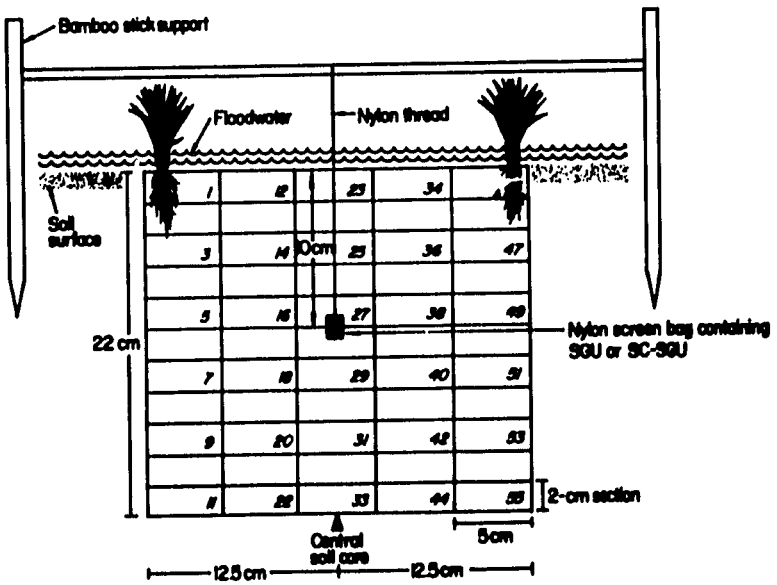
In Pila soil, ammonia volatilization from supergranules was negligible, indicating that the modified products are effective in minimizing nitrogen loss through ammonia volatilization in a calcareous soil.

The results in Pangasinan sandy loam suggest that, in coarse-textured soil, placement in the root zone may not always minimize ammonia loss. That partially explains the variable results of briquet (or supergranule) placement in the international trial on nitrogen fertilizer efficiency in rice.

Transformations of deep-placed urea in flooded soils. The vertical distribution of ammonium nitrogen following application of different forms of urea on the surface and at 10-cm soil depth was studied in 20-cm-long undisturbed cores of wetland soils. During incubation a constant head of water was maintained above the soil, and leachate was collected for analysis. Ammonium nitrogen remained in the topsoil for 4 weeks after surface application of prilled urea (PU) (Fig. 4). For PU, SGU, and deep-placed PU in mudballs, the ammonium nitrogen concentration was greatest near the



4. Distribution curves of ammonium nitrogen (NH_4^+-N) after application of different forms of urea in undisturbed flooded soil cores. IRRI, 1978.



5. Schematic cross section of deep placement site of supergranule urea (SGU) or sulfur-coated supergranule urea (SC-SGU) in a wetland rice soil and method of soil core sampling. IRRI, 1978 wet season.

placement sites and decreased with time; for SCU 21, the ammonium nitrogen concentration increased during 4 weeks. With time, the ammonium nitrogen moved more below than above the placement site, presumably because of water percolation.

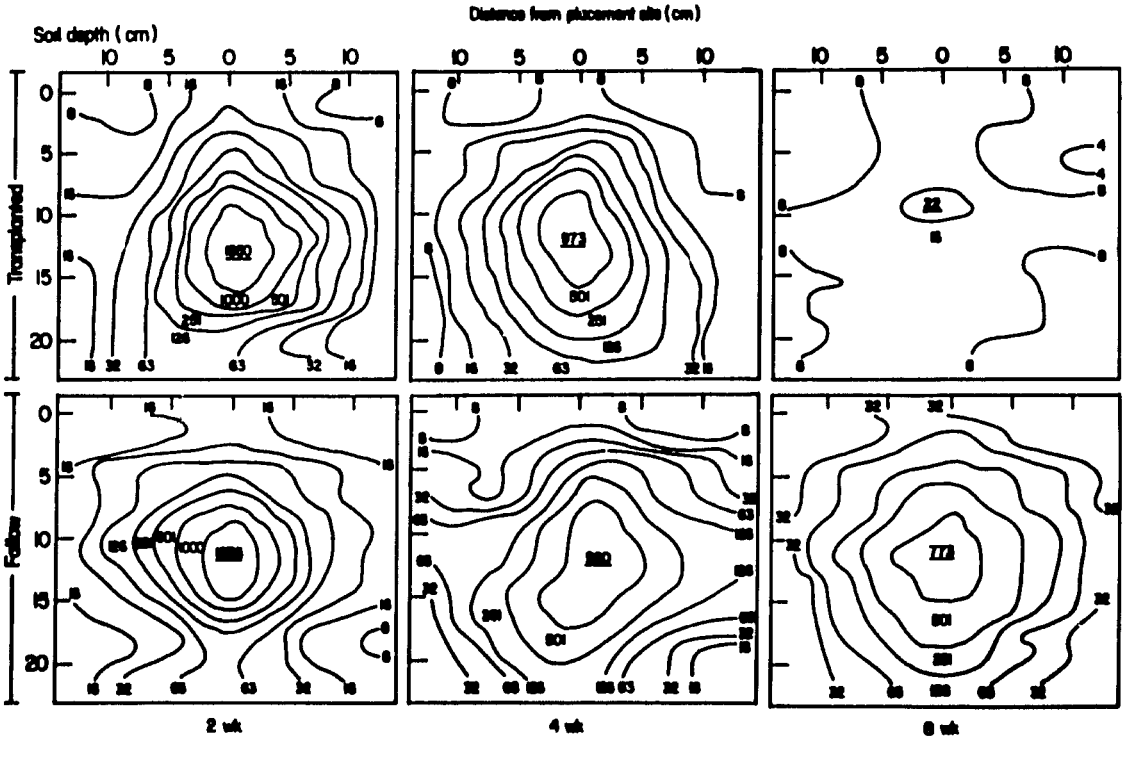
The movement and spatial distribution of ammonium nitrogen after the placement of 2 g SGU and sulfur-coated supergranule urea (SC-SGU) at 10-cm soil depth were studied in a wetland soil growing rice at IRRI during the 1978 wet season. The cross section of the placement site of SGU and SC-SGU and the method of soil core sampling are schematically shown in Figure 5. The contour plots of ammonium nitrogen (micrograms of nitrogen per cubic centimeter of wet soil), computed using the Maximum Likelihood Program (MLP) developed at the Rothamsted Experiment Station (England), are shown in Figures 6 and 7.

After 2 weeks the ammonium nitrogen concentration gradient was 1,850 to 32 μg N/cm^3 over a distance of 10–12 cm from the placement site of SGU. For the SC-SGU, the corresponding gradient was 287 to 32 μg N/cm^3 over a distance of 5–7 from its placement site.

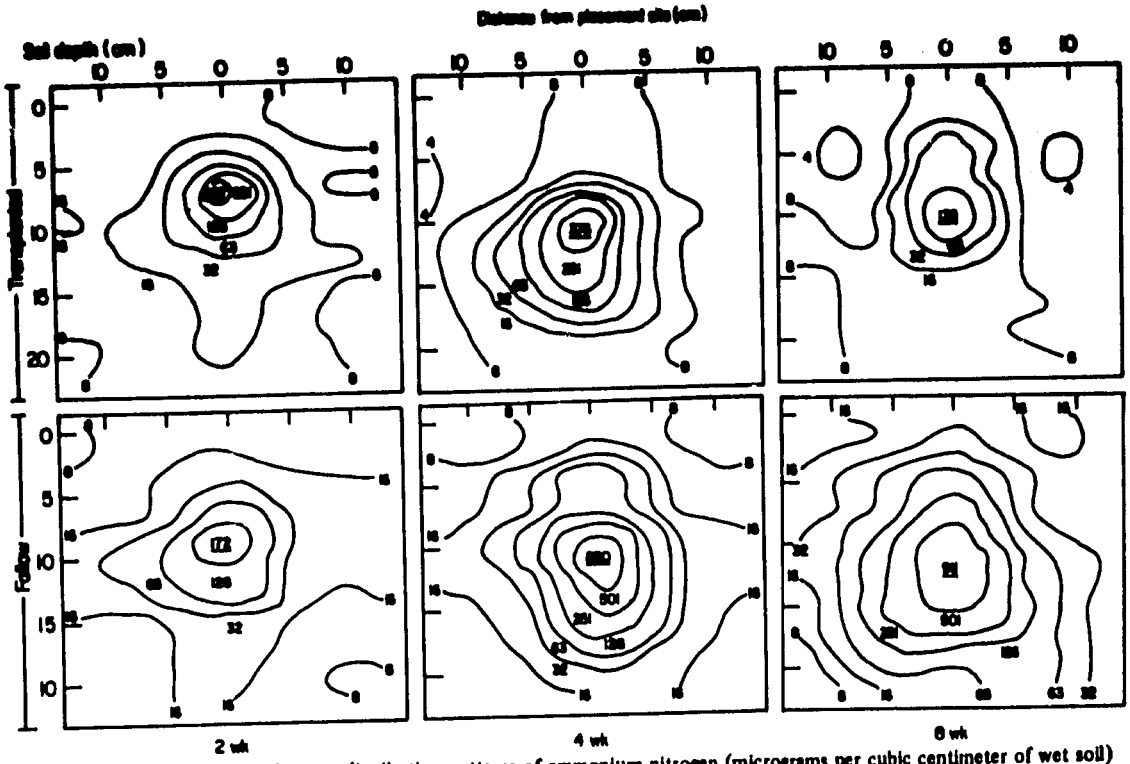
The concentration gradient of ammonium nitrogen for SGU placed in transplanted plots decreased with time. The especially marked decrease for the period of 4 to 8 weeks was attributed primarily to the movement of ammonium ions during the first 4 weeks and to movement and root-sink effects thereafter. This observation is supported by the rice root distribution patterns in a root-box study (Fig. 8) conducted in the greenhouse.

For SC-SGU placed in the transplanted plots, the concentration gradient of ammonium nitrogen increased during the first 4 weeks and then decreased because of the slow release of nitrogen during the initial period and the root-sink effect thereafter.

By and large, the movement of ammonium nitrogen in the soil-urea reaction zone was downward > lateral > upward.



6. Computed contour plots showing distribution patterns of ammonium nitrogen (micrograms per cubic centimeter of wet soil) after 10-cm deep placement of 2 g supergranule urea in a wetland soil. IRRI, 1978 wet season.



7. Computed contour plots showing distribution patterns of ammonium nitrogen (micrograms per cubic centimeter of wet soil) after 10-cm deep placement of 2 g sulfur-coated supergranule urea in a wetland soil. IRRI, 1978 wet season.

It seems that application of urea at 10-cm soil depth would help in reducing nitrogen loss from a wetland soil and in controlling nitrogen supply to the rice plant.

