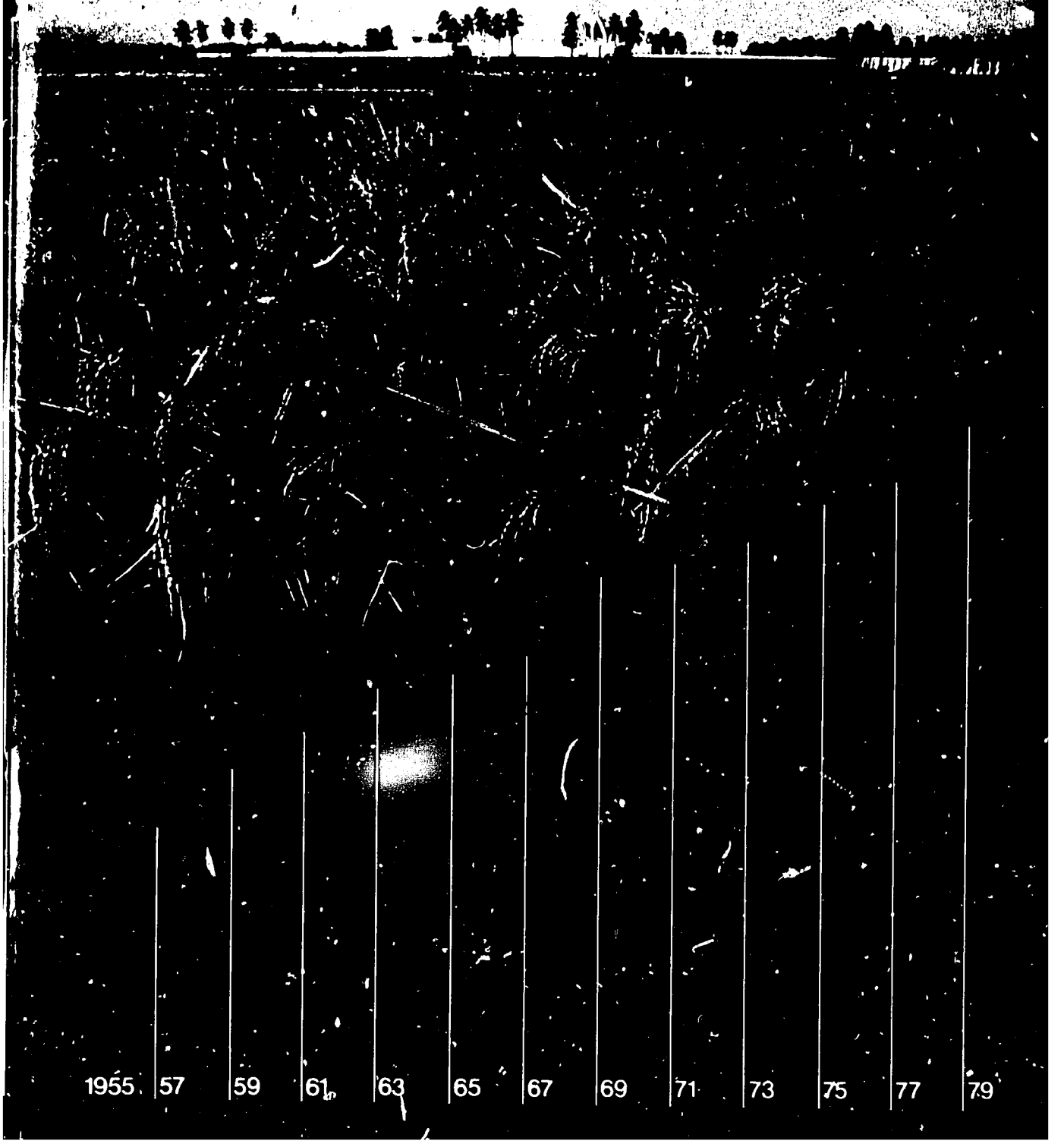
Research Highlights for 1981

International Rice Research Institute



PN-AAL-349
ISN = 14043

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

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

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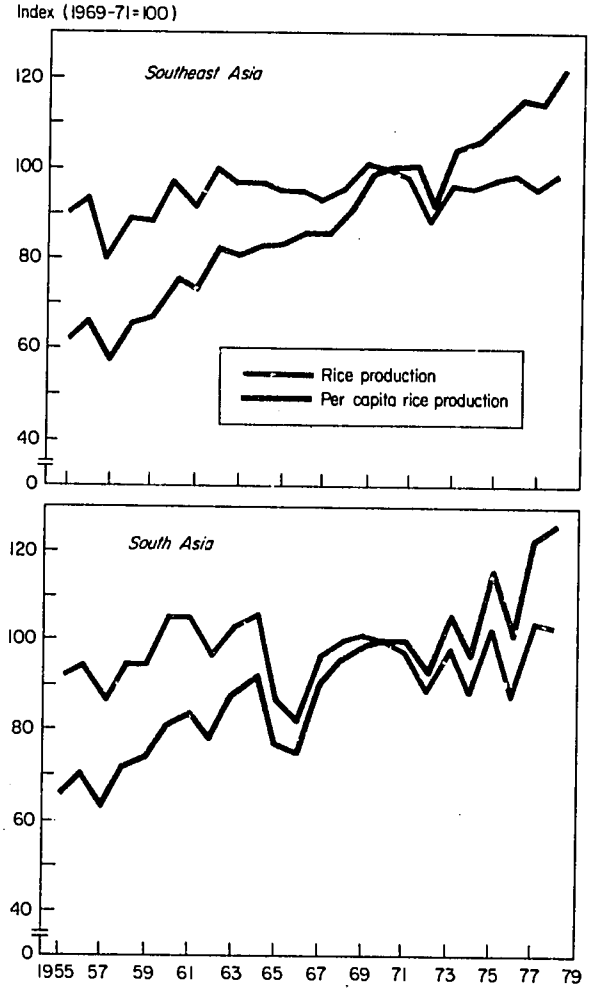
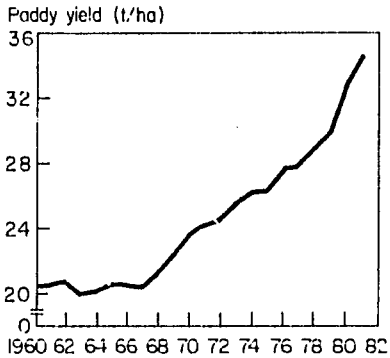
MOVING AHEAD BUT STANDING STILL

Rice production in most Asian countries during the past decade has continued to rise. Total production has increased and so has yield per hectare. For most countries, however, the increases have done no more than keep pace with population growth — so that while in terms of rice production we seem to be moving ahead rapidly, in terms of the rice available to each individual we were doing little better than standing still (Fig. 1).

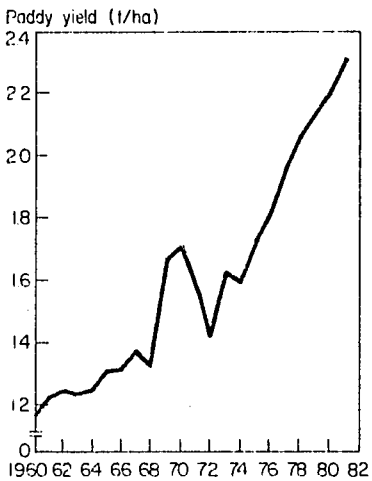
There has been a steady increase in the mean yield in Indonesia

1. Trends in rice production and per capita rice production in South and Southeast Asia.





2. Yields of paddy in Indonesia have steadily moved higher since 1968. The first modern variety was released in 1967. Varieties resistant to brown planthopper biotype 1 were released in 1975; varieties resistant to biotype 2, in 1976. Peta Baru 36 (IR36) was released in 1977.



3. Paddy yields in the Philippines have increased steadily since 1972, a year marked by an unusual combination of heavy rains and severe drought. IR36, which in 1981 became the world's most widely grown rice variety, was released by the Philippine Seed Board in 1976

since 1967 (Fig. 2), in the Philippines since 1972 (Fig. 3), and in Burma since 1978 (Fig. 4). Progress in Indonesia and Burma since 1978 has been outstanding.

Indonesia, for many years a major importer of rice, produced more rice than it consumed in 1981 — although rice imports were continued to build reserves. This success is to the credit of the Indonesian research and extension agencies involved. IRRI is proud to have shared in that success. We have contributed through our training programs (in which Indonesians have participated more than any others), through our cooperative projects in Indonesia, and through the success of Peta Baru 36, the IRRI-bred variety (IR36) now grown on more than 60% of the irrigated rice area in Indonesia.

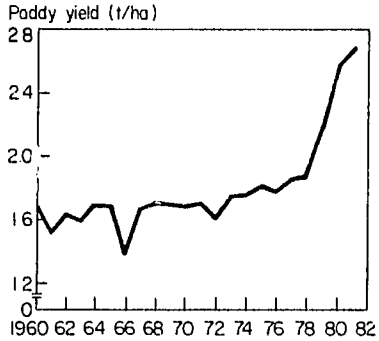
As rice yields and production have increased in Indonesia, so has per capita consumption of rice — from about 115 kg/person per year in 1970 to 130 kg in 1980.

Burma, Indonesia, and the Philippines give the satisfying feeling of "moving ahead." Other areas still remind us that we are "standing still." For parts of India and Bangladesh, rice production lags behind population growth. In the Punjab in Northern India, rice yields have increased steadily since 1960 and in recent years have averaged more than 4 t/ha. In Eastern India in 1979, the latest year for which statistics have been published, average yields were still less than 2 t/ha (Fig. 5). Similarly in Bangladesh, although yields have tended to increase during the past decade, the national average yield was still only 2 t/ha in 1980 (Fig. 6).

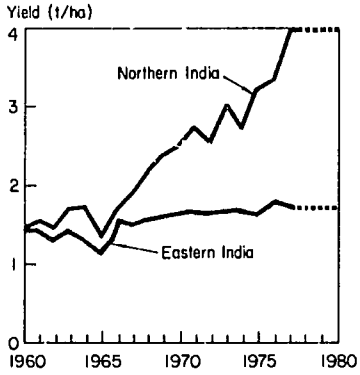
We often get the comment that the modern IR rices are suited only to well-irrigated fields and have little impact elsewhere. Our

These terraced rice fields in Bali, Indonesia, present an example of Indonesian farmers' adoption of modern high yielding rice varieties. In 1981 an estimated 90% of the rice area in Bali was planted to IR36.

IR36 on farms in Laguna Province is an example of the almost complete shift to modern rices in the Philippines. In a survey in the province, 100% of the farmers said they grew modern varieties.



4. Paddy yields in Burma turned upward sharply in 1978. That year (crop year 1977-78) 10% of the rice area was planted to modern varieties. By 1980-81 the area planted to modern rices was 41% of total area. In 1977-78, the Agriculture Corporation launched its Whole Township Production Program, a concentrated rice extension effort.



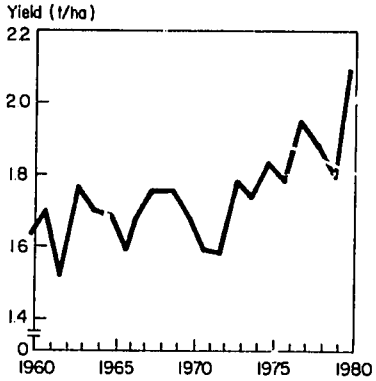
5. Yields trends of rice in northern and eastern India show the failure of production in eastern India to move above the 2 t/ha yield levels.

IRRI and Burmese plant breeders discuss rice variety trials on an experiment station in Burma. P. B. Escuro, IRRI plant breeder (center), has worked in Burma since 1978. Escuro is flanked by Burmese Plant Breeder U Saw Stanley (left) and IRRI Plant Breeder J. S. Nanda (right).

Research Highlights for 1975 posed the question, "What about the other three" — the other three being the farmers without irrigation who farm three-quarters of the rice lands in tropical Asia — and described our efforts initiated to develop rices adapted to the nonirrigated areas.

The nonirrigated areas are usually referred to as rainfed, but they embrace a wide range of rice-growing environments, including lands subject to seasonal deep flooding and tidal inundations. Figure 7 illustrates the categories and relative extents of the world's rice land.

At first glance the irrigated area is slightly more than half of the total, but when we exclude the temperate-area rice lands of



6. Average rice yields in Bangladesh moved above the 2 t/ha level in 1980.

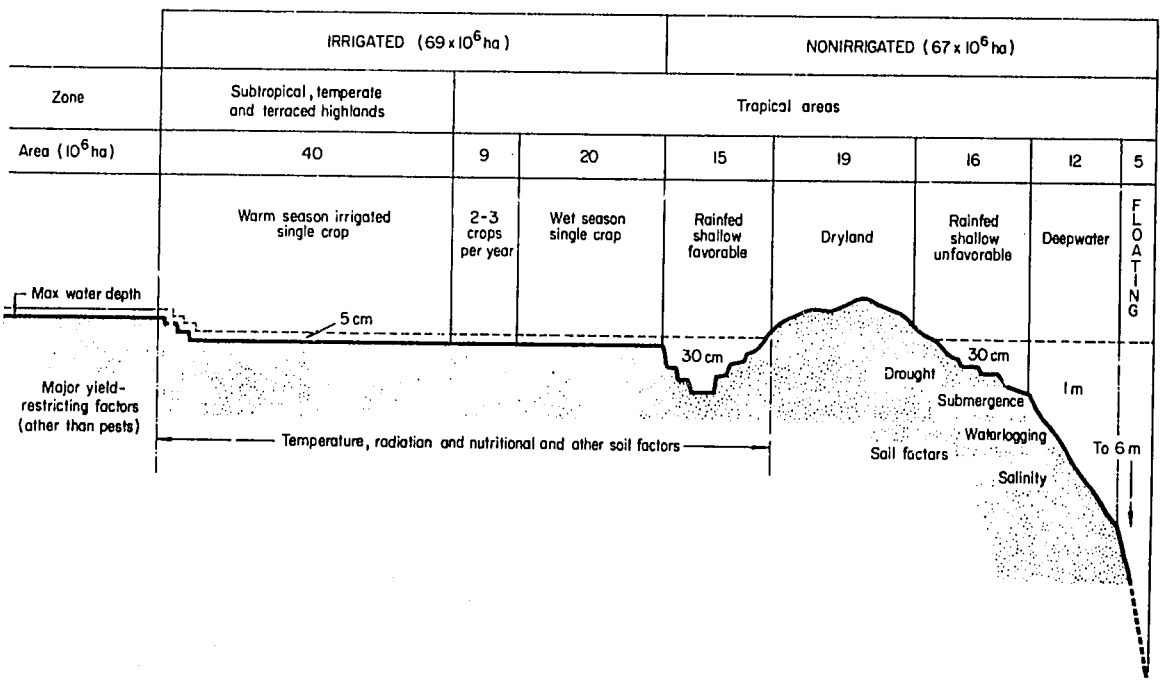
7. The world's rice areas divide almost equally into irrigated and rainfed. More than 60% of the irrigated area is, however, in China and India. Only about 20% of the rainfed area — shallow rainfed — has environments favorable to rice growing.