LONG-TERM FERTILITY EXPERIMENTS

Agronomy Department

IRRI. The average yields of the three varieties — IR8, IR26, and IR36 — for 29 consecutive crops (Table 5) show a response of 3.2 t to 140 kg N/ha in the dry season and about 1 t to 60 kg N/ha in the wet season. There has been no response to phosphorus, potassium, or compost since the experiment was started in 1964. Yields in recent years have declined, partly because of the poor performance of IR8, and possibly because of zinc deficiency (Fig. 9).

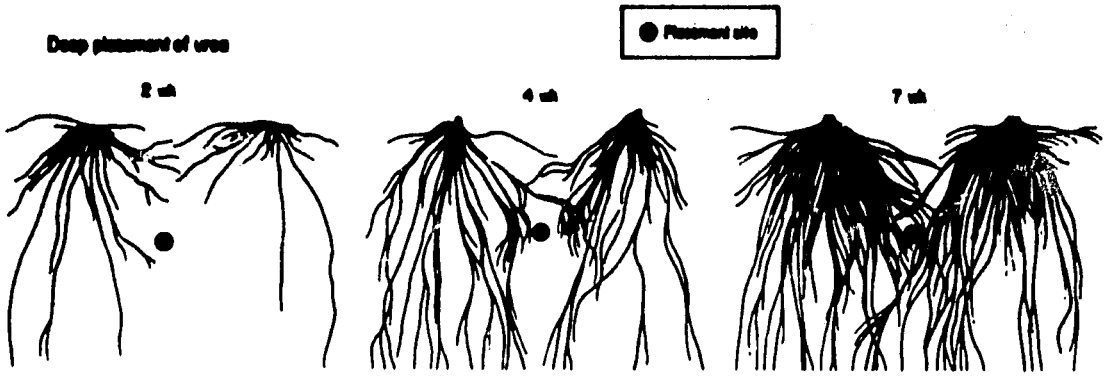
Philippine Bureau of Plant Industry stations. The 22 crops at Maligaya and Bicol and 18 crops at Visayas (Table 6) responded to nitrogen, phosphorus, and potassium at all sites except at Visayas, where there was no response to potassium alone. Total response to nitrogen could not be determined because the experiments did not include a treatment with phosphorus and potassium and without nitrogen.

Yield responses to phosphorus and potassium are related to soil-test values for the nutrients (Table 7). Responses for 11 years have been quite consistent, as indicated in Figures 10, 11, and 12. Responses to nitrogen, phosphorus, or

Table 5. Fertilizer levels and average yields of 3 rice varieties in the long-term fertility experiment. IRRI, 1964–78 dry and wet seasons.

Rate (kg/ha)				Yield av (t/ha)	
Nitrogen		P_2O_5	K_2O	14 yr, dry	15 yr, wet
Dry	Wet				
0	0	0	0	4.0	3.6
140	60	0	0	7.2	4.5
0	0	30	0	4.2	3.8
0	0	0	30	4.1	3.7
140	60	30	0	7.2	4.6
140	60	0	30	7.3	4.6
140	60	30	30	7.2	4.6
140[a]	60	30	30	7.2	4.6

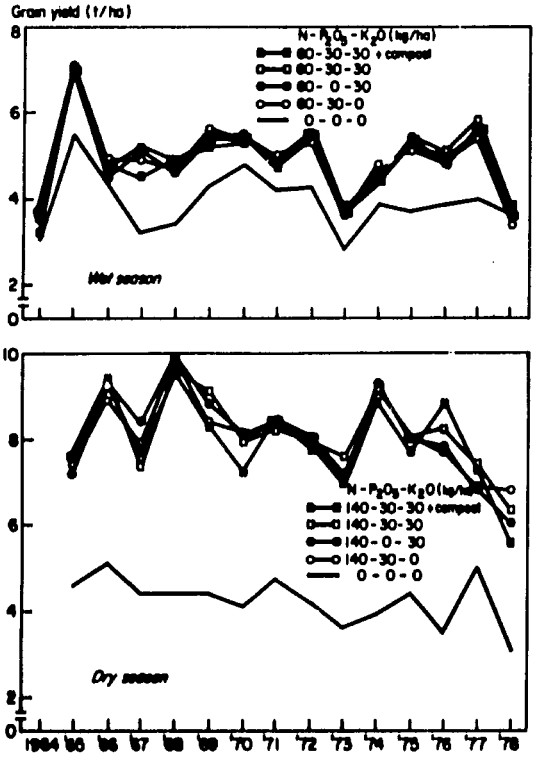
[a]Includes 10 t compost.



8. Distribution of rice roots of IR36 around a urea supergranule placed at 10-cm depth in flooded soil in a root box in the greenhouse. IRRI, 1978.

potassium show no appreciable changes during 22 crops of continuous rice.

Farmers' fields. The fourth and fifth crops were harvested in 1978 at Luisiana (Laguna) and Tanay (Rizal). Yields for five crops are shown in Figure 13 and soil-test data in Table 7. At both sites response to nitrogen was large, but responses to phosphorus and potassium were small. There was no response to potassium at Luisiana.



9. Long-term fertility experiment, IRRI, 1964–78 dry and wet seasons.

PHOSPHORUS SOURCE TRIALS OF TWO PHILIPPINE SOILS

Agronomy Department

Experiments were initiated during the 1977 wet season in farmers' fields to evaluate sources of fertilizer phosphorus on flooded rice. Results through the 1978 wet season show that after three croppings response to phosphorus from all sources and at all rates of application was consistent at Teresa (Table 8). At Lucban, the trend was the same during the second planting, but during the wet-season plantings only superphosphate at 40 and 60 kg P_2O_5/ha, Phosmak at 40 kg P_2O_5/ha, and local guano at 120 kg P_2O_5/ha produced a significant response in the first planting; the third crop showed no response (Table 9). At Luisiana, where the first crop showed no response to phosphorus, the second crop showed significant response to superphosphate at all rates and to NCR phosphate at 40 kg P_2O_5/ha (Table 10).

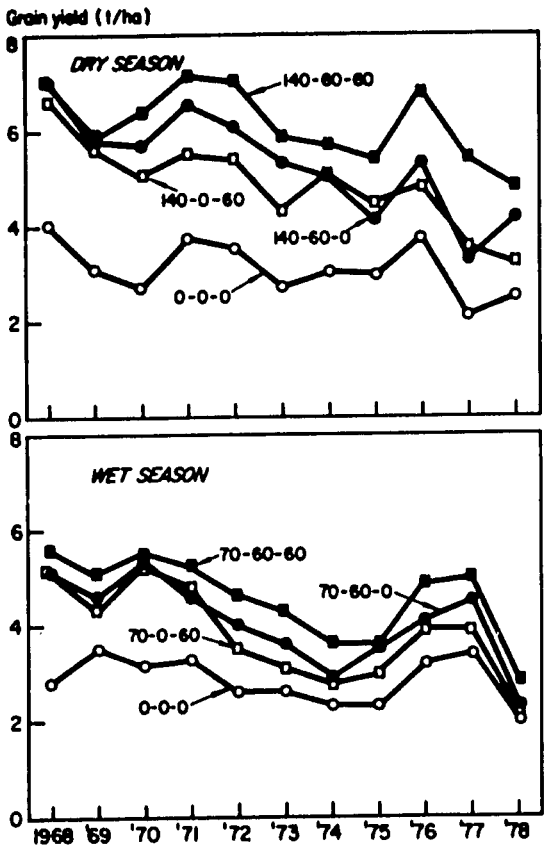
METHODS OF APPLYING ZINC TO RICE

Agronomy Department

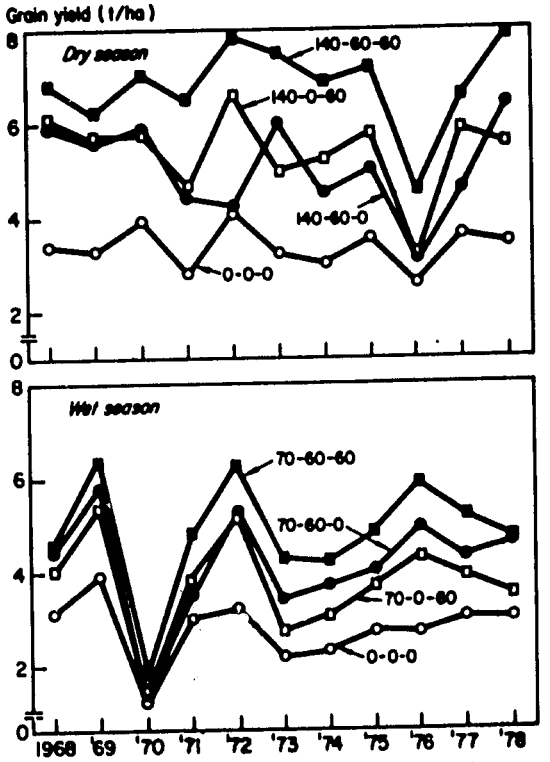
Field experiments at Tiaong, Quezon, evaluated the effect on transplanted and direct-seeded rice of zinc oxide and sulfate applied by different methods and at different

Table 8. Fertilizer levels and average yields of long-term fertility experiments, Bureau of Plant Industry (BPI) stations, Philippines, 1968–78 dry and wet seasons.

BPI station rate (kg/ha)				Yield (t/ha)							
Nitrogen		P_2O_5	K_2O	Maligaya		Bicol		Visayas		Av	
Dry	Wet			11 yr, dry	11 yr, wet	11 yr, dry	11 yr, wet	7 yr, dry	11 yr, wet	29 crops, dry	33 crops, wet
0	0	0	0	3.1	2.8	3.4	2.7	2.8	2.4	3.1	2.8
140	70	0	0	4.8	3.8	4.5	3.3	4.9	3.3	4.8	3.4
140	70	60	0	5.2	3.9	5.0	4.1	5.6	4.4	5.2	4.1
140	70	0	60	4.8	3.8	5.5	3.7	4.8	3.1	5.0	3.5
140	70	60	60	6.0	4.6	6.8	4.8	5.7	4.8	6.2	4.7
140	70	60	60 + 30	6.1	4.5	6.9	4.9	6.0	4.5	6.3	4.8



10. Long-term fertility experiment, Maligaya, Philippines. 1968–78 dry and wet seasons. *N-levels: 60 kg N/ha, wet season; 120 kg N/ha, dry season.



11. Long-term fertility experiment, Bicol, Philippines, 1968–78 dry and wet seasons.

rates. The soil had pH 8.4, 9.6% organic matter, and 0.04 ppm available zinc as extracted by 0.05 N HCl.

Where no zinc was added, rice plants produced no grain (Table 11). Dapog seedlings raised in zinc oxide suspension and regular wet bed seedlings dipped in 2% zinc oxide solution or transplanted in soil in which 11 kg Zn/ha as zinc sulfate had been incorporated produced more than 3 t/ha. Treating the seedbed with zinc sulfate was not a satisfactory method of applying zinc. Applying zinc sulfate suspension to dapog seedbeds does not require much time and

Table 7. Soil-test values and relative yields of long-term fertility experiments, IRRI, 1978.

Location	Soil pH	CEC[a]	Phosphorus (ppm)		Exchangeable potassium (ppm)	Relative yield (%)		
			Bray 2	Olsen		Without phosphorus	Without potassium	Without nitrogen
IRRI	6.6	36	6	7	466	100	100	84
Maligaya	6.6	29	6	0	24	61	86	—
Bicol	4.8	30	4	1	27	79	79	—
Visayas	6.4	54	6	0	103	74	100	—
Luisiana	5.6	22	6	4	42	93	100	63
Tanay	7.8	39	6	4	39	89	91	64

[a]Cation exchange capacity.

Table 8. Effects of different sources of fertilizer phosphorus on the grain yield of the first, second, and third consecutive crops of IR36 rice. Teresa (Rizal), Philippines, 1977–78.[a]

Treatment	Yield (t/ha)		
	1977 wet season (first crop)	1978 dry season (second crop)	1978 wet season (third crop)
No phosphorus	4.1 e	3.4 e	3.1 d
Superphosphate, 20 kg P_2O_5/ha	4.9 cd	5.7 ab	4.2 abc
Phosphal (HRP[b])	4.9 cd	4.6 cd	3.7 c
Superphosphate, 40 kg P_2O_5/ha	5.9 ab	5.8 a	4.2 abc
Phosphal	5.2 c	5.2 abcd	4.5 ab
Guano (LRP[c])	5.4 bc	4.5 d	4.1 bc
Superphosphate, 60 kg P_2O_5/ha	6.1 a	6.1 a	4.6 a
Phosphal	4.9 cd	5.5 abc	4.2 abc
Guano, 80 kg P_2O_5/ha	4.6 d	4.7 bcd	4.4 ab
Guano, 120 kg P_2O_5/ha	5.0 cd	5.3 abcd	4.7 ab

[a]Soil characteristics: pH (1:1) = 6.4, cation exchange capacity (meq/100 g) = 35.0, available phosphorus (ppm Bray 2) = 8.0, exchangeable potassium (ppm) = 16.0, total nitrogen (%) = 0.06, soil series /order: Binangonan/Vertisol. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Highly reactive phosphate. [c]Less reactive phosphate.

Table 9. Effects of different sources of fertilizer phosphorus on the grain yield of the first, second, and third consecutive crops of IR36 rice. Lucban (Quezon), Philippines, 1977–78.[a]

Treatment	Yield (t/ha)		
	1977 wet season (first crop)	1978 dry season (second crop)	1978 wet season (third crop)
No phosphorus	4.5 b	5.2 c	4.4
Superphosphate, 20 kg P_2O_5/ha	5.1 ab	6.0 b	4.7
Phosmak (HRP[b])	4.6 ab	6.2 ab	4.7
Superphosphate, 40 kg P_2O_5/ha	5.2 a	6.6 ab	4.6
Phosmak	5.0 ab	6.6 ab	4.7
Guano (LRP[c])	4.9 ab	6.0 b	4.5
Superphosphate, 60 kg P_2O_5/ha	5.3 a	6.6 a	4.6
Phosmak	5.2 a	6.3 ab	4.4
Guano, 80 kg P_2O_5/ha	4.9 ab	6.7 ab	5.0
Guano, 120 kg P_2O_5/ha	5.2 a	6.6 ab	4.8

[a]Soil characteristics: pH (1:1) = 5.5, cation exchange capacity (meq/100 g) = 20.0, available phosphorus (ppm Bray 2) = 6.0, exchangeable potassium (ppm) = 156, total nitrogen (%) = 0.14, soil series/order: Luisiana/Ultisol. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Highly reactive phosphate. [c]Less reactive phosphate.

labor; farmers prefer it to dipping seedlings after they are pulled from wet beds.

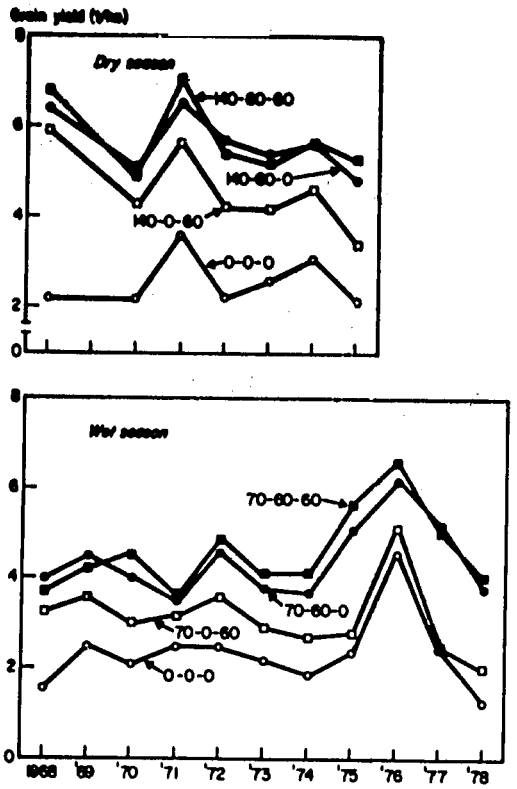
In direct-seeded rice, field application of zinc sulfate at 4.5 kg/ha and coating pregerminated seeds with zinc oxide at 1.6 kg Zn/ha produced more than 3 t rice. Lower rates were less effective.

RATES AND TIME OF APPLYING PHOSPHORUS AND POTASSIUM

Agronomy Department

New experiments were started in two farmers' fields in the 1978 wet season to evaluate response to nitrogen, phosphorus, and potassium. Soil-test data from samples taken before the experiment would be used to calibrate different phosphorus and potassium extraction procedures for response in the field.

Nitrogen, phosphorus, and potassium produced responses at both sites (Table 12). At



12. Long-term fertility experiment, Visayas, Philippines, 1968–78 dry and wet seasons.

Lucban, 60 kg N/ha increased yield 1.3 t/ha; at Bugallon 30 kg N/ha increased yield by 0.9 t/ha. At both sites, 30 kg P_2O_5/ha increased yield by more than 1 t; there was no further increase from 60 kg P_2O_5/ha. Response to 30 kg K_2O/ha was 0.7 t at Lucban and 2.0 t at Bugallon, with no further increase from 60 kg K_2O.

NITROGEN RESPONSE OF PROMISING LINES

Agronomy Department

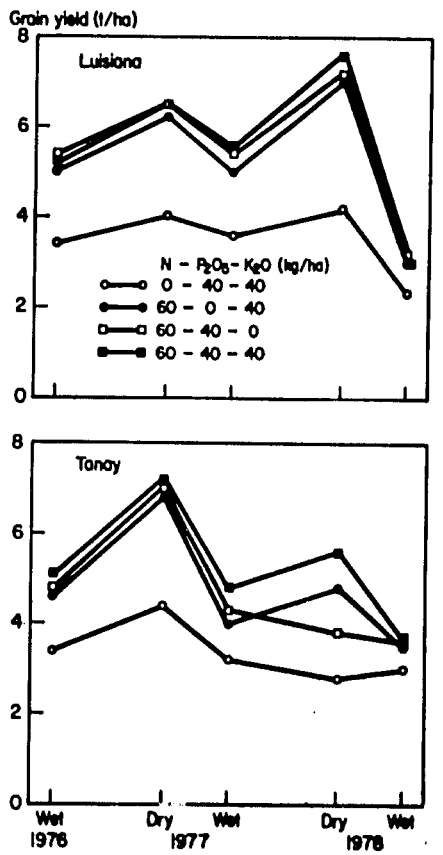
Experiments on 18 to 28 varieties or lines at 5 or 6 nitrogen rates are conducted on irrigated plots each year at IRRI, Bicol, Maligaya, and Visayas in the dry and wet seasons. Five-year-average (1974–78) yields of the five highest yielding entries at each site are presented in Figure 14.

In the dry season, the 120 kg N rate at IRRI averaged 7.2 t grain/ha, and 150 kg N produced 7.4 t. At the other sites the most practical rate appears to have been 90 kg N. In the wet season, 60 kg N/ha was most practical at all sites.

Table 10. Effects of different sources of fertilizer phosphorus on the grain yield of the first and second crops of IR36 rice, Luisiana (Laguna), Philippines, 1977–78.[a]

Treatment	Yield (t/ha) 1977 wet season (first crop)	Yield (t/ha) 1978 dry season (second crop)
No phosphorus	2.6	4.3 c
Superphosphate, 20 kg P_2O_5/ha	2.7	5.1 ab
NCR phosphate (HRP[b])	2.6	4.5 bc
Superphosphate, 40 kg P_2O_5/ha	2.6	5.4 a
NCR phosphate	3.0	5.0 ab
Guano (LRP[c])	2.7	4.8 abc
Superphosphate, 60 kg P_2O_5/ha	3.2	5.4 a
NCR phosphate	3.2	4.7 abc
Guano, 60 kg P_2O_5/ha	3.3	4.9 abc
Guano, 120 kg P_2O_5/ha	3.0	4.9 abc
	n.s.	

[a]Soil characteristics: pH (1:1) = 5.4, cation exchange capacity (meq/100 g) = 23.3, available phosphorus (ppm Bray 2) = 6.0, exchangeable potassium (ppm) = 78, total nitrogen (%) = 0.17, soil series/order: Luisiana/Ultisol. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Highly reactive phosphate. [c]Less reactive phosphate.

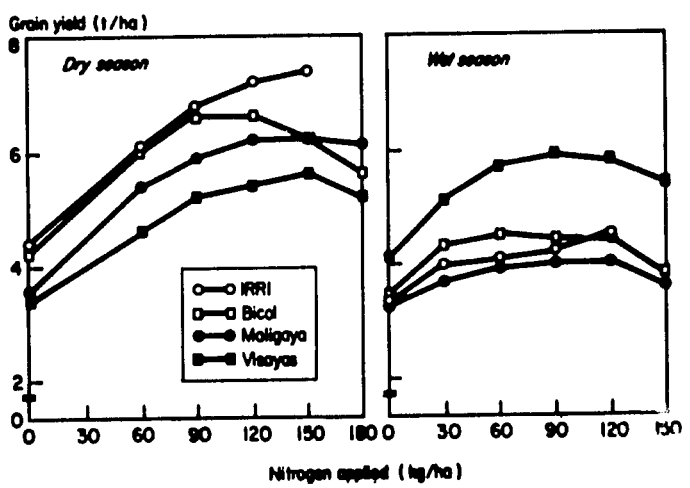


13. Long-term fertility experiment, Luisiana (Laguna) and Tanay (Rizal), 1976–78 wet and dry seasons. Nitrogen levels were 60 kg/ha in the wet season and 120 kg/ha in the dry.

Table 11. [illegible] on the response of transplanted and direct-seeded rice on a calcareous soil, Tiaong (Quezon), Philippines, 1978.