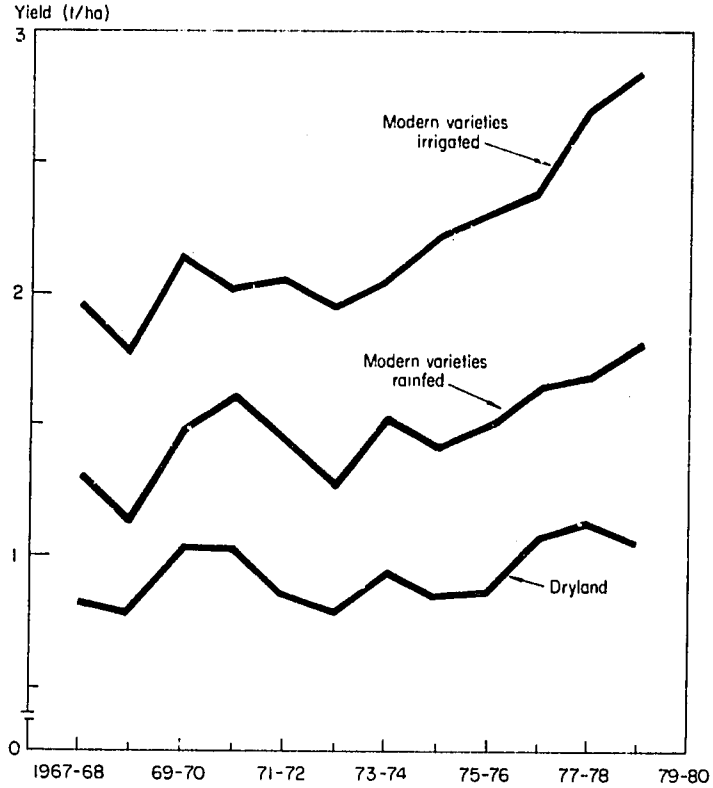
China, Japan, and the United States, the proportion of irrigated land falls below one-third of the total.

The rainfed rice area subdivides on the basis of water regime into dryland, shallow, deepwater, and floating rice areas. Dryland areas are those not normally submerged, the shallow areas are subject to flooding to 30-cm depth, deepwater areas flood to 1-m depth, and floating rice areas are those where floods normally exceed the 1-m depth. These subdivisions are convenient for mapping purposes, but a poor guide to the rice varieties needed for the rainfed areas.

The shallow rainfed areas, for instance, include a large proportion (about half) in which conditions during much of the growing season closely approximate those of fully irrigated areas. For these favorable shallow rainfed areas, varieties developed for irrigated areas are well suited, expecially if they have some ability to tolerate or recover from drought, as IR36 has.

The irrigated rice area in the Philippines and Indonesia accounts for only about 30% of the total, but much of the remainder is shallow rainfed rice land, and much of that in the favorable category. Adoption of modern varieties by farmers in





8. Data from the Philippine Bureau of Agricultural Economics indicate a steady increase in yields from modern rice varieties in irrigated and rainfed fields.

those areas has contributed to yield improvements in recent years (Fig. 8) — even though occasional drought inevitably restricts yields.

Our 1981 constraints studies show that although farmers use modern varieties on at least the more favored rainfed areas, they are reluctant to use more than low levels of fertilizer because of the risk that drought or other factors will prevent a response. Studies to date (see page 93) suggest that the farmers are probably correct in their refusal to risk expenditure on inputs, and emphasize the need to develop better varieties and management practices for the rainfed areas. If we can incorporate in varieties a greater degree of drought resistance, as well as resistance to insects and diseases, a positive response to fertilizers would be more certain and yield levels would increase considerably.

In Eastern India, the large proportion of the area subject to flooding to 60-cm depth and where the water remains stagnant for much of the year presents to scientists a challenge that has yet to be met. The failure to make progress in these areas is shown by an almost static yield curve (Fig. 5).

There has been little improvement in the yields obtained from dryland rice — for instance in the Philippines (Fig. 8). For these

more drought-prone areas, there is an even greater need to develop better adapted varieties. The same is true for the deepwater areas, although varieties RD17 and RD19, which were released in 1980 in Thailand for deepwater farmers, continue to show promise.

Sharper focus on rainfed rice research

We can continue progress in the irrigated areas and will maintain our efforts to develop technology to increase rice yields for farmers with irrigated land — where rice production is currently "running fast."

But we are not moving ahead of population growth in the rainfed areas, where yields have been "standing still" for some time, and are only now starting to creep forward. If we are to make rice production keep pace with population growth during the next decade, it is essential that we "run faster" with rice improvement for the rainfed areas.

During 1981 we initiated plans to give a much sharper focus to our efforts to develop improved varieties for the different rainfed areas. Interdisciplinary teams for dryland rice and deepwater rice were established earlier. Those teams have been strengthened and we now have teams organized to deal with the shallow but submergence-prone areas, the waterlogged areas, and the tidal swamp areas. There are serious barriers to progress for these problem areas, but as seen in Figure 7, those rice lands form a large enough proportion of the world's rice area to make breaking of the barriers essential.

The research highlights we include herein describe some of our 1981 work directed to improvement of rainfed as well as irrigated rice. Because of the increase in the irrigated land area in the past 6 years, we now speak of our efforts directed to improve the lot of the "other two" — the tropical rice farmers who do not have the benefits associated with irrigation. About half of our budget is directed to improving the lot of these less advantaged farmers.

MAJOR RESEARCH RESULTS

GENETIC EVALUATION AND UTILIZATION

COLLECTING AND SHARING THE RICE GERMPLASM

Collection and preservation of the primitive rice germplasm take on new urgency as the modernization of agricultural areas quickens its pace in many Asian countries. The continual expansion of use of high yielding rice varieties is accompanied by the replacement — and often the complete disappearance — of the traditional varieties. With the construction of dams, highways, and houses and the clearing of forested areas, populations of self-perpetuating wild rices adjoining cultivated areas dwindle.

Many traditional varieties and several wild rices have high levels of resistance to several diseases and insects — resistance that we can add to the improved varieties.

There was dramatic proof of the value of the world germplasm collection in March 1981 when seed of several traditional Khmer varieties was returned to Kampuchea. War in Kampuchea had destroyed much of the germplasm in farmers' fields, and aid agencies in Kampuchea requested samples of the Khmer rices from our germplasm bank. These were sent to Kampuchea and multiplication of seed for Kampuchea's farmers started.

Expanded sharing of germplasm

During the year our germplasm bank sent about 4,400 seed samples of *O. sativa* to 206 foreign rice researchers, and IRRI scientists used 29,051 samples. We supplied 1,021 samples of other species in the genus *Oryza*. During 1980 and 1981, the total number of seed samples supplied stayed at the 35,000 level — which does not differ from samples supplied annually in 1976-79 — but the number of requests has shown a steady increase.

Conservation and use of the wild rices

During late 1981 an IRRI-IBPGR Rice Advisory Committee toured East India's Jeypore Tract. The area is known for its rich rice diversity, having the immediate wild relatives of *O. sativa* and the primitive cultivars. The Committee members observed

1. A tribal woman in the Jeypore Tract, East India, gathers free-shattering wild rice for food. As the metal pan is flipped across the wild rice panicles, the awned grains drop into her basket.

enormous genetic diversity in the tribal area of Jeypore, one of the few areas in the world where tribal women gather free-shattering self-perpetuated wild rice as a food supplement (Fig. 1).

The wild rices have, however, been noticeably decreasing in frequency and area and are becoming increasingly *sativa*-like in areas adjoining farmers' fields, compared to what they were a few decades ago. The Committee recommended to the IBPGR and IRRI that the collection and conservation of the wild relatives of rice be given a higher priority than it now has.

IRRI scientists expanded testing of wild rices and several wild species with high levels of resistance to disease and insect pests were identified. An *O. nivara* strain originating from Uttar Pradesh, India, has provided the only source of resistance to the grassy stunt virus since the source was identified in 1969. Two wild rices from Taiwan were found to have higher levels of ragged stunt virus resistance than all cultivars screened. Such resistant wild rices, however, are now extinct in Taiwan.

IRRI rices named in 10 countries

Fourteen IRRI varieties or breeding lines were named and released by national rice improvement programs in 1981.

The first IRRI line named and released by a national program, after IRRI stopped naming rices in 1975, was IR36 — named by the Philippine Seed Board. It has become the world's most widely grown rice variety, growing on more than 10 million hectares in Southeast Asia alone during 1981. In 1981 too, IR36 was named an all-India variety. It had earlier been released for farmers in West Bengal and Orissa States.

Other rices named in 1981 include:

- IR841-63-5-18, a selection with long slender grains, released in Argentina. It has also been released in Brazil.
- IR1529-430-3 released in Bolivia as Saavedra 5. This line was earlier recommended in Cuba.
- IR1416-131-5, a blast-resistant line from a cross of the well-known Tetep variety, released in Liberia as Suakoko 12.
- Two high yielding selections with medium growth duration, IR751-592 and IR1529-680-3-2, recommended in Burma as Shwe-Thwe-Lay and Yenet-1, respectively. IR1529-680-3-2 was released earlier in Vietnam and in 10 African countries. It has excellent yield potential.
- IR1545-339-2-2, a breeding line with sturdy stems, released in Ecuador.
- IR1561-228-3-3, an early-maturing line with high yield potential, recommended in Mauritania. This line was released earlier in Vietnam, Kenya, and Egypt.
- IR50, IR52, and IR54, which were named in the Philippines in 1980, were released in Indonesia.
- The Philippine-released varieties IR42 and IR46 were released in Nigeria and Cameroon, respectively. Nigeria also recommended IR30.

AGRONOMIC CHARACTERISTICS

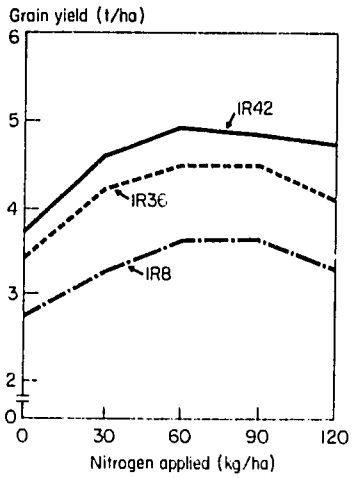
New early-maturing rices

We continued to test new early-maturing rices during both (dry and wet) growing seasons at IRRI. Many mature in 100 days or less. Several lines are 8-10 days earlier than IR36 and yield as well as IR36 (Table 1).

These early-maturing lines were in trials in the Philippines and in IRTP nurseries worldwide. Two of the most promising selections are IR9729-67-3 and IR9752-71-3-2. They are in advanced stages of testing.

Table 1. These 9 promising early-maturing lines were tested at IRRI during 1981. The 2 lines with dry season yields higher than IR36 can be considered for release in national rice programs.

Selection	Growth duration (days)	Yield (t/ha)	
		1981 dry season	1981 wet season
IR9752-71-3-2	98	7.5	4.7
IR9729-67-3	100	7.2	5.1
IR15429-268-1-2-1	97	6.8	5.1
IR19735-5-2-3-2-1	100	6.5	4.9
IR19743-25-2-2-3-1	96	6.4	4.6
IR8455-78-1-3-3	100	6.2	4.6
IR19729-5-1-1-3-2	97	6.1	4.3
IR19746-28-2-2-3	97	6.0	4.5
IR19743-40-3-3-2-3	97	6.0	4.5
IR36 (check)	108	6.9	4.7

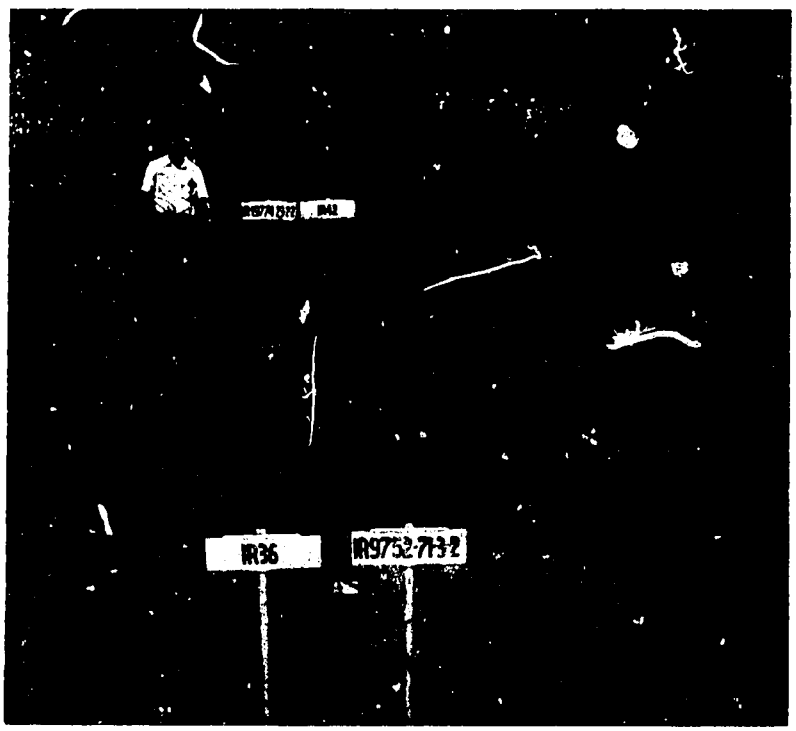


2. IR42 shows as the most efficient user of nitrogen in these grain yield responses of IR36 and IR42 to 4 levels of nitrogen. Data for the 1976-81 wet seasons were for IRRI and the Bicol, Maligaya, and Visayas Experiment Stations of the Philippine Bureau of Plant Industry.