Zinc source	Application method	Rate (kg Zn/ha)	Grain yield[a] (t/ha)					
			Dry season			Wet season		
			IR26	IR34	Av	IR26	IR36	Av
			Transplanted rice					
Zinc oxide	Seedling dip	3.2	5.1 a	3.3 a	4.2	3.5 a	2.8 ab	3.2
Zinc oxide	Seedling soaking (dapog)	2.2	—	—	—	3.8 a	3.4 a	3.6
Zinc oxide	(do)	1.6	4.6 a	3.0 a	3.8	3.8 a	2.5 b	3.1
Zinc oxide	(do)	1.0	—	—	—	3.6 a	2.8 ab	3.2
$ZnSO_4 \cdot 7 H_2O$	Broadcast and incorporated	11.0	4.5 a	2.4 a	3.4	3.2 a	2.7 ab	3.0
$ZnSO_4 \cdot 7 H_2O$	Seedling dip (paste soil)	2.0	3.6 b	2.4 a	3.0	—	—	—
$ZnSO_4 \cdot 7 H_2O$	Broadcast (seedbed)	0.6	0.4 c	1.1 b	0.8	—	—	—
No zinc	—	—	0 c	0 c	0	0 b	0 c	0
			Direct-seeded rice					
$ZnSO_4 \cdot 7 H_2O$	Broadcast and incorporated	4.5	3.7 a	[b]		4.4	3.1	3.8
Zinc oxide	Seed coating	1.6	3.2 ab	[b]		4.6	2.8	3.7
$ZnSO_4 \cdot 7 H_2O$	Broadcast and incorporated	2.3	1.7 bc	[b]		4.1	2.8	3.4
$ZnSO_4 \cdot 7 H_2O$	Seed coating (paste soil)	0.5	1.6 bc	[b]		3.4	1.8	2.6
No zinc	—	—	0.5 c	[b]		0.9	0.6	0.8

[a]In a column in each cultivation method, any two means followed by the same letter are not significantly different at the 5% level. [b]No yield data because rat and bird damage and lodging were severe.



14. Nitrogen response of promising lines: av of 5 highest yielding entries at IRRI, Bicol, Maligaya, and Visayas, Philippines, 1974–78 dry and wet seasons.

ELECTRO-ULTRAFILTRATION TECHNIQUE OF EVALUATING POTASSIUM FERTILITY OF WETLAND SOILS

Agronomy Department

Electro-ultrafiltration (EUF) of soils is principally a combination of electrodialysis and ultrafiltration. It can be used in soil fertility studies to determine the solubility rate and the desorption rate of nutrient ions from soil particles. The soil is extracted with deionized water under an external electrical field. In a vacuum the soluble and desorbed ions are continuously removed from the extraction chamber together with the filtered effluent. Ions are collected at definite time intervals as different fractions of cation and anion filtrates.

An experiment was conducted in the 1978

Table 12. Phosphorus and potassium fertility trial using IR8. Luchan (Bicol) and Bugallon (Pangasinan), Philippines, 1978 wet season.

Treatment	Yield[a] (t/ha)	
	Luchan	Bugallon
60-60-60	4.4 a	4.4 bc
0-60-60	3.1 c	3.6 d
60-0-60	2.9 c	3.4 d
60-60-0	3.7 b	2.9 e
60-30-60	4.1 ab	4.7 ab
60-60-30	4.4 a	4.9 a
60-0-0	2.7 c	2.8 e
30-60-60	—	4.5 abc
60-60-60 + Zn	—	4.2 c
Soil analysis:		
pH (1:1)	5.6	7.4
Cation exchange capacity (meq/100 g)	20.0	32.0
Available phosphorus (ppm Bray)	2.0	10.0
Exchangeable potassium (ppm)	54.0	19.0

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

dry and wet seasons at the Bicol and Maligaya stations, where potassium soil-test values obtained through EUF correlated with rice yields.

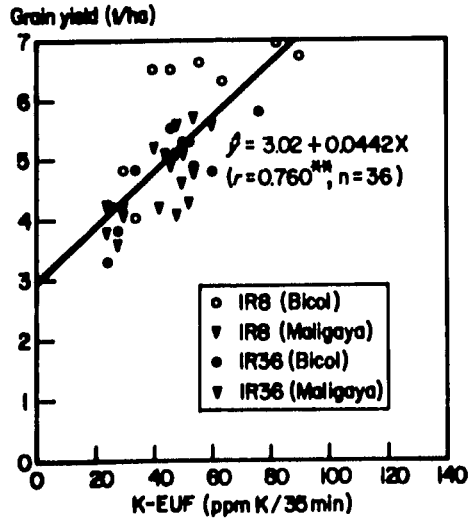
There were 3 replications of 3 treatments: no potassium, 60 kg K_2O/ha (basal), and 90 kg K_2O/ha (60 kg K_2O basal and 30 kg K_2O top-dressed at panicle initiation). All plots, with rice varieties IR8 and IR36, received 140 and 70 kg N/ha (140 in the dry season, 70 in the wet) and 60 kg P_2O_5/ha. The surface soils were sampled several times during the growing season from transplanting until maturity.

In the laboratory extractions 3 fractions of cation and anion filtrates were collected in one extraction of 35 minutes: fraction I — 10 minutes (5 minutes at 50 V, plus 5 minutes at 200 V); fraction II — 20 minutes at 200 V; fraction III — 5 minutes at 400 V. Extraction was carried out at 15°C. The cation filtrate was analyzed for potassium on the atomic absorption spectrophotometer.

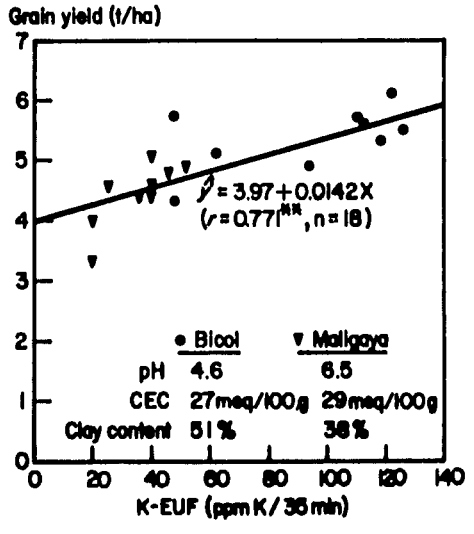
The K-EUF fraction I indicates the potassium concentration in the soil solution (intensity factor), whereas the K-EUF total (sum of the three fractions) shows the potassium-capacity factor.

The K-EUF total correlates well with the exchangeable potassium, as shown by the following regression equations:

$$\hat{Y} = 8.4 + 1.148\,X \text{ for Bicol } (r = 0.985^{**}, n = 180)$$
$$\hat{Y} = 20.6 + 1.116\,X \text{ for Maligaya } (r = 0.920^{**}, n = 180)$$
$$\hat{Y} = 17.2 + 1.068\,X \text{ for Bicol + Maligaya } (r = 0.960^{**}, n = 360);$$



15. The relationship between the potassium electro-ultrafiltration (K-EUF) total 30 days after transplanting and the actual yield at 2 sites. Philippines, 1978 dry season.



16. The relationship between the K-EUF total at 20 days after transplanting and the actual yield at 2 sites, Philippines, 1978 wet season.

where Y = exchangeable K in ppm (exchanged with 1N NH_4 acetate pH 7) and X = K-EUF ppm 35 minutes.

The dry-season potassium response was much more pronounced than the wet-season response.

Figure 15 shows the relationship between the K-EUF total 30 days after transplanting (1978 dry season) and the actual grain yield of the respective plots (av of 3 years, 1976, 1977, and 1978 dry season) for both varieties at both sites.

Figure 16 shows the same relationship between K-EUF total 20 days after transplanting (1978 wet season) and the actual grain yield (av of 3 years, 1976, 1977, and 1978 wet season) for IR36 at both sites.

At the later sampling dates, particularly at the heading stage when the level of available potassium sank to a minimum, the relationship between the potassium-soil test values and grain yield appeared weaker.

Soil and crop management

Rice culture

Agronomy and Multiple Cropping Departments

RICE CULTURE 266
Planting methods and nitrogen rate for continuous rice 266
Planting date and nitrogen rate 266
Differential tillage treatments in a second rice crop 266
One crop vs 2 crops vs 3 crops/year in continuous rice 268
Evapotranspiration and transpiration from paddy fields 268

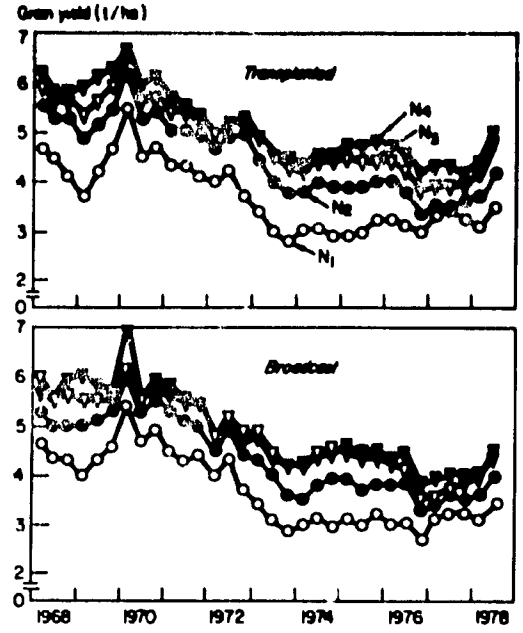
Planting methods and nitrogen rate for continuous rice (*Agronomy*). The continuous rice cropping experiment compares transplant and broadcast planting of six varieties at four nitrogen levels. Three crops are grown per year, and the 48th crop since 1962 was harvested in January 1979. Average yields for the last 32 crops (Table 1) show that at the 100 kg N/ha level in the 2 dry-season crops and the 60 kg N/ha for the wet-season crop, transplanting produced 0.2 t/ha or 4% more than broadcast planting. At lower nitrogen rates, differences were either less or nonexistent. Differences due to nitrogen rates were consistent in both planting methods (Fig. 1). Yields have declined over the last 10 years, possibly because of zinc deficiency.

Planting date and nitrogen rate (*Agronomy*). A date-of-planting experiment in which 4 varieties are planted monthly at 4 nitrogen levels has been going on for 10 years. IR8 and H-4 have been used in each test, and two improved varieties have been changed regularly. H-4 has shown a negative nitrogen response in the wet season, and IR8 has declined in yield in recent years because of increasing susceptibility to diseases (Fig. 2). The planting dates can be arrayed as follows based on these data: January, February, December, March, November, June, July, April, May, August, October, and September. The best nitrogen rate was 120 kg/ha for dry-season crops and 60 kg/ha for wet-season crops (Fig. 3).

Table 1. Av[a] yields of transplanted and broadcast rice at 4 nitrogen rates[b] for 32 crops. IRRI continuous cropping experiment, 1968–78.

Nitrogen rate (kg/ha)		Yield (t/ha)	
Dry season[b]	Wet season[c]	Transplant	Broadcast
0	0	3.7	3.7
60	30	4.5	4.4
100	60	4.9	4.7
150	90	5.1	4.8

[a]For 6 varieties. [b]Dry-season nitrogen rates for 1970–78, slightly lower in 1968–69. [c]Wet-season nitrogen rates for 1975–78, slightly higher in 1968–74.



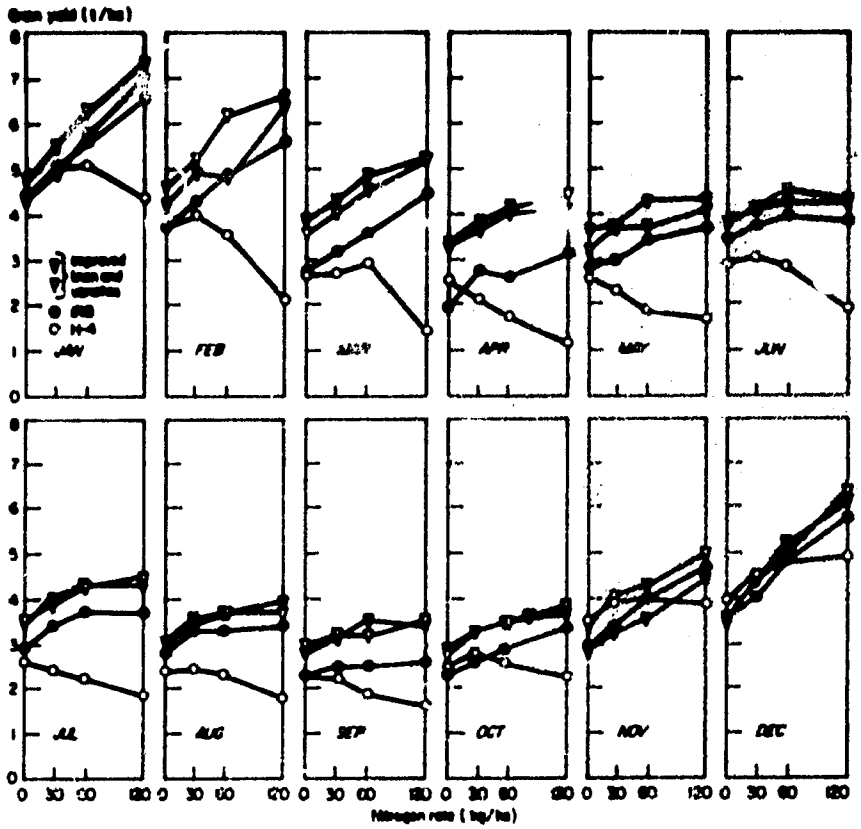
1. Yields of transplanted and broadcast rice in a continuous cropping experiment (av of 6 varieties for 32 crops, 3-crop moving av). IRRI, 1968–78. N1 = 0 N; N2 = 50 kg N/ha in the dry season, 30 kg in the wet; N3 = 100 kg N/ha in the dry season, 60 kg in the wet; N4 = 150 kg N/ha in the dry season, 90 kg in the wet.

Differential tillage treatments in a second rice crop (*Agronomy and Multiple Cropping*). A trial to determine the effect of the degree and duration of tillage (using carabao as the source of draft power) on the grain yield of a second rainfed rice crop was conducted at IRRI from October 1977 to January 1978.

At the rainfed site the total tillage time spent during land preparation varied with the tillage treatments (Table 2). Use of a hand tractor reduced the actual time spent on tillage. The no-tillage treatment had significantly higher weed weights 20 days after transplanting or seeding.

Although weed weights were low, hand-weeding time was extremely high. The numerous small weeds (predominantly *Fimbristylis littoralis*) were difficult to pull because water was insufficient and the soil had hardened.

The method of planting influenced the growth of weeds under rainfed conditions: weed weights were significantly lower in wet-seeded



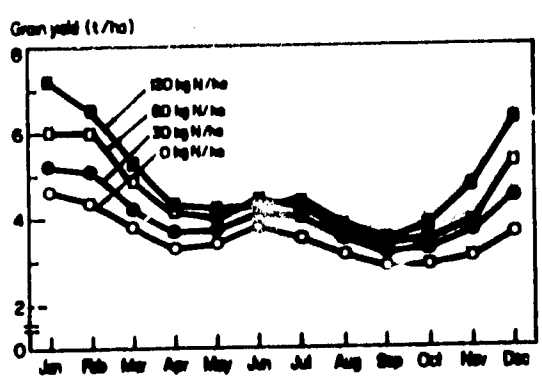
2. Nitrogen response of 4 varieties (av of 10 yr). Date-of-planting experiment, IRRI, 1968–77.

than in transplanted rice. Hand-weeding time with either method of planting, however, did not significantly differ. A similar trend was obtained on the irrigated site.

Grain yields at the rainfed site were not different among the tillage treatments but were significantly higher than the no-tillage treatment. Yield from direct-seeded rice was significantly higher than that from transplanted rice.

At the irrigated and rainfed sites, the total tillage time during land preparation followed a similar trend. An increase in the frequency of harrowing increased the total tillage time and thus increased the cost of labor during land preparation. Weed weights 25 days after transplanting or seeding did not differ significantly, but hand-weeding time varied with the tillage treatment.

The grain yield of IR36 was not affected by harrowing the paddy 1, 2, or 3 times at 5- to 7-day intervals under irrigated conditions, probably because the weed population (predo-



3. Average yields of the best 2 of 4 irrigated varieties planted each month for 10 years. IRRI, 1968–77.

Table 2. [illegible] IRRI, 1977–78.

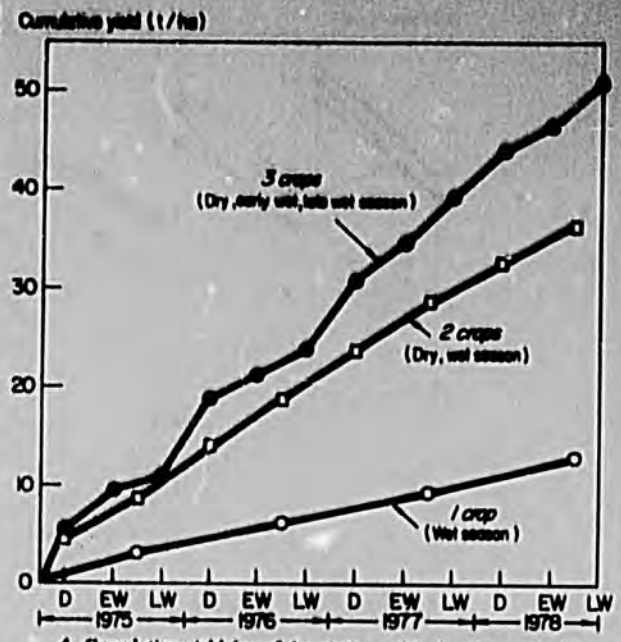
Tillage treatment[a]	Total tillage time (days/ha)	Weed wt[b] (g/m²)	Hand-weeding time (h/ha)	Grain yield (t/ha)
Rainfed, wet seeded				
1 plowing fb 3 harrowings	27	14 a	324 a	2.7 a
1 plowing fb 2 harrowings	24	17 a	481 ab	2.6 a
1 plowing fb 1 harrowing	18	21 a	367 a	2.5 a
1 plowing + 1 harrowing[c]	13	19 a	574 ab	2.3 a
1 harrowing	11	17 a	533 ab	2.3 a
No tillage[d]	—	62 b	862 b	1.8 b
1 plowing fb 3 harrowings (hand tractor)[f]	17	4	321	2.1
Irrigated, transplanted				
1 plowing fb 3 harrowings	18	3 a	12 a	4.1 a
1 plowing fb 2 harrowings	17	2 a	14 ab	4.1 a
1 plowing fb 1 harrowing	11	8 a	12 ab	4.1 a
1 plowing + 1 harrowing	12	7 a	16 abc	3.9 ab
1 harrowing	4	13 a	21 bc	3.8 ab
No tillage[e]	--	9 a	27 c	3.4 b
1 plowing fb 3 harrowings (hand tractor)	11	4	7	4.2

[a]Data based on average of 2 methods of planting in 3 replications, except grain yield on the rainfed site, which is an average of only 2 replications. In each column under rainfed or irrigated rice, means followed by a common letter are not significantly different at 1% level. [b]fb = followed by, at interval of 5–7 days. [c]Taken 20 days after transplanting (DT) or seeding on the rainfed site and 25 DT on the irrigated site. [d]Harrowing was done on the same day. [e]Sprayed with 0.6 kg a.i. paraquat/ha shortly before transplanting or seeding. [f]Unreplicated. [g]Spot weeded just before transplanting or seeding.

minantly *Monochoria vaginalis*) was low. The no-tillage plots gave the lowest yield but that yield was not significantly lower than that for the 1 plowing plus 1 harrowing and the 1 harrowing treatments. Yield in plots where a hand tractor was used was comparable with that with a carabao when 1 plowing was followed by 3 harrowings.

Results of the study indicated that reducing the time spent in land preparation can reduce the turnaround time without reduction in the grain yield of the second crop.

One crop vs 2 crops vs 3 crops/year in continuous rice (*Agronomy*). The frequency of growing irrigated rice 1, 2, or 3 times/year has been compared for about 15 years on the same



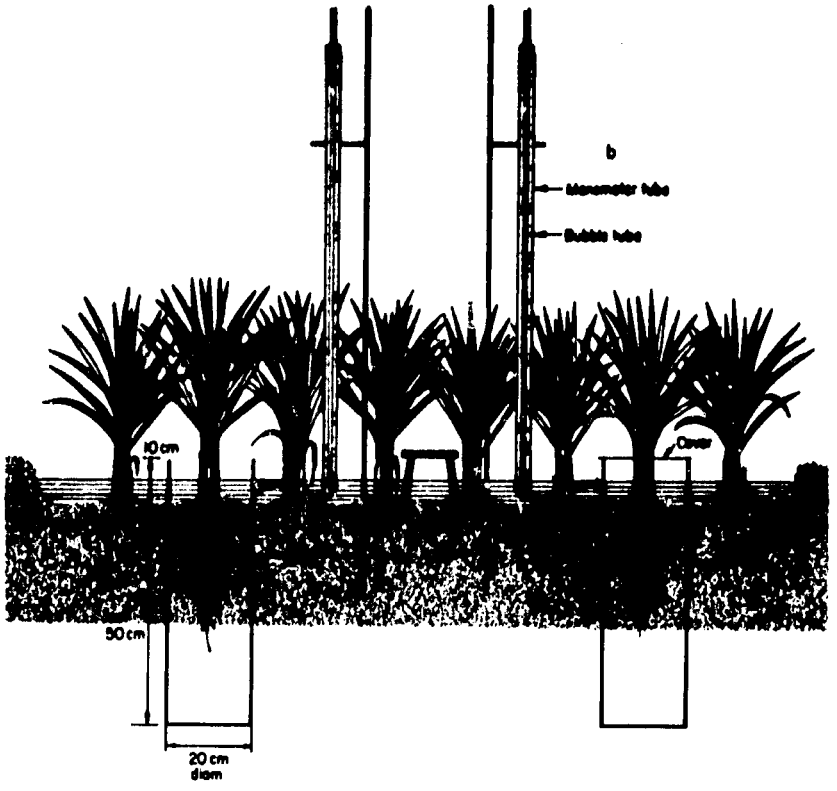
4. Cumulative yield (av of 4 varieties and 2 planting methods) of rice grown under different crop cycles per year. IRRI, 1975–78.

plots. The dry-season crop is planted in January, the early wet-season crop in May, and the late wet-season crop in September. The single wet-season crop is planted in July. Plots grow weeds when not planted to rice. Cumulative yields for 4 years, 1975–78, are shown in Figure 4 and the average by crop in Table 3. Allowing the land to rest by growing weeds did not increase the yields of the wet-season crops. Total production was closely related to the number of crops grown.