IR42 — efficient utilizer of soil nitrogen

Each year, we test elite breeding lines and varieties for their nitrogen response and yield potential in wetland rice fields. In 1981 the data for all 1976-81 wet season experiments at IRRI plus cooperative experiments at three stations of the Philippine Bureau of Plant Industry were averaged.

Based on 6 years of data IR42 was a more efficient utilizer of soil and fertilizer nitrogen than IR36, the most widely grown variety in the world. IR8, which is susceptible to insects and diseases, performed poorly at all nitrogen levels (Fig. 2).



IRRI Plant Breeder G. S. Khush looks at maturity differences among 2 popular IR varieties and 2 new early-maturing lines in replicated yield trials at IRRI. IR9752-71-3-2 matures 10 days earlier than IR36. Note that IR42 shows no panicle formation.

DISEASE RESISTANCE

Even though the threat of disease outbreak in rice fields has been reduced by the disease resistance of modern rices, disease resistance still plays an important role in rice production. Our plant pathologists continued to develop and improve screening methods for use in their search for genetic sources of disease resistance.

Testing of breeding lines and varieties, and basic research on pathogen variability and the inheritance and mechanism of disease resistance also continued.

About 60% of our Plant Pathology Department's time is devoted to the evaluation of rice resistance to diseases. In 1981, 224,011 entries were tested for their reaction to 8 fungal, 1 bacterial, and 3 viral diseases. The entries included materials from world germplasm bank collections, breeding lines, and international nurseries.

Screening methods

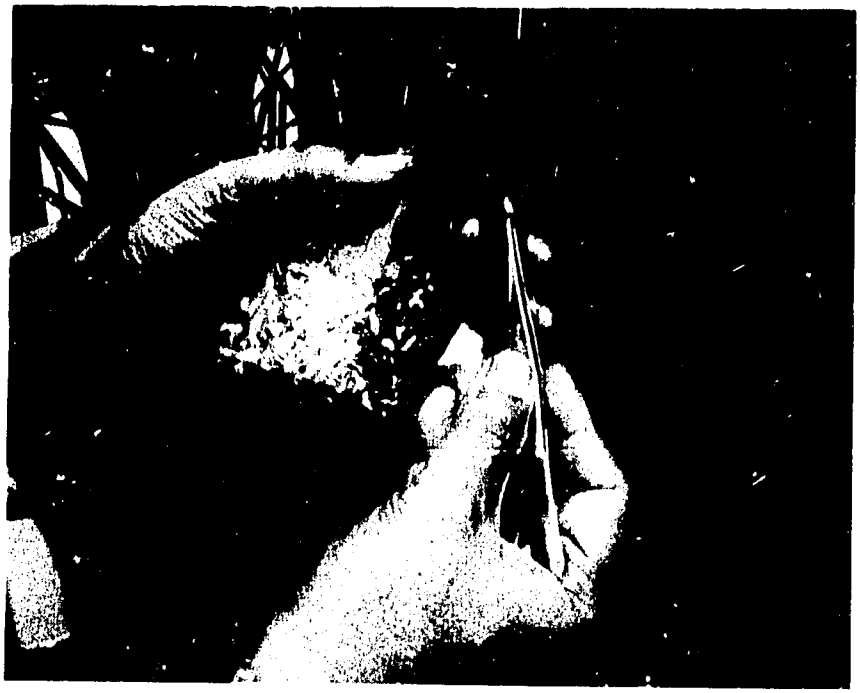
Screening methods that can efficiently handle thousands of entries are essential for developing and testing varietal resistance to diseases. In 1981, we continued to refine the screening method developed earlier for blast, bacterial leaf blight, tungro, sheath blight, grassy stunt, and ragged stunt and established methods for sheath rot and bakanae.

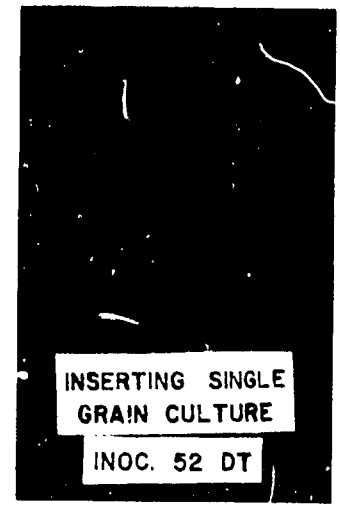
Sheath rot. For sheath rot screening, the fungus *Acrocylindrium oryzae* was cultured on moist, sterile rice hulls for 2 weeks. A single hull served as inoculum and was inserted between the leaf sheath and culm 1 cm below the ligule of a rice plant. We found that rice plants at maximum tillering to panicle initiation were the most suitable for inoculation (Fig. 3). We classified varieties with less than 1% infection as resistant; those with more than 20% as susceptible.

Bakanae disease. For bakanae, we found that soaking seeds 4 days in a concentrated spore suspension was an efficient inoculation method. The soaked seeds were planted and infected seedlings were counted at weekly intervals for 4 weeks. Evaluation of resistance was based on percentage of infected seedlings: varieties with less than 20% were resistant; those with more than 40% were susceptible.

Sources of ragged stunt resistance

Rice ragged stunt was identified as a new virus disease in 1977 and since then we have searched for possible sources of resistance for use in breeding programs.





3. In screening for sheath rot resistance, rice plants were inoculated by inserting a single grain inoculum 1 cm below the ligule, between the leaf sheath and the culm (left). The results of the inoculation test were evaluated 2 weeks after inoculation (right).

In 1981, we screened different accessions of wild taxa and found 35 accessions of 11 *Oryza* species with a high degree of resistance to ragged stunt. *O. officinalis* had 11 accessions with resistance, *O. minuta* had 7, and *O. brachyantha* had 6.

Sitopas, a variety from Indonesia, was susceptible to ragged stunt in a quantitative test, but infected plants grown to maturity in the screenhouse showed masking of symptoms except vein-swelling. Diseased Sitopas plants produced as many filled grains as healthy plants (Fig. 4), indicating that the variety is tolerant of ragged stunt.

Inheritance of resistance

Inheritance of resistance against isolates of 6 races of blast *Pyricularia oryzae* was studied in 15 crosses. We identified six resistance genes in Pai-kan-tao, eight in IR1905-81-3-1 and IR3259-PP-160-1, and nine in IR3259-PP8-172-7. IR1905 was derived from IR8/Tetep and IR3259 was from IR8[3]/Tetep. The identified genes for resistance expressed dominance and can be incorporated in blast-susceptible varieties by backcrossing.

In bakanae studies seven crosses were tested against three races of *Fusarium moniliforme*. Dominant resistance was found, apparently governed by a single dominant gene or complementary genes depending upon crosses and race used.

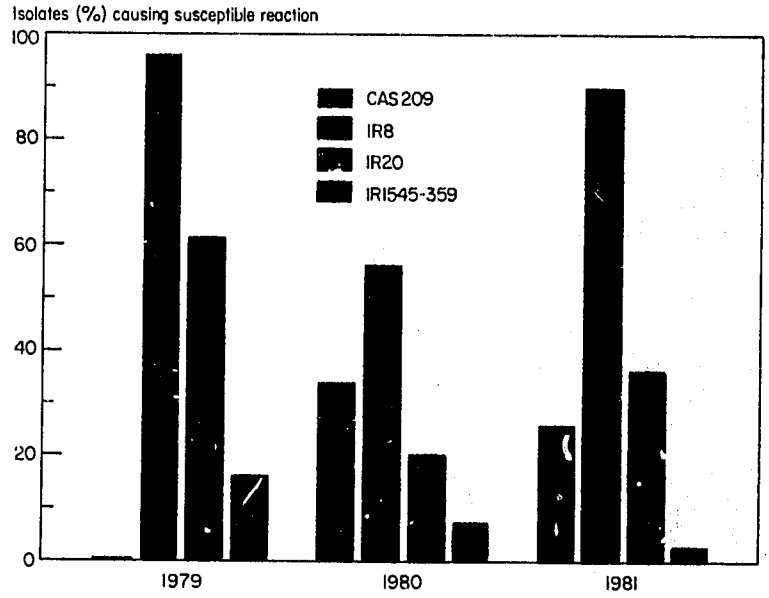
We used 10 crosses in studying inheritance of leaf scald resist-

4. This hill of the Sitopas variety from Indonesia is infected with ragged stunt, but the symptoms are masked and the plants had complete panicle exsertion.

ance. F_2 progenies segregated into a 3-to-1 ratio of resistant and susceptible plants, which indicated the presence of a single dominant gene.

Virulence of bacterial leaf blight field populations

In investigations of the virulence of bacterial leaf blight, about 50 naturally infected leaves from various rice varieties were randomly collected at IRRI from 1979 to 1981. The isolates differed in virulence regardless of test variety or year (Fig. 5). We found, however, that the virulence of most of the isolates collected at IRRI during the last 3 years resembled the virulence of race



5. In tests of isolates of bacterial leaf blight, the field populations of *Xanthomonas campestris* pv. *oryzae* collected in 1979-81 at IRRI showed specific virulence that changed from year to year on 4 varieties.

group II. This identification of predominantly virulent isolates can be used in selecting varieties with resistance genes to reduce incidence of bacterial leaf blight in a particular area.

Resistance to tungro virus and its vector

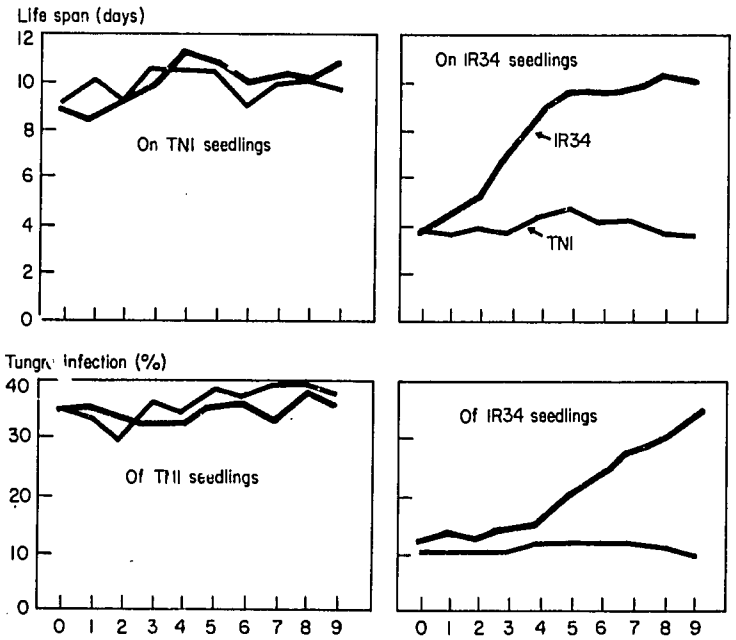
Tungro virus is transmitted by the green leafhopper and the resistance of a rice variety to tungro is attributed to its resistance to the virus, to the green leafhopper, or to both.

At IRRI IR34 has consistently shown low tungro infection in the field and the greenhouse. We reared a green leafhopper colony on IR34 for nine consecutive generations and used insects of each generation to inoculate IR34 seedlings.

The tungro resistance of IR34 is influenced by its resistance to the green leafhopper (Fig. 6). The colony gradually adapted to IR34 as shown by the increases in life span of the generations. At the same time the percentage of tungro-infected IR34 seedlings gradually increased.

Green leafhopper resistance and tungro virus infection

The 23 modern IR varieties (IR5 to IR54) were tested to determine their levels of resistance to the green leafhopper and degree of tungro virus infection. Seedling preference was highly related to degree of tungro infection, both in greenhouse and field studies (Fig. 7). IR28, IR29, IR34, IR50, and IR54 were least preferred by the insect in the greenhouse and had low levels of tungro



6. The life span and tungro infection capability of green leafhoppers increased when insects were reared consecutively on either TN1 or IR34 plants for 9 generations. This shows that the insects gradually adapted to IR34 and so tungro infection of IR34 also gradually increased. Hence, the resistance of IR34 to tungro is influenced by the resistance of the variety to the vector insect.

IR54 (left), which is highly resistant to the green leafhopper, has only 4% tungro virus infected plants, but IR42 (right), which is moderately resistant to the green leafhopper vector, was heavily infected.