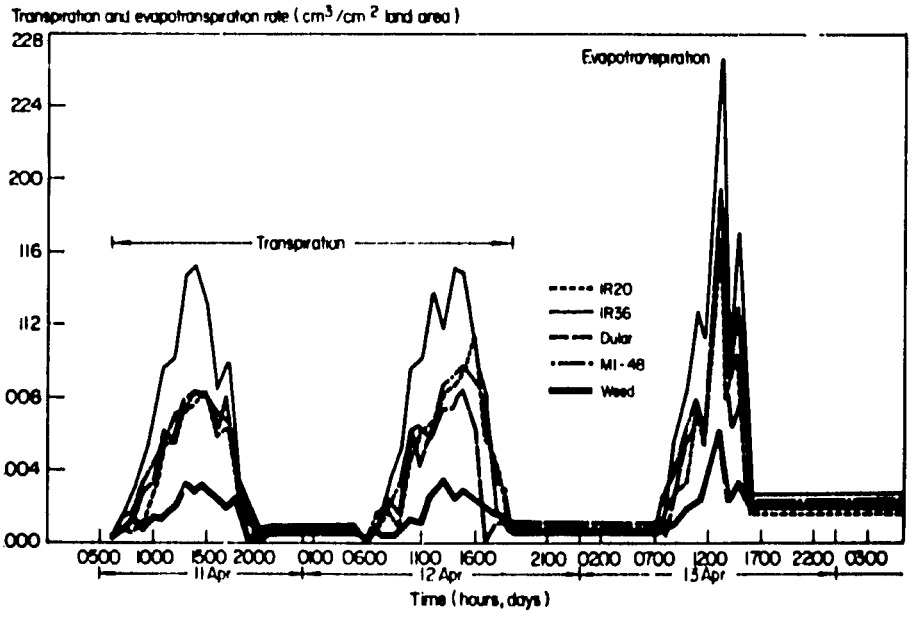
Evapotranspiration and transpiration from paddy fields (*Agronomy*). *Instrumentation*. Several methods have been used for measuring evapotranspiration (ET) and transpiration (T) of rice in the field. Large weighing lysimeters were accurate but expensive; less

Table 3. Grain yield (av of 4 varieties and 2 planting methods) of rice grown under different crop cycles per year. IRRI, 1975–78.

Crop cycle	Grain yield (t/ha)			
	Dry season	Wet season		Total
		Early	Late	
Three crops	5.7	3.8	3.2	12.7
Two crops	5.4	3.6		9.0
One crop		3.1		3.1



5. Microlysimeters for measuring evapotranspiration (a) and transpiration (b). IRRI, 1978.



6. Transpiration and evapotranspiration from rice fields on 3 clear days 11, 12, 13 April 1978. Values are the mean for 8 microlysimeters. IRRI, 1978 dry season.

Table 4. Water loss rate of 4 rice varieties. Values are the mean for 8 microlysimeters. IRRI, 1978.

Period	Water loss (mm/day)					Pan evaporation (mm/day)	Solar radiation (cal/cm² daily)
	IR56	IR30	Dular	M1-48	Av		
			Transpiration				
11 Apr 1978	10.27	6.40	6.96	6.96	7.06	7.9	600
12 Apr 1978	10.96	7.66	6.12	7.79	8.06	6.6	600
			Evapotranspiration				
13 Apr 1978	10.03	8.96	8.17	8.66	9.6	8.8	603

expensive methods were likely to be time-consuming and less accurate. An attempt to develop a simple, inexpensive method that does not sacrifice sensitivity and accuracy was made.

The resulting microlysimeter is shown in Figure 5. The unit consists of a polyvinyl chloride cylinder 20 cm in diameter, 65 cm long, with a small hole 5 cm below the upper rim for attaching the water reservoir or manometer to the cylinder through plastic tubing. A predetermined water level is maintained in the microlysimeter using the Mariotte System. The amount of water lost as T or ET (with or without cover) is delivered from the reservoir or manometer and is measured at desired time intervals. Results of preliminary testing of the device for wetland rice have been encouraging.

Measurement. Field measurements of T and ET were made in the 1978 dry season. Hourly measured values of T or ET on three consecutive clear days are presented in Figure 6. The microlysimeter was highly sensitive to diurnal changes in T and ET rates. Total water loss throughout the day (T on 11 and 12 April and ET on 13 April) for 4 rice varieties are given in Table 4.

Environment and its influence

Plant Physiology Department

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TEMPERATURE

Effects of temperature and humidity on high-temperature-induced sterility. The effects of temperature and vapor pressure deficit on sterility induced by high temperature were examined in artificially lighted cabinets, using the method reported in the 1977 Annual Report. N22 (a heat-tolerant variety) showed higher fertility than IR9129-457-1 (a susceptible line) in all treatments except one — 35°/21°C with a 36-mb vapor pressure deficit (Table 1). The trends in the effects of temperature and humidity were similar to those of the previous experiment (1977 Annual Report).

The pollen grains and germinated pollen grains on a stigma were counted just after anthesis. Figure 1 shows the relationship between fertility and pollen grain numbers for the two varieties. As in a previous study (1976 Annual Report), sound spikelets were those with more than 20 pollen grains or more than 10 germinated pollen grains. In N22, there was no problem with pollen shedding in high temperatures and various humidities, and pollen germination correlated well with fertility. It may be assumed, then, that in N22 the poor germination ability of pollen grains on a stigma is the major cause of sterility.

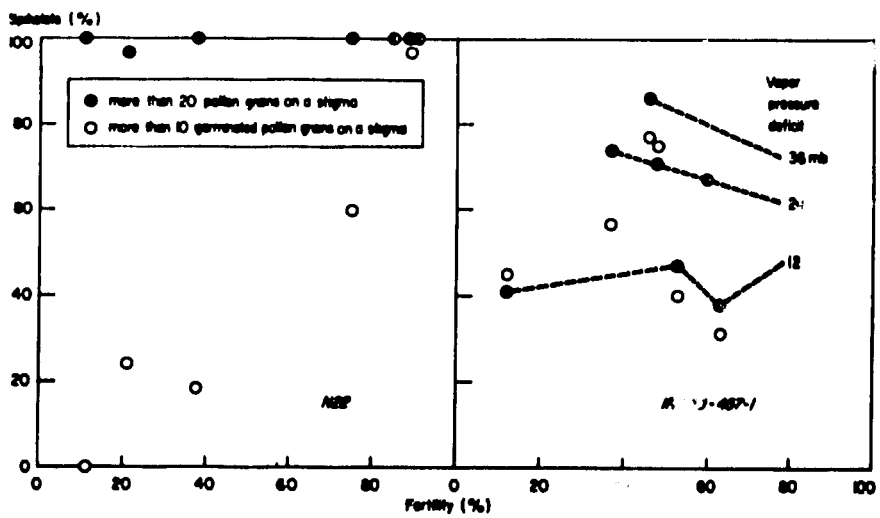
In IR9129 no clear correlation was observed between fertility and number of pollen grains or germinated pollen grains on a stigma (Fig. 1). Pollen shedding on a stigma was not plentiful but germinability was rather high. That may indicate that the sterility occurs after pollen germination. Although an increase in the vapor pressure deficit clearly increased the percentage of sound spikelets, the increase did not improve fertility (Fig. 1).

Table 1. Effect of temperature and 3 levels of vapor pressure deficit on fertility. IRRI, 1978.

Day/night temperature (°C)	Fertility (%)		
	12 mb	24 mb	36 mb
		N22	
29/21	91.1	89.1	—
32/21	85.2	74.7	—
35/21	20.7	38.1	11.2
		IR9129-457-1	
29/21	63.4	50.2	—
32/21	53.3	46.1	—
35/21	12.2	37.2	45.6

SOLAR RADIATION AND WATER BALANCE

Evapotranspiration and water requirement of wetland rice (a model). Evapotranspiration of a rice crop may be analyzed and described in two ways. First, the energy exchange characteristic of a rice canopy varies with the stage of growth, and is independent of the level of solar radiation. Second, evapotranspiration of a rice crop at a given time is a function of the incident solar



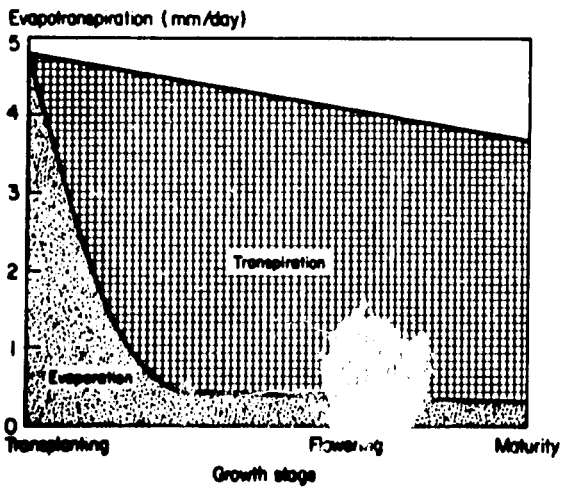
1. Relation between fertility and the number of pollen grains or germinated pollen grains on a stigma. IRRI, 1978.

radiation at that time and is affected by weather conditions.

The ratio of net radiation to total incoming shortwave radiation varies from 0.70 at the early stages of growth to 0.55 at ripening (1977 Annual Report). This information allows us to estimate potential evapotranspiration at different stages of growth under a constant level of solar radiation. At an early stage of growth, the ratio of evaporation to transpiration from free water surfaces is high, but it decreases as leaf area increases. Japanese workers have found that the ratio of transpiration to evapotranspiration reached a plateau at a leaf area index of 2.5. With this information, it is possible to construct an evapotranspiration model of a rice crop under a constant level of solar radiation (Fig. 2).

It is often said that the water requirement of a rice crop is highest at the reproductive growth stage. But it is difficult to determine whether the increased evapotranspiration at that stage is caused by the plant's life process needs or by high levels of solar radiation. The model indicates that evapotranspiration in a rice crop is greatest during early growth and declines as growth advances if the level of incident solar radiation remains constant.