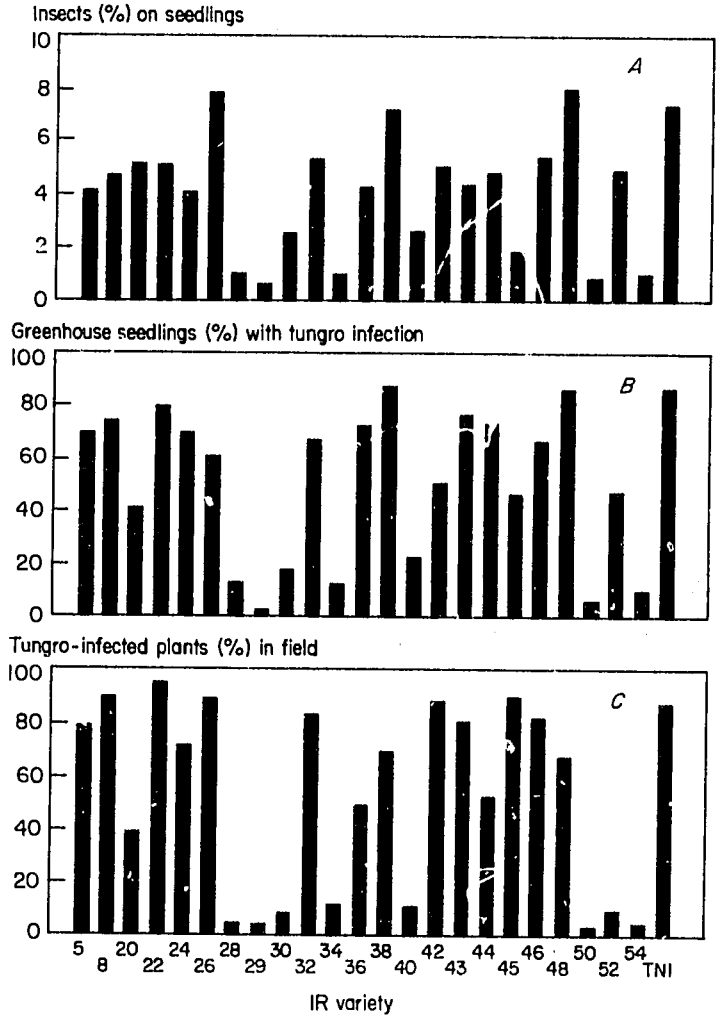
infection in the greenhouse and in the field.

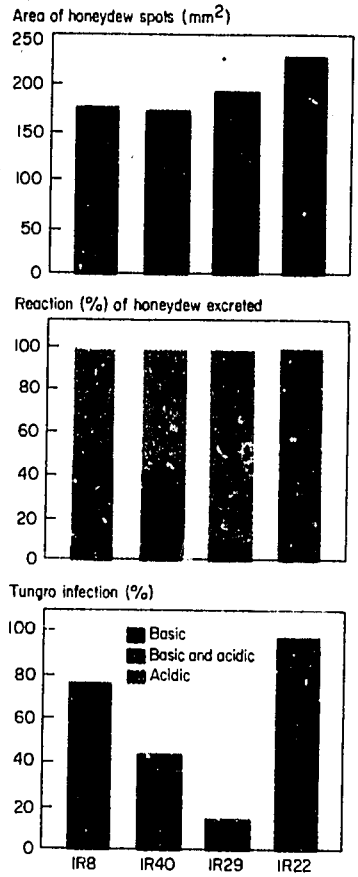
Unlike the brown planthopper, the green leafhopper feeds substantially on resistant varieties. It does not, however, survive on resistant varieties. In our *1980 Research Highlights* we reported biochemical evidence that indicated that the green leafhopper feeds on the phloem in a susceptible variety and in the xylem in a resistant variety. In 1981 we made tests to determine whether the green leafhopper could transmit tungro virus equally to resistant and susceptible varieties.

We placed tungro-carrying green leafhoppers on 100 plants each of susceptible IR22, moderately resistant IR8 and IR40, and highly resistant IR29. Insect feeding was equal on all varieties (Fig. 8). However, tungro infection ranged from 98% on susceptible IR22 to only 14% on highly resistant IR29.

The high amount of basic honeydew from insects feeding on susceptible IR22 and the absence of basic honeydew from insects feeding on resistant IR29 confirmed the 1980 study. That also indicated that feeding in the phloem is necessary for tungro inoculation and development within the plant. In contrast, viru-

7. Relationship between seedling preference of the green leafhopper and tungro infection. A. Percent of insects on seedlings of each variety 24 hours after infestation. B. Percent of seedlings infected with tungro in a greenhouse 15 days after infestation (21 days after sowing). C. Tungro-infected plants in the field after infestation with viruliferous green leafhoppers. Viruliferous hoppers were released 33 days after transplanting and tungro infection was recorded 68 days after transplanting. TN1 is a susceptible variety.





8. Two tungro viruliferous green leafhopper adults were allowed to feed for 22 hours on plants of 4 varieties. The area of honeydew on bromocresol-treated filter papers for the varieties was about the same but tungro infection (20 days after feeding) was low for IR29, which is green leafhopper resistant. Resistance is also indicated in the low percentage of acidic honeydew. IR22 is a susceptible variety.

liferous hoppers feeding in the xylem, as in the case of IR29, are not efficient in transmitting the tungro virus or else virus from xylem feeding does not develop in the plant.

INSECT RESISTANCE

The modern rice varieties, sometimes called the HYV or high yielding varieties, are often criticized because they are "not as resistant to pests as the farmers' traditional varieties." A favorite ploy of some critics is to tie the modern rices to "high yields only where farmers use costly agricultural chemicals."

The new rices, however, continue to outyield traditional rices even where low levels of inputs are used, and to far outyield the traditionals where those inputs are increased. The advantage of the higher yielding new rices is that genetic transfer has given

In 1981 field studies, Utri Rajapan remained green and undamaged by brown planthopper, but Kirikunda (left) was hopperburned. Note the lack of sooty mold at the base of Utri Rajapan compared to that of Kirikunda. Sooty mold grows on the honeydew excreted by the brown planthoppers. Highly susceptible TN1, which was grown between the 2 varieties, was completely destroyed and its plants had decomposed.

them the disease and insect resistance of the traditional rices, sometimes in an improved form.

In 1981 we continued to improve insect resistance levels in the modern rices.

Resistance of IR and traditional rice varieties

Critics of the modern rices suggest that outbreaks of the brown planthopper and other rice insect pests have occurred because of:

- a loss of low levels of resistance in breeding for high yields in the modern varieties; and
- changes in cultural practices that have accompanied the growing of high yielding varieties.

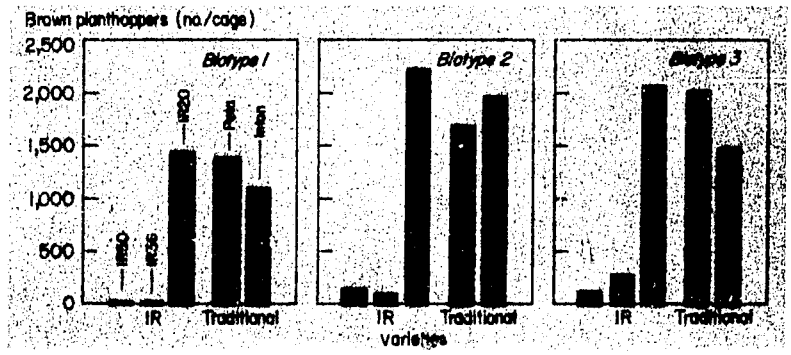
We compared the level of brown planthopper resistance in the traditional varieties Peta and Intan with the resistance of two popular IR varieties. Populations of brown planthopper were allowed to develop on the varieties as a measure of susceptibility.

The brown planthopper population on IR20, for which resistance has never been claimed, was similar to that on the traditional varieties Peta and Intan (Fig. 9). IR36 and IR50 had lower insect populations than the traditional varieties.

Insect resistance levels in IR varieties

We tested all IR varieties (IR5 to IR54) released to date to determine their resistance to some of the major rice insect pests of Asia (Table 2). IR50, named by the Philippine Government in 1979, is resistant to the brown planthopper, the green leafhopper,

9. IR36 was released in the Philipp' es in 1976 and has become the world's most widely grown modern rice. IR50 was released in 1979. In 1981 tests brown planthopper biotypes 1, 2, and 3 were fewer on both modern varieties than on two traditional varieties common in the Philippines before the advent of high yielding varieties. The planthopper populations represent the progeny of 5 pairs of 3-day-old adults at 25 days after infestation.



and the striped borer, and is moderately resistant to the yellow stem borer.

We also tested the germplasm collection for resistance to the whitebacked planthopper, zigzag leafhopper, and leaffolder. Resistant sources were identified and that resistance was incorporated into breeding lines.

Brown planthopper variability

The brown planthopper species *Nilaparvata lugens* is considered

Table 2. The resistance of all IR varieties to rice insect pests was checked at IRRI in 1981.[a] Insects used for screening were from field collections in the Philippines.

Variety	Brown planthopper biotypes			Green leafhopper	Whitebacked planthopper	Zigzag leafhopper	Yellow stem borer	Striped stem borer	Leaf-folder	Case-worm	Whorl maggot
	1	2	3								
IR5	S	S	S	MR	S	S	S	S	S	S	S
IR8	S	S	S	MR	S	S	S	S	S	S	S
IR20	S	S	S	MR[d]	S	S	MR	R	S	S	S
IR22	S	S	S	S	S	S	S	S	S	S	S
IR24	S	S	S	MR	S	S	S	S	S	S	S
IR26	R	S	R	MR	S	S	S	MR	S	S	S
IR28	R	S	R	R	S	S	S	S	S	S	S
IR29	R	S	R	R	S	S	S	S	S	S	S
IR30	R	S	R	R	S	S	S	MR	S	S	S
IR32	R	R	MR[c]	MR	S	S	S	MR	S	S	S
IR34	R	S	R	R	S	S	S	MR	S	S	S
IR36	R	R	MR[c]	MR	S	S	MR	R	S	S	S
IR38	R	R	MR[c]	MR	S	S	S	MR	S	S	S
IR40	R	MR	S	MR	S	S	MR	R	S	S	MR
IR42	R	R	S	MR[d]	S	S	S	MR	S	S	S
IR43	S	S	S	MR	S	S	S	MR	S	S	S
IR44	R	R	MR[c]	MR	S	S	S	R	S	S	S
IR45	R	S	R	MR	S	S	S	S	S	S	S
IR46	R	S[b]	R	MR[d]	S	S	S	S	S	S	S
IR48	R	R	S	MR	MR	S	S	S	S	S	S
IR50	R	R	MR[c]	R	S	S	MR	R	S	S	S
IR52	R	R	MR[c]	R	MR	S	S	MR	S	S	S
IR54	R	R	S	R	S	S	MR	MR	S	S	S

[a]Based on replicated experiments. Hopper resistance based on greenhouse evaluation of seedlings; yellow and striped stem borer resistance based on screenhouse evaluation of 40- to 70-day-old plants; leaffolder and caseworm resistance based on the reaction of 30- and 11-day-old plants in the greenhouse; whorl maggot resistance based on field observations 30 days after transplanting. Varieties with Standard Evaluation System for Rice ratings of 1-3 are considered resistant (R), 5-7 moderately resistant (MR), and 9, susceptible (S). [b]IR46 has field resistance. [c]Reactions to biotype 3 vary, occasionally being S and often R. [d]Occasional S reaction.

10. Three color forms of the brown planthopper — brown, black, and red.

a plastic species with a wide genetic variability. Because of its plasticity it develops resistance to insecticides rapidly and overcomes the resistance of varieties through a selection process.

The brown planthopper's genetic variability is exemplified by the various colors of individuals in the species. We isolated three color forms from the IRRI culture — a predominant brown, a black, and a red (Fig. 10). The three also differ in their ability to survive and multiply on resistant varieties. The red hopper builds a high population on Mudgo and ASD7, which have the *Bph 1* and *bph 2* genes for resistance, respectively. The black and brown hoppers have low populations on those varieties.

Biotype selection

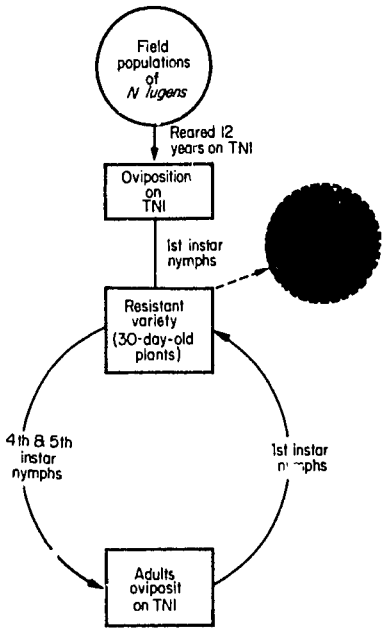
Because of the genetic variability within the brown planthopper species, a small proportion of the individuals are able to feed on and damage a variety that is resistant to other individuals in the same population. When a resistant variety is planted over a wide area, the virulent insects that can survive and multiply on a resistant variety increase in number and become predominant after several generations. To keep ahead of the biotype selection process it is necessary to be able to evaluate breeding lines for resistance to a particular biotype before that biotype becomes predominant in the field. This way we can release varieties with genes for resistance to a particular biotype as soon as it is observed that the presently grown variety is becoming susceptible.

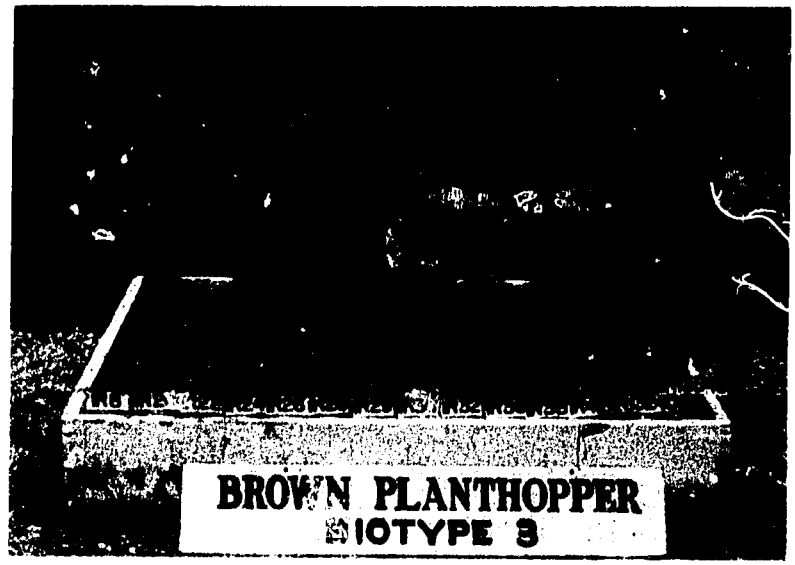
Using the technique shown in Figure 11, we are able to select for biotypes in the greenhouse and screen breeding lines against them. We selected a biotype that kills IR36 in the seedling stage and evaluated IR breeding lines for resistance to it. The lines IR13543 (with the *Bph 3* gene) and IR13240 (with *bph 4*) were resistant to biotype 3, which killed IR36 (Fig. 12), and also have resistance to biotypes 1 and 2. Most elite IR breeding lines evaluated in 1981 were resistant to the three biotypes.

Tolerance for brown planthopper attack

We are considering use of tolerance as one of several strategies to cope with the brown planthopper biotype problems. Tolerance is the ability of a variety to grow and produce grain — or to repair injury — despite an insect population about equal to one that destroys a susceptible variety. Because tolerance does not put pressure on the insect to change, there is no cause for a shift in the biotype.

Tolerance alone does not decrease the insect population, and so our objective is to combine tolerance with resistance in improved





11. Scheme used to select brown planthopper biotypes that can destroy resistant varieties.

12. Reaction of selected IR varieties and breeding lines to brown planthopper biotype 3. Variety IR36, which is widely grown in Indonesia, Philippines, and Vietnam, is moderately resistant or susceptible (as seen here) when exposed at the seedling stage to high hopper populations of biotype 3. The breeding lines IR13543 and IR13240 are highly resistant to biotypes 1, 2, and 3, and can be released as varieties if IR36 becomes susceptible because of a biotype shift.

varieties. A biotype that can overcome the resistance of these varieties may develop, but the remaining tolerance would allow the variety to produce some grain despite a high insect population. If that happens, it would allow detection of a shift in the biotype in farmers' fields and give time to replace the variety with a resistant one before farmers had severe crop losses.

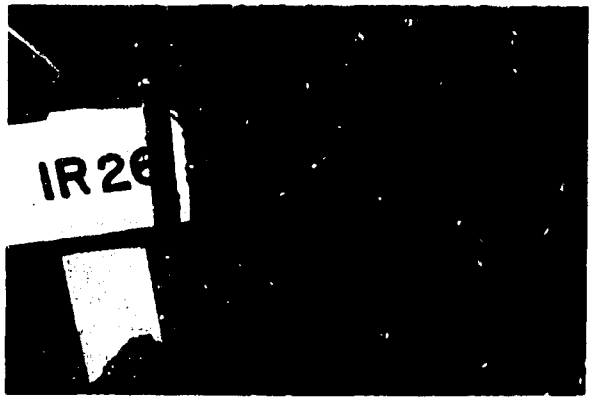
In 1980 we reported that Triveni had some tolerance. In 1981 we identified Utri Rajapan as a variety with a high level of tolerance. We measured tolerance by the formula:

$$\text{Functional plant loss index (FPLI)} = 1 - \left[\frac{\text{dry wt of infested plants}}{\text{dry wt of uninfested plants}}\right]\left[1 - \frac{\text{damage score}}{9}\right]$$

Insects on Utri Rajapan and those on IR26, which is susceptible to biotype 2, had the same dry weight, indicating that the insects fed, survived, and multiplied. However, the FPLI of Utri Rajapan indicated less damage than in IR26. The insect apparently required less food to maintain itself on Utri Rajapan and thus caused less damage (Fig. 13). Our studies also showed that loss in root weight in Utri Rajapan was one-half that in IR26 when both varieties were exposed to identical populations (Fig. 14).

Biochemical base of brown planthopper resistance

We checked the nutritional and biochemical differences of rice varieties with different genes for brown planthopper (biotype 1)



13. Tillers of IR26 were severely damaged and were covered with sooty mold from the feeding of brown planthopper. Those of Utri Rajapan, which is tolerant of the brown planthopper, remained green and undamaged.

14. Tolerance for brown planthopper can be seen in the development of the root system of these plants, which were exposed to planthopper feeding. Thirty days after infestation of IR26 and Utri Rajapan with 75 brown planthoppers/plant, the root system was smaller in IR26 than in Utri Rajapan. The IR26 plant was also stunted and wilted. Healthy plants of IR26 and Utri Rajapan are seen at left and right.

resistance. No major differences were observed among the test varieties in respect to their total amino acid composition, free amino acids, and total sugars and starch. Only Rathu Heenati and Ptb 33 had a lower amino acid content than that of susceptible TN1.

Biochemical extracts from the resistant and susceptible varieties were obtained from their leaf sheaths. Topical application of the extract from the resistant varieties on brown planthoppers caused a significantly higher mortality than that caused by the extract of susceptible TN1 (Table 3). The extract from 60-day-old resistant plants was more toxic than the extract from 30-, 45-, or 100-day-old resistant plants; however, the toxicity from the susceptible variety remained low at all plant growth stages.

In a multichoice feeding test, ingestion by brown planthopper females of a 10% sucrose solution with steam distillate extract from a susceptible variety was greater than ingestion of sucrose solution alone or that with extract from a resistant variety. In another multiple choice test, more brown planthopper females settled and fed on TN1 tillers sprayed with TN1 extract or on acetone-sprayed tillers than on tillers sprayed with the extract of

Table 3. Topical application of a steam distillate extract[a] from a brown planthopper-susceptible variety was less toxic on newly emerged, brachypterous brown planthopper biotype 1 females than the extract of resistant (R) varieties.

Variety	Corrected mortality (%) after 24 hours[b]	
	10	20
TN1 (susceptible check)	14.9 a	31.8 a
Mudgo (R)	37.3 bc	59.2 bcd
ASD7 (R)	35.4 bc	56.4 bc
Rathu Heenati (R)	29.9 bc	63.9 cd
Babawee (R)	34.4 bc	58.9 bc
Ptb 33 (R)	40.9 c	70.8 d
ARC6650 (R)	26.8 bc	51.7 b

[a]At doses of 10 and 20 μg extract/0.1 ml acetone per insect. [b]In a column, means followed by a common letter are not significantly different at the 5% level.

15. The dark spots on these filter paper discs represent the amount of honeydew excreted by biotype 1 brown planthopper females feeding on TN1 plants treated with steam distillate extracts of susceptible TN1 and resistant ARC6650 and Ptb 33 rice varieties.

the resistant Ptb 33 or ARC6650 varieties (Fig. 15).

Thus, it appears that susceptibility or resistance of rice varieties to brown planthopper is determined by the presence of certain chemicals in the plant.

GRAIN QUALITY

The eating quality of a rice variety is a major factor in its acceptance by consumers, the most important among them being the farmers themselves. Eating quality, however, is greatly influenced by cooking method.

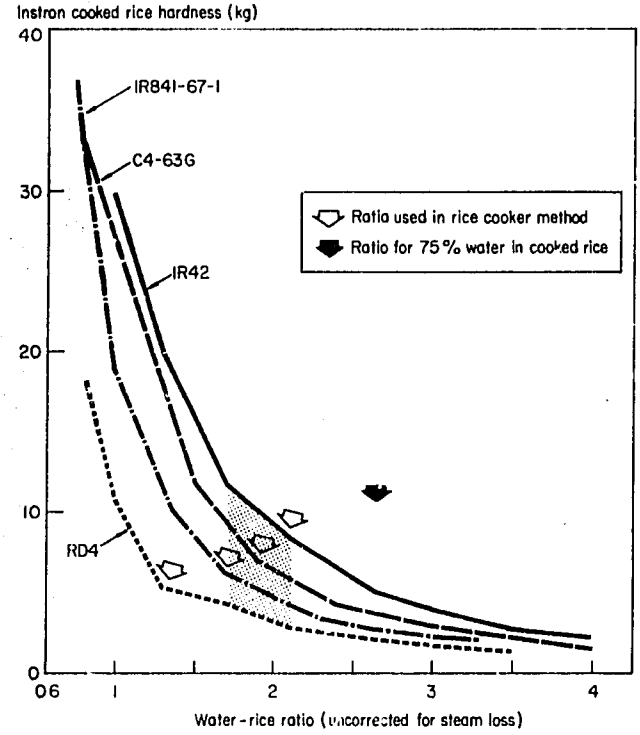
Research Assistant Cynthia Pascual records texture of cooked rice as she removes it from the rice cooker while Assistant Scientist Consuelo Perez checks hardness of the samples in the Instron tester.

Cooking water-rice ratio as screening method

Rice is cooked either in the amount of water it will absorb to obtain a desired texture or in excess water to provide an optimum degree of cooking — time required for the center of the grain to become translucent. The water content of rice cooked in excess water ranges from 69 to 76%.

Rice breeders working with rices with diverse amylose contents have faced diverse eating quality scores that resulted from cooking, rather than from grain quality.

We demonstrated the primary role of a water-rice ratio in determining cooked rice hardness of representative well-characterized waxy, low-amylose, intermediate-amylose, and high-amylose rices. The water-rice ratio for acceptable soft texture (less than 10 kg hardness) increased with increasing amylose content of the sample from 1.1 to 1.9 (Fig. 16). This justifies housewives' practice of adjusting the water level to obtain acceptable texture of cooked rice and our method of using adjusted cooking water-rice ratio based on amylose content. However, for screening purposes a constant water-rice ratio of 1.7 would be



16. The hardness of cooked rice decreases progressively with increase in the cooking water-rice ratio. In 1981 tests, differences in hardness among amylose types were maintained but were higher at water-rice ratios of 1.7-2.1 than at 2.65 representing 75% water content of cooked rice. For screening purposes, a single ratio between 1.7 and 2.1 (shaded area) would be more sensitive than the adjusted water ratio based on amylose content (white arrow) or the ratio 2.65.

adequate to distinguish between the 4 amylose types if all types are involved in the breeding program.

Our 1981 survey of cooking methods used by researchers worldwide revealed that water-rice ratios of 1.5 or less were commonly used on low-amylose rice and ratios of 1.8-2.1 were used on intermediate- and high-amylose rice. The 75% water in cooked rice obtained at a water-rice ratio of 2.65 was not very sensitive in distinguishing the amylose types.

Amylopectin of waxy rice

We have demonstrated that the rate of hardening of cooked waxy rice products is faster in rices with high gelatinization temperature (GT) than in those with low GT. The reason is the greater molecular size of the major starch fraction, amylopectin, in the high-GT rice.

Laboratory analyses confirmed that the major difference between high-GT and low-GT rices was in size of molecule rather than in its fine structure or degree of branching.

NUTRITIONAL QUALITY

Rice remains the major source of protein for the people of most of Asia; for many it is the only protein source.

These preschool children give full attention to their special rice diet at the Food and Nutrition Research Institute, Manila. The cooperative study of dietary nitrogen balance started in 1979.

Protein quality of milling fractions

We repeated a cooperative nitrogen balance study of diets including brown, undermilled, and milled rices with casein (2:1 nitrogen contribution) for preschool children. The 1981 tests at the Nutritional Evaluation Laboratory, Food and Nutrition Research Institute (Manila), was at a nitrogen intake of 200 mg/kg body weight. The results confirmed our 1980 results that the 3 diets have similar apparent nitrogen digestibilities and retention compared with values for the casein control.

We also continued a study on nitrogen balance in rats in cooperation with the National Institute of Animal Science, Denmark. Tests with IR32 milling by-products revealed that bran and polish had lower true digestibility, higher biological value, and resultant comparable net protein utilization relative to brown and milled rices (Table 4). They also had lower digestible energy.

Table 4. Nitrogen balance studies with 5 growing rats and IR32 brown rice and its milling fractions[a] showed milled rice to be superior in true digestibility and percentage of digestible energy. The study was done with the National Institute of Animal Science (Copenhagen).

Sample	True digestibility (%)	Biological value (%)	Net protein utilization (%)	Digestible energy (%)
Brown rice	96.9 b	68.9 b	66.7 bc	94.3 b
Bran	78.8 d	86.6 a	68.3 b	67.4 d
Polish	82.5 c	86.3 a	71.2 a	73.3 c
Milled rice	98.4 a	67.5 b	66.4 c	96.6 a

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

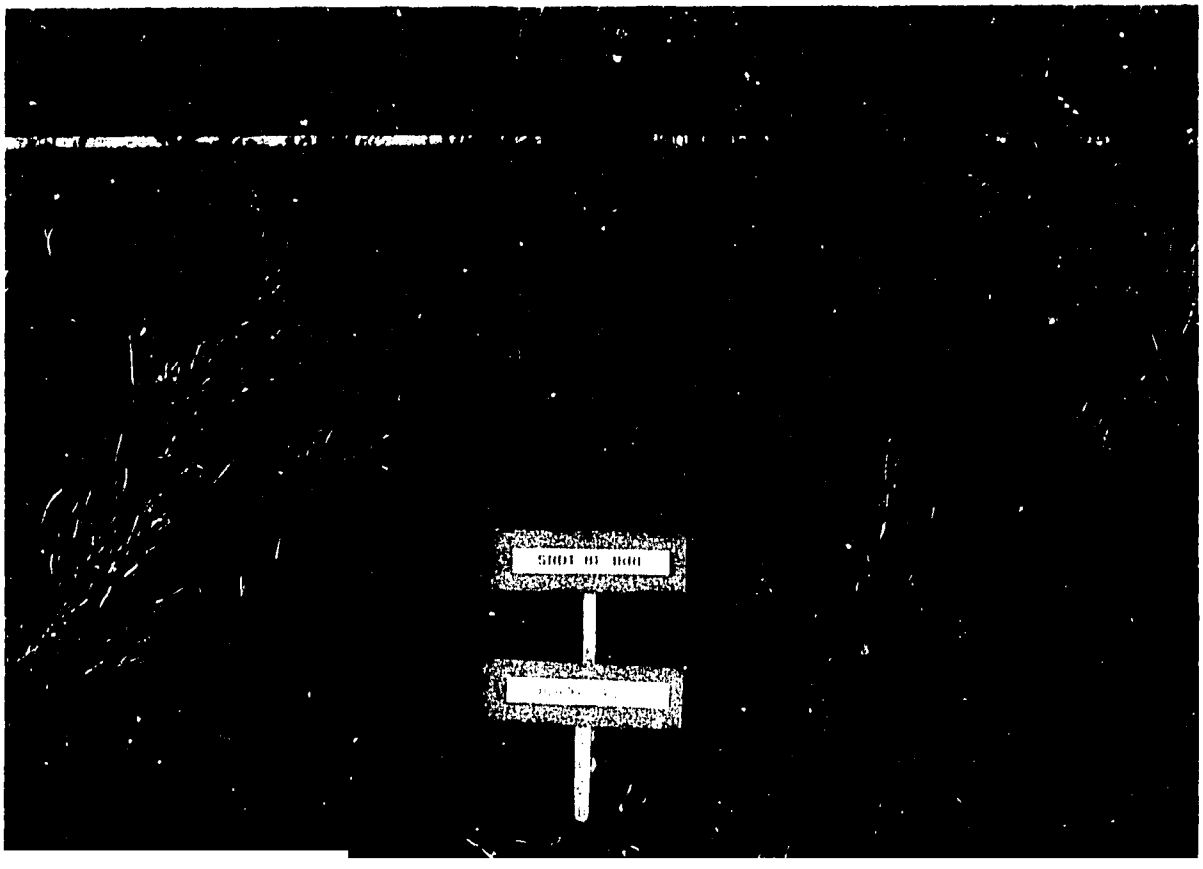
Sulfur amino acids in plants grown on sulfur-deficient soils

Studies of cereals and legumes have demonstrated that sulfur containing amino acids may be lower in the seed proteins of plants produced on sulfur-deficient soils. Sulfur amino acids are not nutritionally limiting in rice protein, but their reduction may reduce the protein quality of rice-legume diets.