It is likely that, in the Philippines and other parts of tropical Asia, measured evapotranspiration of a rice crop is highest at the reproductive growth stage if incident solar radiation or evaporative demand is also highest at that time. Thus, increases in evapotranspiration during the reproductive growth stage are attributed to climatic changes rather than to changes in needs in the growth process.



2. Evapotranspiration model of an irrigated rice crop under a constant level of solar radiation (400 cal/cm² per day). IRRI, 1978.

Table 2. Average water requirement of a paddy field in the Philippines. IRRI, 1978.

	Wet season	Dry season
Solar radiation* (cal/cm² per day)	387	463
Evapotranspiration (mm/day)	4	5
Seepage and percolation (mm/day)	2	4
Daily total water requirement (mm)	6	9
Monthly total water requirement (mm)	180	270

*Average values for the wet season (July-November) and the dry season (January-May).

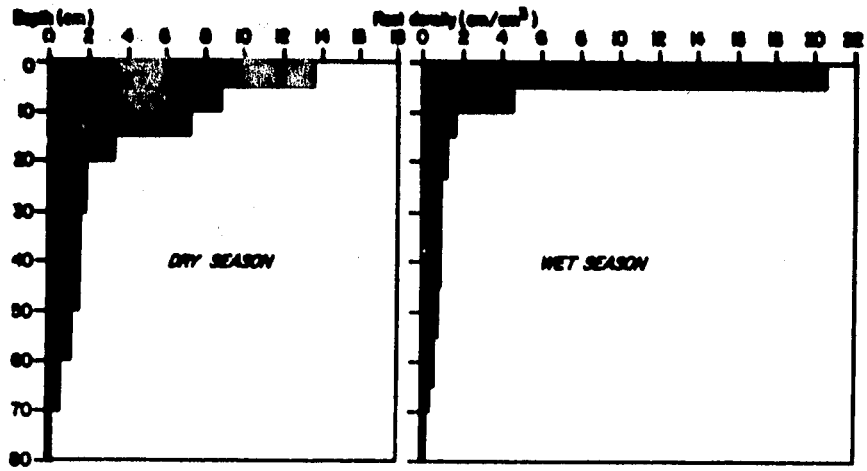
Water requirement of rice crops in the Philippines. The water requirement of a rice crop after the field has been prepared for planting is the sum of evapotranspiration, and seepage and percolation. For Philippine soils, mean rates of seepage and percolation for 10 field sites ranged from −1.0 mm to 17.2 mm/day. The mean values for the sites were about 2 mm/day in the wet season and 4 mm/day in the dry.

Potential evapotranspiration can be estimated from solar radiation data for the wet season (July-November) and the dry season (January-May) (1977 Annual Report).

The daily and monthly water requirements estimated on this basis are in Table 2. The estimates appear to agree with a popular assumption that the water requirement for 1 rice crop is 1,000 mm, assuming that the crop duration is 4 months and land preparation requires 200 mm.

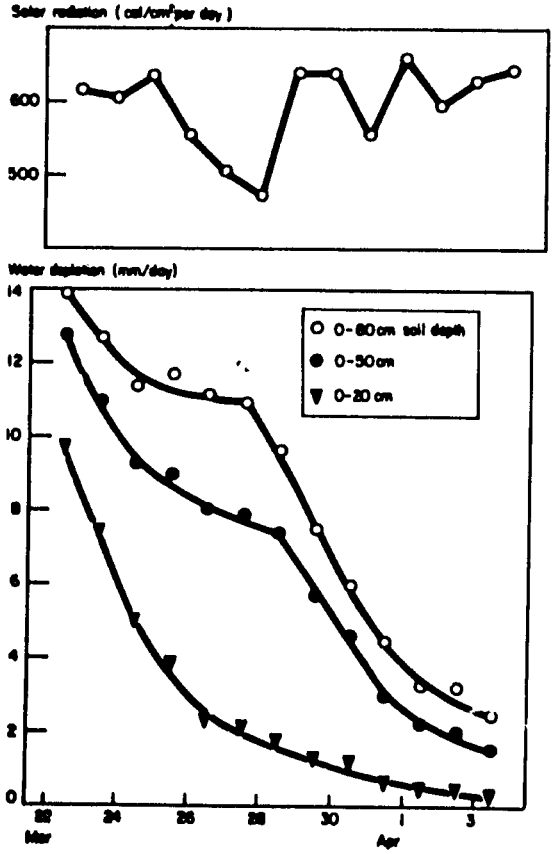
Water absorption of dryland rice. Figure 3 shows the root density profiles of a dryland rice variety (OS4) during the dry and wet season. The roots penetrated deeper in the dry season than they did in the wet even when irrigation was adequate.

The rate of water depletion from the field of OS4 was measured daily for a number of days after irrigation on 21 March (Fig. 4). Daily total (0-80 cm) water depletion by evapotranspira-



3. Root density profile of OS4 in different seasons. IRRI, 1978.

tion fluctuated with the amount of solar radiation until 27 March. There was no apparent water stress during this period. The water depletion rate declined sharply after 28 March. The decline represents drought stress.

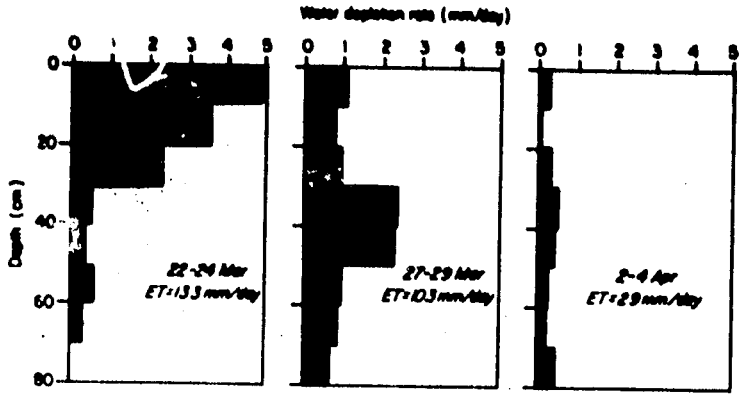


4. Solar radiation and water depletion rate in the field of OS4 after irrigation on 21 March. IRRI, 1978.

During the first few days after irrigation, water was absorbed primarily from the upper soil layers; that is, above the 30-cm depth (Fig. 5). The soil layers from which water was absorbed gradually became deeper. On 27–29 March, when drought stress was just beginning, water was absorbed mostly from a depth of 30–50 cm. On 2–4 April, under stronger stress, plants were able to absorb water at a very low rate, even though soil moisture content below 50 cm was still high (more than 40%). Low absorption at this stage might be attributable to stomatal closure.

Figure 6 shows the relationship between root density (ρ) and maximum water absorption rate (q) by unit length of root. The absorption rate decreased with increasing root density. Thus, absorption efficiency by unit length of root was rather low at the high root density layer near the soil surface and increased with depth. It is to be noted that water absorption by roots varied with root density as well as with soil moisture content.

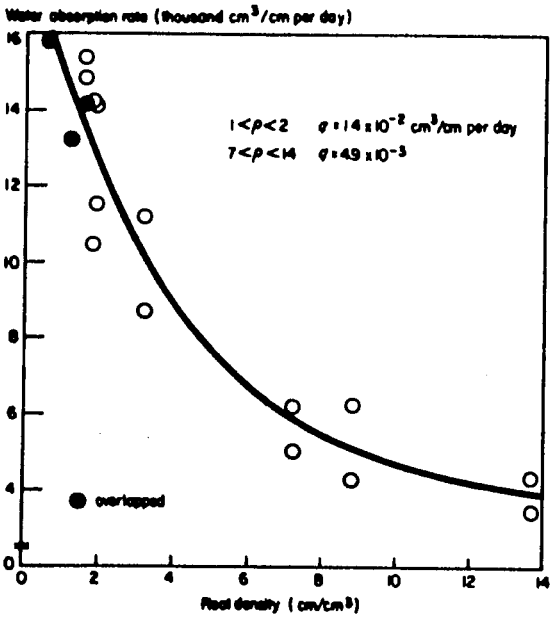
Mechanical impedance of root growth. The root elongation rate of rice seedlings is limited by penetration resistance in water-saturated soil (1977 Annual Report). It may also be affected by moisture content in soil less than saturated. Experiments were conducted to clarify the relationships between bulk density, moisture con-



5. The depth distribution of the root absorption rate of OS4 at 3 times after irrigation on 21 March. IRRI, 1978.

tent, and penetration resistance of soil, and root elongation rate by the core sampler method (1977 Annual Report).

Soil penetration resistance increased with an increase in soil bulk density (Fig. 7). The increase was remarkably high at a soil moisture content below 25%. The root elongation rate decreased with increased bulk density, reaching a plateau at bulk density below 1.2 g/cm³ and moisture content above 30%, which was probably the upper limit of the root elongation rate. The root elongation rate increased with an increase in soil moisture content when the bulk density remained constant.



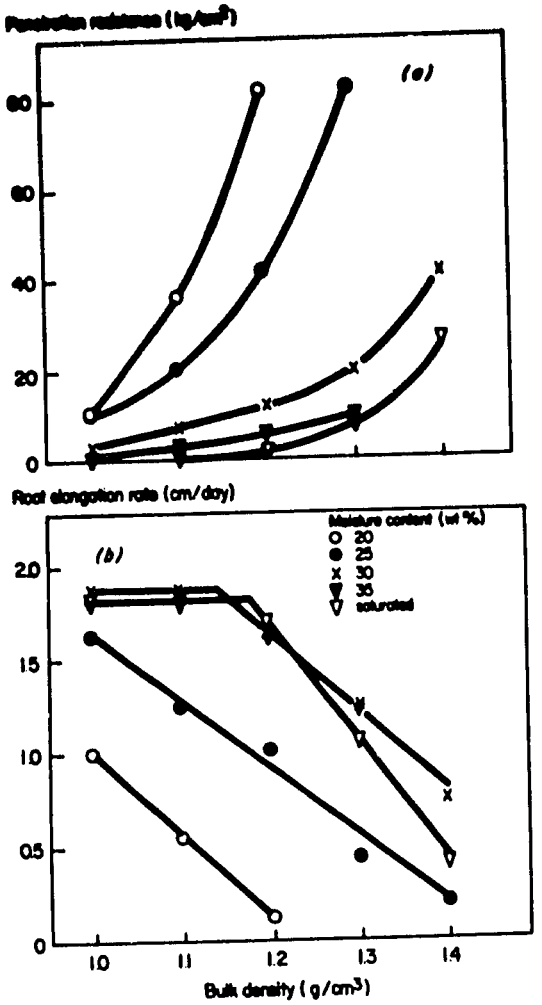
6. Relationship between root density (ρ) of OS4 and water absorption rate (q) by unit length of root. IRRI, 1978.