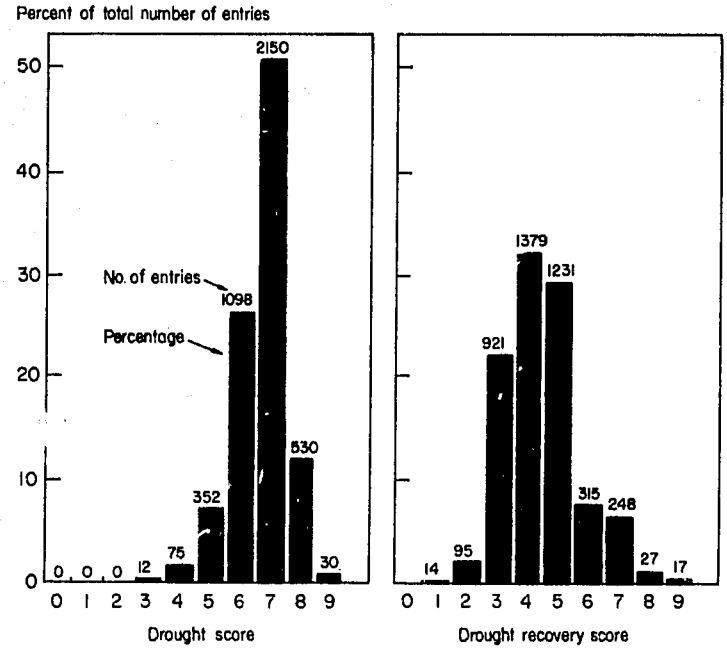
We did a preliminary screening of brown rice grown in sulfur-deficient soils in Indonesia and Bangladesh, with and without sulfur added to the soils. We found no adverse effect of soil sulfur deficiency on the content of sulfur containing amino acids, cystine, and methionine in brown rice protein. Total sulfur amino acids in 4 Indonesian samples averaged 4.9% of brown rice protein with sulfur-treated soil and 5.2% without sulfur. BR3 rice from Bangladesh had corresponding values of 5.1% of brown rice protein for both samples. Thus the soil sulfur deficiency affected total yield of seed but not its composition.

DROUGHT RESISTANCE

Even a short drought that hits the rice crop at the wrong time — especially at heading — can cut yields drastically.



Among the 4,247 rices tested at IRRI for drought resistance during the dry season, IR24760-24-2 appeared highly promising. It was one of 12 entries with a score of 3, which means tip drying did not extend beyond one-fourth of most leaves.



17. Dry season drought reaction screening of 4,247 rices during the 1981 dry season identified several entries with good drought stress and drought recovery scores. Screening was at 10 bars of soil moisture tension. Information on the best entries is made available to scientists developing rices for dryland and other rainfed cultures where drought is a problem.

Drought resistance is absolutely essential in rices grown by the dryland rice farmers and can remove the burden of risk for farmers growing rainfed wetland and deepwater rices in periods of uncertain rainfall. Even the farmer growing irrigated rice benefits from drought resistance in areas of irrigation systems where water supply is uncertain.

An unusual dry spell from 19 July to 6 September 1981 at IRRI gave us a rare opportunity to check rices for drought tolerance during the wet season.

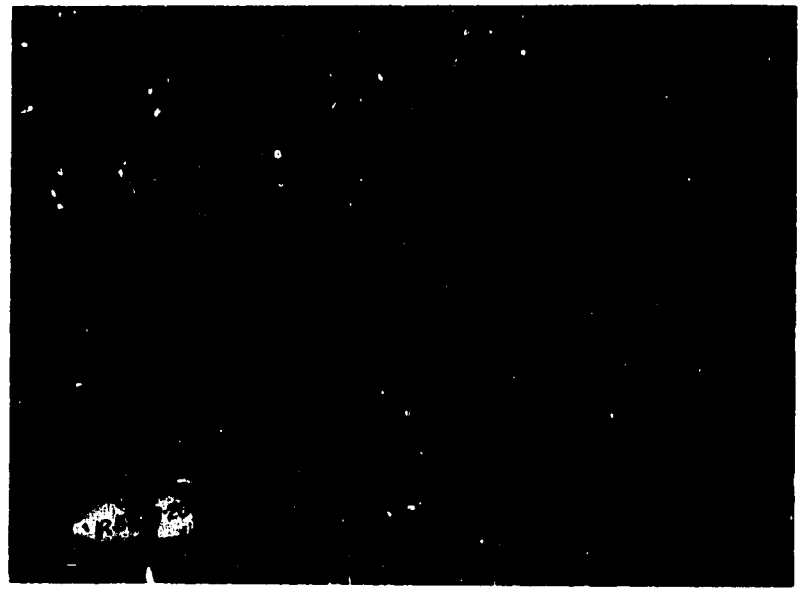
Promising drought-resistant rices

Our 1981 screening for drought resistance identified 12 among 4,247 rices tested with a score of 3 (Fig. 17). Two entries — IR13204-3-3-3-1 and IR24760-24-2 — were most promising when both drought stress score and recovery score were considered.

Drought resistance in IR lines

During the extended drought at IRRI and at a research site in neighboring Batangas Province, many varieties and lines in yield trials were severely stunted and most of the leaves died. When the rains resumed in September, many lines did not recover.

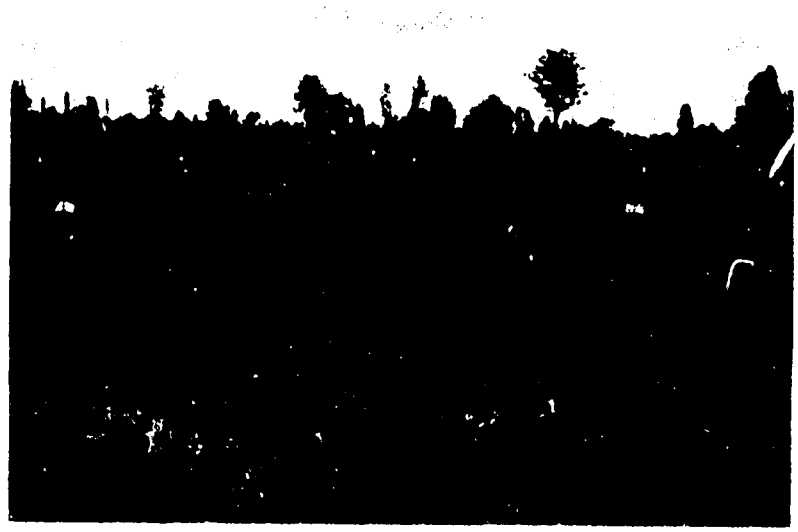
On the other hand, a few of the most drought-resistant lines retained green leaves and slowly but steadily achieved reproductive growth. Among the drought-resistant lines were IR3646-9-



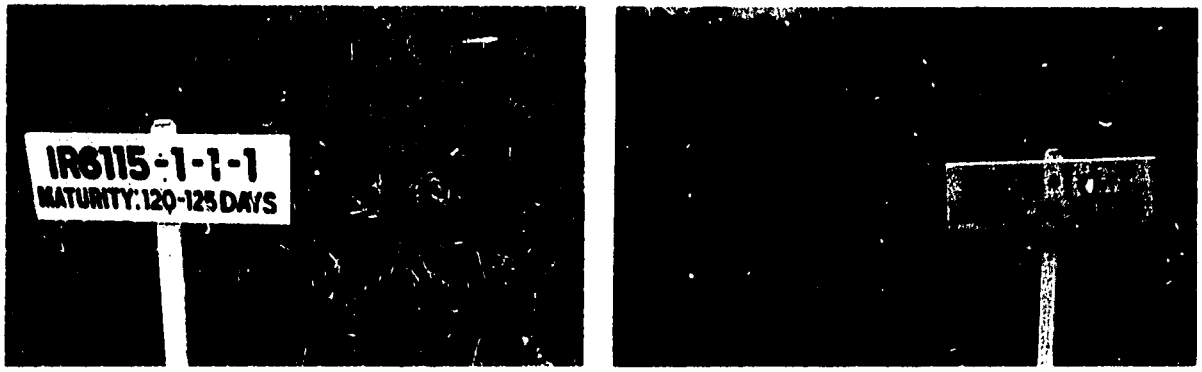
18. This plot of IR5873-20-1 survived an extended drought on a Batangas, Philippines, farm and gave a yield of 1.5 t/ha in 1981 drought resistance trials.

1, IR3646-13-1, IR5873-20-1, and IR10068-11-1. Non-IR lines with comparable performance in the yield trials were TOX378-N1B-N12-N1B from the International Institute of Tropical Agriculture (Nigeria), and UPLRi7 and UPLRi5 from the University of the Philippines at Los Baños. Figure 18 shows IR5873-20-1, which survived the drought and yielded 1.5 t/ha in a farmer's field in Batangas.

A similar drought occurred in northeastern Thailand at about the same period. Figure 19 shows the uninterrupted reproductive growth of IR3646-9-1 at the Khon Khaen Agricultural Research Center.



19. Drought-resistant IR3646-9-1 (extreme right) in these plots in Thailand maintained growth during a severe drought that hit the trial at the crop's reproductive stage.



20. IR6115-1-1-1 dried and turned completely brown (left) during a 1981 drought that hit IRRI plots. After a series of showers the plants resumed green growth and produced panicles (right).

Drought recovery in IR lines

The ability to recover from drought — after soil water is replenished — is another varietal facet of drought response. Many traditional rices and modern semidwarf breeding lines are excellent in recovery ability but rather poor in drought resistance, primarily due to a poor root system.

Some IR lines have been repeatedly tested in alternating dry and wet soils and selected for a moderate level of drought resistance as well as good recovery ability. Figure 20 shows IR6115-1-1-1 plants adversely affected by drought in early September, and the same plants 40 days later when they had fully recovered — after a series of showers — and produced fertile panicles.

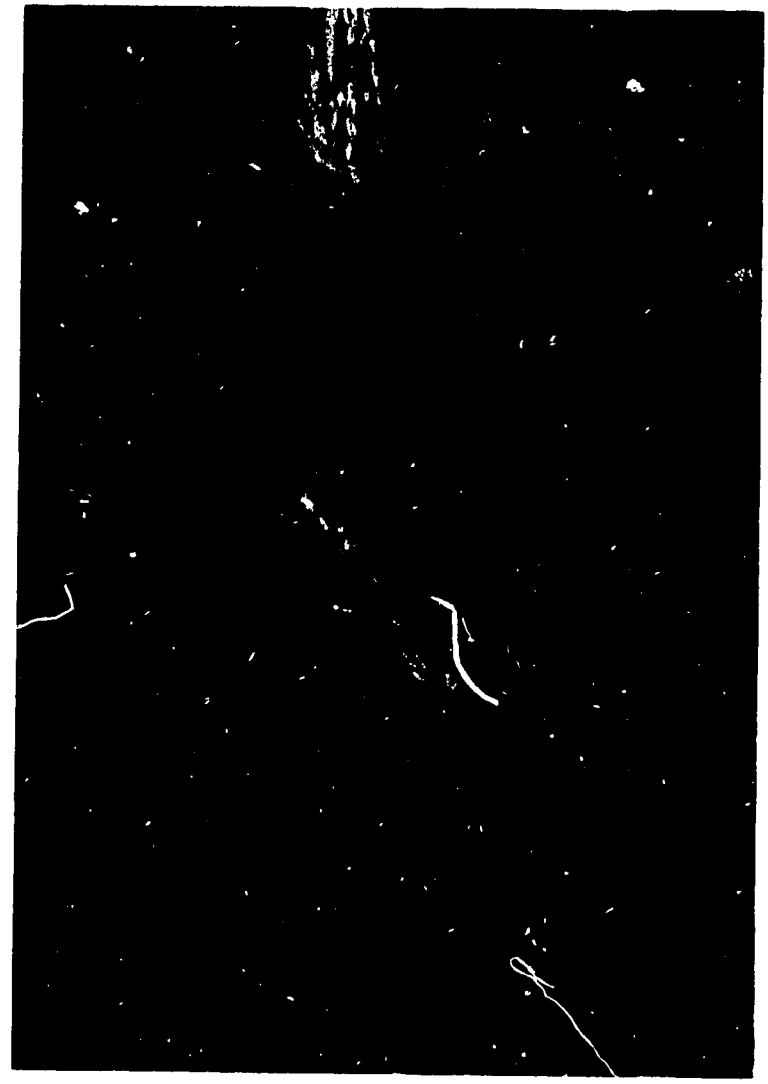
Reproductive stage drought screening

Our work since 1979 has confirmed that drought during the reproductive stage of rice is generally more damaging than drought during the vegetative growth. A relatively mild short-duration drought at or near flowering may drastically reduce the number of fertile spikelets and drop yield to a fraction of its potential (Fig. 21). We continued work on an efficient reproducible field method for detecting varietal differences in resistance to drought at flowering.

The method has three key attributes:

- entries are subjected to several levels of drought severity at flowering,
- planting is staggered to concentrate the flowering period of all entries in as narrow a time frame as possible, and
- drought scores and performance criteria are adjusted to account for differences in the date of flowering in relation to timing of the stress period.

The entries tested in 1981 flowered during or slightly beyond the stress period imposed and grain yields tended to decline linearly as a function of the flowering date (Fig. 22). The linear



21. Reproductive stage water stress may disrupt the flowering process or desiccate and kill the panicle entirely, as shown in many entries in our 1981 dry season test.

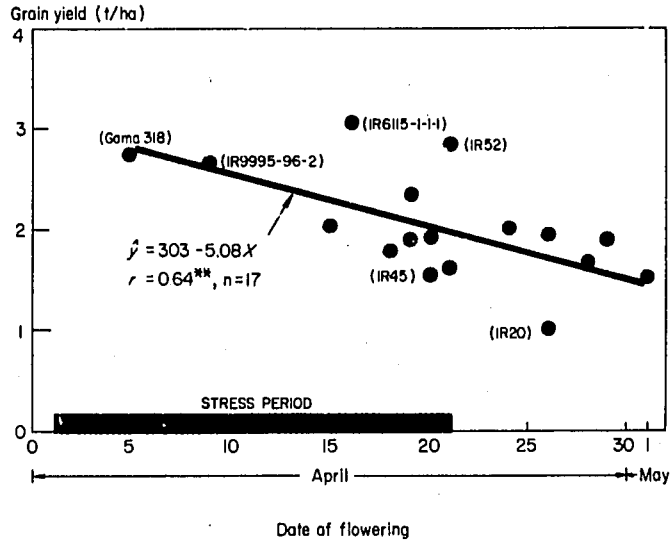
regression estimated an expected performance for each entry. IR6115-1-1-1 and IR52 tended to demonstrate outstanding performance although both flowered during the maximum stress period. IR20, the drought-susceptible check, showed poor performance.

An infrared thermometer for drought resistance screening

We know that rice varieties with superior root systems maintain transpiration during drought and are less affected by water stress. However, screening large numbers of rices for root system characteristics is extremely costly.

In 1981 we started obtaining information about root system

22. When drought strikes a rice crop at the reproductive stage, yields are strongly influenced by the date of flowering in relation to the time of stress. Entries whose yields were highest above the regression line are the most desirable. In the regression, X is days after start of stress.



23. The infrared thermometer gives instant remote readings of canopy temperatures when pointed at a field plot. The instrument identifies cool rices in drought conditions. Such cultivars are desirable because they have a superior ability to extract and utilize stored moisture.

performance by infrared radiation measurement. An infrared thermometer was used to determine temperature of the crop from a distance of several meters (Fig. 23). Genotypes with superior root systems were cooler during drought because they continued

Table 5. Canopy temperatures in a drought-stressed rice crop taken with an infrared thermometer. Temperatures varied significantly among entries subjected to 2 levels of drought stress. Drought-resistant entries had consistently cooler canopies than susceptible entries.

Entry	Temperature (°C) of crop canopy[a]	
	Mild drought	Severe drought
IR30	31.2 a	33.5 a
IRAT9 (susceptible check)	31.2 a	33.0 ab
IR36	31.0 ab	33.1 ab
IR5179-2	30.3 abc	32.6 abc
RP1158-111-1	30.1 abc	31.5 c
IR5929-12-3	29.3 cd	31.7 bc
IR52 (resistant check)	29.2 cd	31.2 c

[a]Values followed by a common letter are not significantly different from each other at the 5% level.

transpiring water. IR52, a drought-resistant variety recently released in the Philippines, showed the lowest canopy temperatures of all entries tested in the dry season (Table 5).

The infrared thermometer can be used for fast evaluation of large numbers of entries in field trials.

Microscopic studies of the rice spikelet at flowering

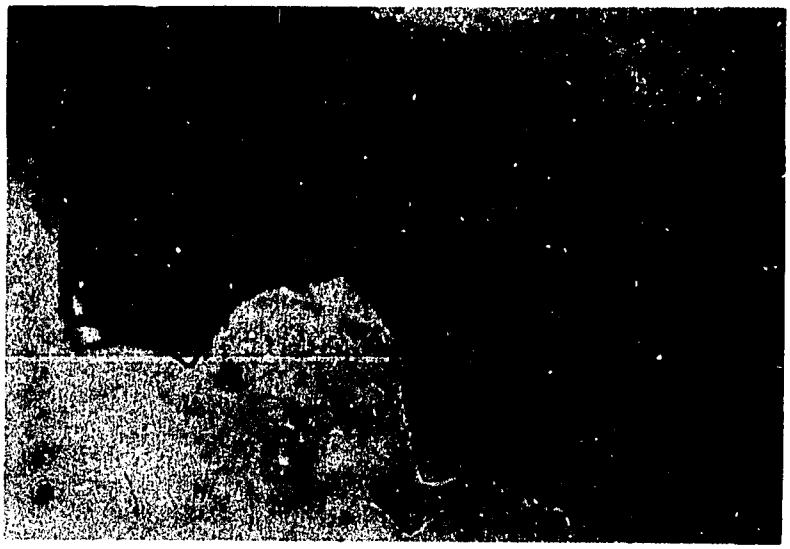
The spikelets of rice are prone to desiccation after the panicle emerges, whereas those for other cereals such as wheat are resistant. This leads to speculation about the factors responsible for the poor ability of the rice spikelet to control water loss, and the possibility of modifying the spikelet to obtain better flowering and grain growth during drought.

One possibility may lie in increasing the thickness of the siliceous layer that covers the exterior of the spikelet. This layer takes the form of a series of deeply dissected plateaus of silicon-rich materials (Fig. 24), which may play the role of partial barrier to water loss.

We measured the thickness of the siliceous layer in 19 rice genotypes and found a fourfold range of variability among them. Mean thickness varied from 4.1 to 17.8 μm, indicating considerable potential for genetic manipulation if the character is found to be of practical value.

Varietal difference in aluminum toxicity tolerance

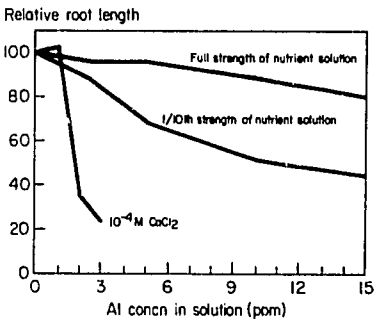
We tested 173 rices for aluminum toxicity tolerance using the relative-root-length technique. Tolerant varieties were mostly dryland varieties and mainly from South America and Africa. There is an apparent association between aluminum toxicity tolerance and deep rooting habit because successful dryland varieties have been mostly selected on the basis of their performance



24. These are cross-sections of the lemma of a rice spikelet at flowering time. The siliceous layer that covers the exterior is stained purple. A thicker siliceous layer may reduce the tendency of spikelets to desiccate when the plant is water stressed.

where roots must extract water from highly acid, aluminum-toxic subsoils.

Concentrations of companion ions in a solution have a profound influence on the critical aluminum concentration. When the concentration of salts is low, the critical concentration for aluminum toxicity is around 2 ppm for susceptible varieties; tolerant varieties can tolerate aluminum toxicity at much higher concentrations (Fig. 25). This finding confirms that aluminum saturation of a soil is a better criterion than exchangeable aluminum for diagnosing soil aluminum toxicity.



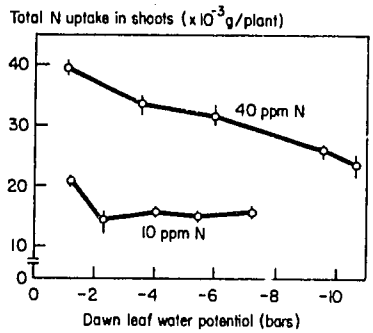
25. The sensitivity of root elongation (variety Cica 4) to aluminum toxicity was affected by the presence of nutrients in the solution. In acid dryland soils, rice becomes sensitive to aluminum because the soil solution contains low amounts of nutrients.

Effects of osmotic stress on nitrogen uptake of rice

A continuing dilemma for rice farmers in drought-prone areas is the amount of fertilizer to use. Drought can affect plant growth through an influence on nutrient uptake but information relating moisture stress of the rice plant to nutrient uptake is limited.

We exposed 21-day-old IR36 seedlings grown in culture solution containing high (40 ppm) and low (10 ppm) amounts of nitrogen and simulated moisture stress (solution water potentials) by addition of polyethylene glycol 6000. We found that moisture stress reduced total nitrogen uptake in shoots grown at both nitrogen levels (Fig. 26). Total nitrogen content increased linearly with cumulative transpiration, but plants in 40 ppm N contained more N than those in 10 ppm N.

Reduced nitrogen uptake, therefore, not only is a result of unavailability of soil nitrogen because of low soil moisture content but is also brought about by plant water stress per se.



26. Nitrogen uptake by the rice plant drops as leaf water potential (moisture stress) increases. Vertical bars indicate the standard deviation of 3 replications.

ADVERSE SOILS

In 1976 a detailed study of problem soils in rice-growing areas of Asia pinpointed more than 100 million hectares of idle land that could grow rice if existing soil toxicities could be overcome. Included were:

- saline soils on 59 million hectares;
- organic (peat) soils on 30 million hectares;
- acid sulfate soils on 5 million hectares; and
- alkali soils on 7 million hectares.

Since 1972 we have screened nearly 100,000 rices for tolerance for soil stresses. By 1980 we had identified 780 outstanding improved rices with disease and insect resistance and tolerance for specific adverse soils.

In 1981 we evaluated the 780 tolerant rices in 52 experiments in farmers' fields with soil problems at 41 sites in the Philippines. Our results were highly encouraging.

Stress tolerance as a substitute for soil amendments

Varietal tolerance for soil stresses is a substitute for, or a supplement to, soil amendments. Table 6 shows that IR43 without lime

Nearly 10,000 ha of land like this remain idle in Pampanga Province, Philippines, because of soil salinity. The problem is compounded by flooding during the wet season and intrusion of tidal water.

Salt-tolerant rices were tested in farmers' fields in the Philippines during 1981. Tolerant lines such as these offer potential to obtain 6 t/ha per year where no rice is now grown.

Table 6. Varietal tolerance appeared a viable substitute for soil amendments for 3 soil problems in 1981 tests. IR54, which has multiple disease and insect resistance, was released in the Philippines in 1980.

Soil problem, variety	Grain yield (t/ha)	
Iron toxicity	*No lime*	*With lime*
IR43	6.2	6.2
IR26	3.9	4.8
Phosphorus deficiency	*No P*	*With P*
IR54	4.7	5.1
IR36	2.4	4.1
Zinc deficiency	*No Zn*	*With Zn*
IR54	4.4	5.2
IR26	3.1	4.2

yielded more than IR25 with lime, and that IR54 without fertilizer outyielded IR26 and IR36 with fertilizer.

Two rice crops where none grew before

Most coastal lands in the Philippines are uncultivated because they are saline in the dry season and deeply flooded in the wet season. By planting IR50 — an early-maturing, salt-tolerant, improved variety — at the end of the wet season and again early in the wet season, we overcame the salt injury in March-April and the flood damage common in July-August. Average yields for 3 sites were 6 t/ha per year, without costly inputs.

The 1981 results indicated that two rice crops are possible on vast tracts in South and Southeast Asia with similar salt and water regimes if early-maturing, salt-tolerant cultivars are grown.

Improved rices suited to specific soil problems

We can now offer national rice improvement programs modern disease- and insect-resistant rices suited to specific problem soils. Some of those rices and the yields obtained in our tests in farmers' fields are listed in Table 7.

Tolerance for a soil stress gives modern varieties a comparative yield advantage of more than 2 t/ha.

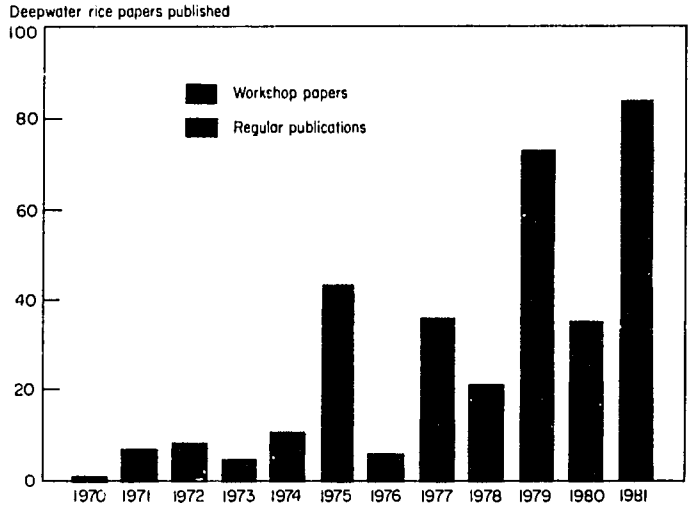
Table 7. These varieties and lines were outstanding in tests in adverse soils in farmers' fields during 1981. No soil amendments were made.