Consequently, the root elongation rate at the same level of soil penetration resistance (10 or 20 kg/cm²) was highest from 25 to 30% soil moisture content (approximately from 3.0 to 0.4 bar) (Fig. 8). Decrease in the elongation rate at the lower moisture content is caused by the shortage of water, and the decrease at the higher moisture content may be caused by a shortage of oxygen.

OXYGEN REQUIREMENT

Oxygen requirement for emergence of seedlings. Flood tolerance, as well as drought tolerance, is important to the early growth of rainfed rices. Flood tolerance varies with variety and environmental temperature. A phytotron experiment demonstrated the varietal differences in emergence ability of seedlings from floodwater and in different temperature regimes (Fig. 9). On days with good weather the water temperature rose 4- C higher than the air temperature.

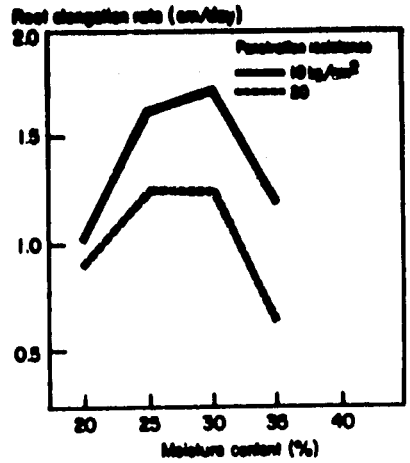
Four indica and three japonica varieties were used. The indicas were IR36, a typical IRRI variety; E425, a dryland rice; Peta, a traditional-type indica; and Leb Mue Nahng, a deepwater rice. The japonicas were Koshihikari and Reimei, both wetland rices; and Hiderishirazu, a dryland rice. Improved wetland varieties of both indicas and japonicas showed higher flood tolerance than dryland rices, the traditional-



7. a) Relationship between penetration resistance and bulk density of soil at different moisture contents. b) Relationship between root elongation rate and soil bulk density at different moisture contents. IRRI, 1978.

type indica, and the deepwater rice. Seedling emergence was strongly inhibited at a day/night temperature regime of 35°/27°C, except in Reimei.

Calcium peroxide (in plaster of Paris) as a seed coating is known to supply oxygen to seeds. Its application to rice seeds resulted in a dramatic improvement in emergence from floodwater of all the indica and japonica varieties tested (Fig. 10), indicating that emergence failure is caused primarily by low oxygen supply. It

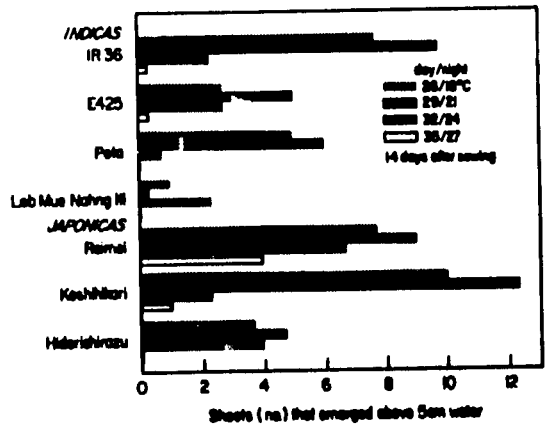


8. Relationship between root elongation rate and soil moisture content at constant penetration resistance. IRRI, 1978.

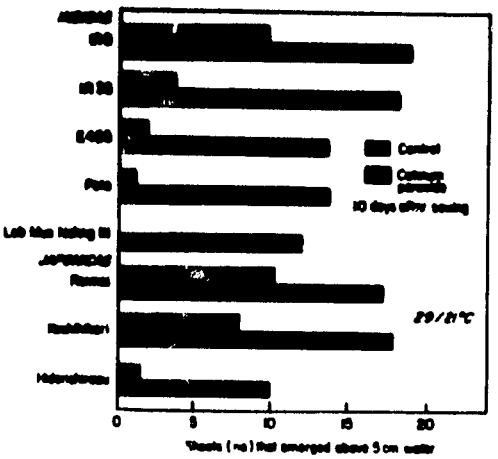
appears that calcium peroxide can be used to improve seedling emergence in flooded land.

"Sudden wilting" in Korea. In 1976, the Korean high-yielding variety Yushin suffered from *sudden wilting*, a newly reported disorder. Other varieties appeared to be healthy in similar or identical conditions. Some visible symptoms of sudden wilting are orange leaf discoloration, development of roots from nodes above the soil surface, total root rot, and lodging.

Two experiments with 3 varieties were conducted in an attempt to determine the cause of the disorder. The number and size of air spaces



9. Emergence of rice seedlings from flooded water at different temperatures. IRRI, 1978.



10. Effect of calcium peroxide on seedling emergence from flooded water. IRRI, 1978.

in each internode were estimated (Table 3). At the fifth internode from the top all tested varieties had a similar number of air spaces, although the spaces in Tongil were larger. At the fourth internode Yushin had only two air spaces, and one of its parents, IR262, had no air spaces at all. Tongil, which did not suffer from the disorder, had 31 air spaces.

Soil-cultured plants of the three varieties were then treated with paraffin to reduce the oxygen supply from the air to the root tissues through the soil-water system. Liquid paraffin was applied to the water surface to a thickness of 5–6 mm at 47 days after seeding. Sudden wilting was observed in Yushin and IR262 about 1 week after the treatment, but Tongil remained healthy.

The experiments suggest that under certain weather and soil conditions a limited ability for oxygen transport in Yushin and IR262 may

Table 3. Air spaces in Korean varieties. IRRI, 1978.*

Variety	Air spaces				
	No.			Mean diameter (mm)	
	3d	4th	5th	4th	5th
Tongil	0	31	31	0.15	0.31
Yushin	0	2	29	0	0.24
IR262	0	0	31	0	0.24

*Ordinal numbers refer to internode position, counting from the top.

Table 4. Air spaces of IR36 under dryland and wetland conditions, IRRI, 1978.*

Condition	Air spaces					
	No.			Mean diameter (mm)		
	3d	4th	5th	3d	4th	5th
Dryland	0	4	21	0	0.09	0.19
Wetland	5	26	28	0.15	0.22	0.23

*Ordinal numbers refer to internode position, counting from the top.

cause suffocation of root tissues, weaken the metabolic activity of the tissue, and induce root rot, with subsequent sudden wilting and lodging.

Internode air space in dryland and wetland conditions. Air space formation in internodes of rice plants differs with environmental conditions during growth and with the variety. Table 4 shows the results of an IRRI experiment to determine the effect of dryland and wetland conditions on air space in the variety IR36. In the dryland field, the air spaces were fewer and smaller than those in the wetland field, and were observed only in the lower internode positions.

Rice roots can easily take oxygen from the air between soil granules in a dryland field; hence the plants develop only a few narrow air spaces in the lower internodes. Flooding makes it difficult for rice roots to take oxygen from their environment. To meet the oxygen deficit, the plants develop more and larger air spaces and in the higher internodes. The ability to develop air spaces gives rice plants a higher tolerance for flooding than is possessed by upland crops.

Air space in deepwater rices. Deepwater rices have adapted to growing in seasonally deepwater areas. They can rapidly elongate at the internodes as the water level rises. Some can grow in more than 4 m of water. Consequently, the translocation of oxygen from the aerial parts of the plant through the submerged parts to the roots is a large undertaking.

Table 5 shows the number and sizes of air spaces in the different internodes of 4 deepwater rice varieties growing in 45 cm of water at the time of sampling. All examined internodes, except the first internode of BKN6986-147-2, had approximately 30 air spaces. This number appears to be near the maximum for rice plants.

Table 5. Air spaces in deepwater rice, IRRI, 1978.[a]

Variety	Air spaces							
	No.				Mean diameter (mm)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
[illegible]-147-2	0	29	28	—[b]	0	0.46	—	
C4-[illegible]	30	32	32	30	0.29	0.60	0.60	0.62
IR442-3-[illegible]	29	30	28	30	0.21	0.46	0.57	0.59
Leb Mue Nahng 111	26	26	—	—	0.32	0.64	—	—

[a]Ordinal numbers refer to internode position, counting from the top. [b]Air space was not estimated because the internode was very short.

The diameter of the air spaces was approximately twice the diameter of air spaces in ordinary rice varieties (Table 3.4). The abundance of fully developed air spaces undoubtedly facilitates oxygen transport through the long submerged internodes of deepwater rices.

Postproduction technology and management

Agricultural Engineering and Plant Pathology Departments

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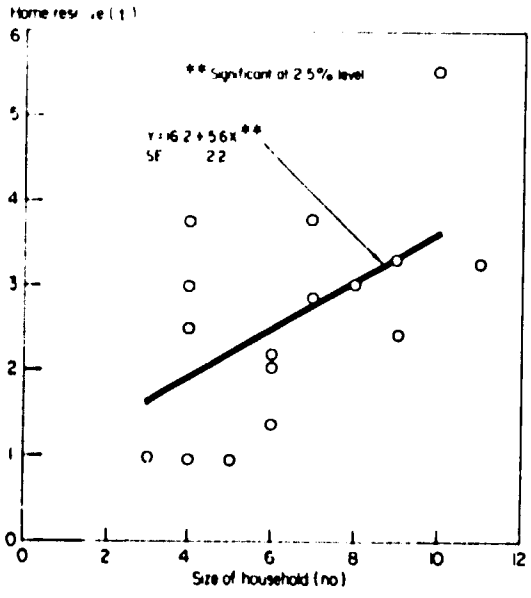
HOUSEHOLD STORAGE OF PADDY

Agricultural Engineering and Plant Pathology Departments

During 1977–78, surveys and technical evaluation trials to examine the nature and characteristics of paddy storage facilities and practices were carried out on farms at two sites in Iloilo and Luzon, Philippines. The 87 farm households included in the survey produced an average of 7.5 t paddy/year, of which 3.6 t was retained for home consumption. About 70% of retained paddy was used for home consumption and 5% for seed; about 24% was held for later sale. The relationship between the number of individuals in each household and the quantity reserved for home consumption is shown in Figure 1. On the average, 280 kg paddy/household member was retained. The intercept value — 810 kg — was the average minimum quantity held in reserve for the entire year. Household size varied from 3 to 11 persons, with an average of 6 adult equivalents. Storage capacity required for this number of consumers would be for 2.5 t or 4.5 m^3.

Field survey. Information on postharvest and storage practices, and disposal of paddy production was gathered by interviews. The data indicated a wide range in types of storage facilities. Seventy percent of the farmers stored paddy in sacks, drums, wooden boxes, bamboo baskets, and other types of containers. The remainder used small granaries where the grain was usually stored in sacks (Fig. 2). Total investment in storage facilities was less than US$40/ household or about $0.04/bag per year. Asked about improved facilities, 90% of the farmers indicated they were not needed.

The most serious qualitative loss was from rodents. About two-thirds of the respondents



1. Relationship between size of household and paddy held for home reserve. Philippines, 1978.

2. Bamboo (above) and wooden (below) granaries, La Union and Apayao-Kalinga provinces, Philippines.