Soil problem	Variety or line	Mean yield (t/ha)	
		IR rices (left)	Local rices
Salinity	IR50, IR5657-33	3.6	1.5
Alkalinity	IR36, IR4595-4	3.6	0.9
Strong acidity	IR42, IR4683-54	4.2	2.2
Peat	IR42, IR8192-31	3.1	1.4
Aluminum toxicity	IR43, IR6115-1	3.8	2.0
Phosphorus deficiency	IR52, IR8192-200	4.4	1.9
Zinc deficiency	IR36, IR8192-31	2.9	0.8
Iron deficiency	IR36, IR52	2.8	0.9

Since the first deepwater rice workshop in 1974, research for that crop has steadily increased and workable technology to help the deepwater rice farmer improve his lot is moving onto his fields. Two modern varieties for deepwater rice areas were released in 1980 and in 1981 dozens of promising lines in advanced tests held promise that newer and better varieties will not be far behind. The 80 Asian scientists who attended the Fourth International Deepwater Rice Workshop in Bangkok during November 1981 presented ample evidence to confirm their progress.

An indication of the increased tempo of deepwater rice research is seen in the rapidly increasing number of publications and other literature concerned with the crop, especially since deepwater workshops were held (Fig. 27).

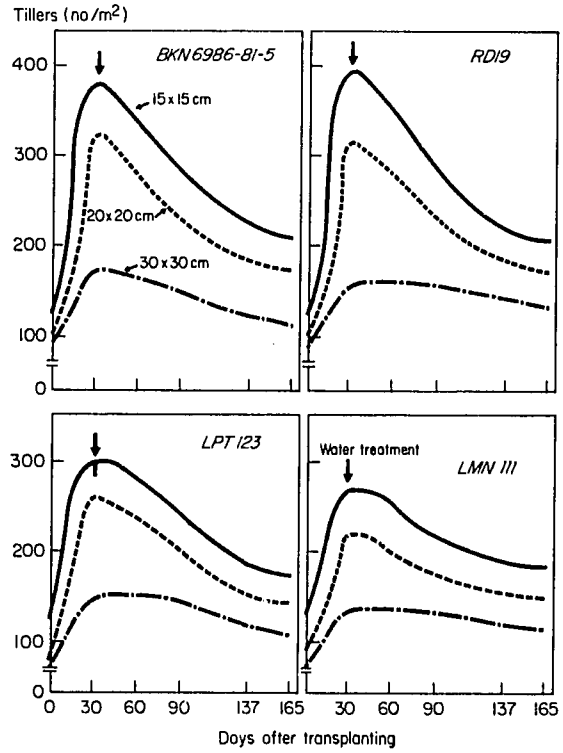
Participants in the 1981 International Deepwater Rice Workshop, which was co-sponsored by IRRI and the Government of Thailand, check deepwater rices at the Prajinburi Deepwater Rice Experiment Station, Thailand. D. HilleRisLambers (left), plant breeder with the Thailand-IRRI Cooperative Deepwater Rice Project, explains a trial to the participants.



27. The number of papers on deepwater rice published by the world's rice scientists has increased, especially in the years after the first international workshop in 1974. In the 1981 workshop in Thailand, 50 papers were presented and discussed.

Stand establishment in deepwater rice

Experiments at Huntra Rice Experiment Station in Thailand brought out the importance of stand establishment for the deepwater rice before the onset of floodwater. In stand establishment tests the spacing for transplanted crops and seed rate for direct-seeded crops were varied. Even though flooding caused a greater



28. Tiller number remained highest at closer spacing (denser planting) for 4 varieties grown at 70-cm water depth at Huntra Rice Experiment Station, Thailand, in the wet season. The higher tiller density resulted in higher yields.

tiller reduction in the denser planted crops than in those planted at traditional density, the denser stands (Fig. 28) gave the advantage of more growth before the onset of floodwater, which resulted in yield advantages.

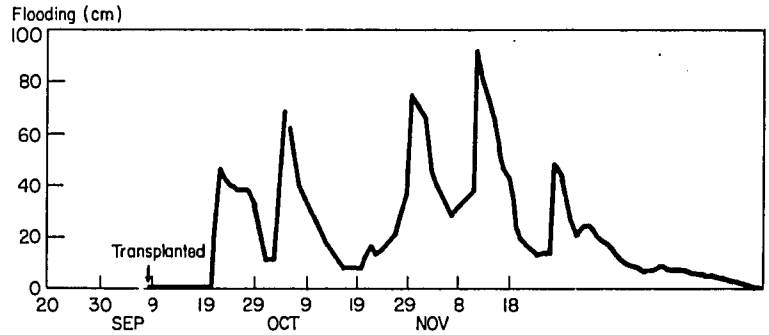
Deepwater rice tests in farmers' fields

Rice varieties for deepwater fields need to be adapted to complex environments that have not been extensively characterized. Breeding lines must be tested on farms to make sure that they:

- are adapted to the prevailing flooding pattern, depth, and timing;
- mature at the appropriate time after maximum flood — but before the drought; and
- survive local soil factors, diseases, and insects.

Deepwater rices were tested on farms in the Cagayan Valley of northern Luzon, Philippines, to identify suitable cultivars to fill a void in the cropping calendar between August and December.

We tested 261 varieties and lines of varying deepwater tolerance and flowering behavior at 4 sites in the Cagayan River backswamp. Hydrographs were made and survival of the varieties was recorded. Figure 29 is a typical hydrograph. Figure 30 shows flooded trials.



29. Flash floods in the Cagayan River Valley put water depths above 60 cm in farmers' fields 3 times in 1981. The crop was transplanted 9 September and flashflooded 10 days later.

30. This flash flooding of rice fields is typical of large areas near Solana, in the Philippines' Cagayan Valley. The flooding here is graphed in Figure 29.

Table 8. Numbe. of varieties in 1981 tests in the Cagayan Valley, Philippines, with low, 50, 75, and 100% survival, grouped on the basis of previous information on their flash flood tolerance.

Flood tolerance	Varieties (no.) with indicated tolerance				All
	100%	75%	50%	Low	
Known tolerance for flash flood	12	3	12	5	32
No previously known tolerance for flash flood	20	38	66	105	229

Among 32 varieties with the best (100%) survival at the hydrograph site, only 12 had been previously identified for their tolerance for flash floods (Table 8).

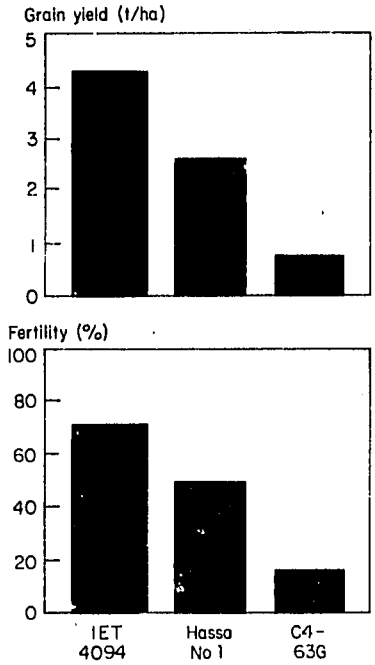
TEMPERATURE TOLERANCE

Increased cold tolerance of rice is needed in temperate regions and in high altitude areas in the tropics. Increased heat tolerance is needed in areas prone to high temperature, such as North India, Pakistan, the Middle East, and tropical Africa. Temperature tolerance for some areas is complicated because a combination of cold tolerance at seedling stage and heat tolerance at flowering is required.

Rapid generation advance for low temperature tolerance

Effective cooperative use of facilities at IRRI and in Korea has resulted in rapid progress in development of cold-tolerant breeding lines. Since 1979 we have used rapid generation advance

A Korea-IRRI planning session for collaborative research on cold tolerance, pests and diseases, and seed multiplication is held annually at IRRI. D. S. Kim, Office of Rural Development, Korea, describes the substation in Korea available for collaborative research on cold tolerance.



31. IET4094, a heat-tolerant selection, outyielded Hassa No. 1 (a local check) and C4-63G (a susceptible check) at Al-Hassa, Saudi Arabia, in 1981.

(RGA) at IRRI to speed the breeding of rices for low temperature areas. By planting the breeding lines in screening facilities made available by the Office of Rural Development in Korea, we were able to screen the lines for optimum growth duration, leaf discoloration, panicle exsertion, and spikelet sterility. In 1981 we entered some RGA lines in the 1982 International Rice Cold Tolerance Nursery for international testing, an indication of the rapidity and usefulness of the process when tied to the screening facilities in Korea.

The five outstanding cold-tolerant lines in the 1981 observational yield trial at Korea were SR5204-91-4-1, IR1524-265-3, IR9202-33-4-2-1, IR7167-33-2-3-3, and IR20897-B-45. SR5204-91-4-1 had yields of 6.9 t/ha. The IR9202 line is from the same cross that provided four top yielders in the 1980 trials. The need for improving cold tolerance at panicle initiation and flowering stage was apparent in many entries.

Field testing of heat-tolerant selections

Heat-tolerant selections identified in phytotron screening at IRRI were put in tests in the field in Saudi Arabia, Iraq, and California, USA. In the test in Al-Hassa, Saudi Arabia, many IET lines from India, which were selected for heat tolerance in the phytotron, performed well. The best heat-tolerant selection, IET4094, yielded 4.3 t/ha while a local check, Hassa No. 1, yielded 2.6 t/ha. A heat-susceptible check, C4-63G, produced only 0.8 t/ha.

The better performance of IET4094 was attributed to heat tolerance as indicated by higher spikelet fertility (Fig. 31).

INNOVATIVE BREEDING METHODS

A new laboratory designed specifically for tissue culture research was opened in May 1981. The new facility, which is attached to the phytotron, gave us space to rapidly develop tissue culture research. The development of a practical system for hybrid rice production also advanced in 1981.

Seed-derived-callus culture system

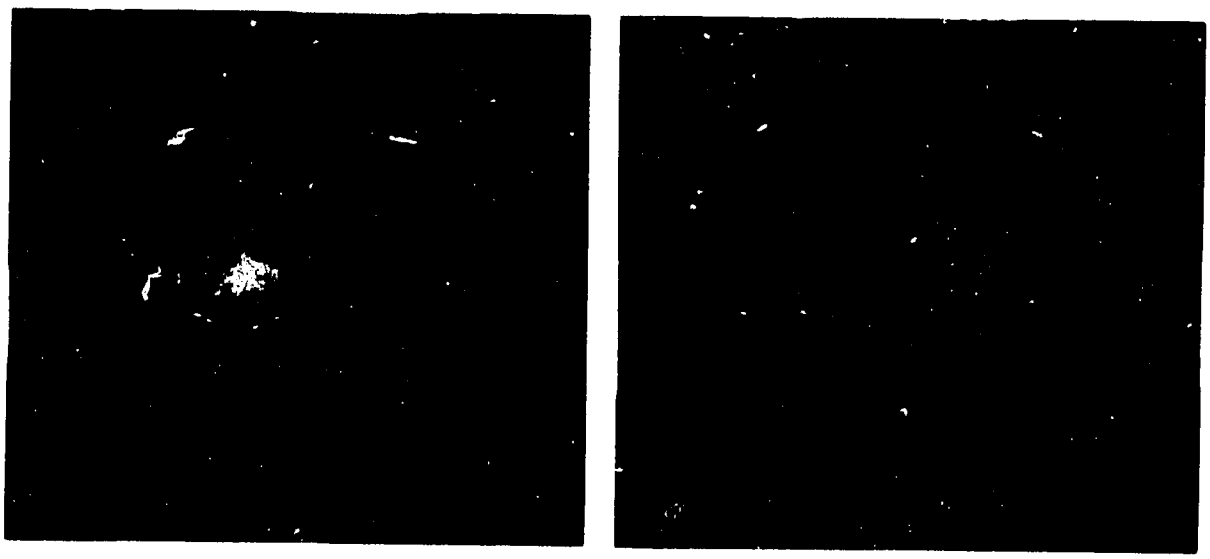
A simple, efficient seed-derived-callus culturing system was worked out for developing salt-tolerant mutant plants. We believe the same system can be used in studies of other kinds of stress tolerance by simply changing the stress or selection pressure applied to the agar medium.

The system consists of six steps:

1. Callus is induced from surface-sterilized brown rice on the modified Murashige-Skoog (MS) medium.
2. The callus is transferred to another culture flask containing the same medium for proliferation.
3. The proliferated callus is divided into small pieces, which are transferred to the modified MS medium with or without NaCl. This step is repeated three to six times before the callus is finally transferred to the regeneration medium for plant regeneration.
4. The regenerated plants are transferred to potted soil and grown to maturity.
5. Seeds from the regenerated plants are grown and screened for salt tolerance using a solution culture technique in an artificially lighted cabinet. With this technique 540 seedlings in the cabinet are screened for 3 to 5 weeks, depending on the degree of salt tolerance. Salt-tolerant mutant plants that are found are transferred to a normal culture solution, then to potted soil.
6. Seeds from the mutant plants are grown in the field and are screened for salt tolerance and agronomic traits.

Selection of salt-tolerant mutant callus and plants. When callus is transferred to a medium containing sodium chloride (15 g/liter), the callus usually turns dark brown, an indication of necrosis. However, when this step is repeated more than three times, callus grows vigorously from the necrotic callus (Fig. 32).

More than 8,000 plants were regenerated by the seed-derived-callus culture in 1981 and massive screening for salt tolerance at



32. When callus is transferred to a medium containing NaCl (15 g/liter), the callus usually turns dark brown, an indication of necrosis. However, when the transfer is repeated at least 3 times, callus grows from the necrotic callus (left). These salt-tolerant callus lines grow better in the subsequent subculture (right).

33. More than 8,000 plants like these have been regenerated by the seed-derived-callus culture system. They are screened at the 3-leaf stage of seedlings in 0.75% NaCl plus nutrient solution. The green surviving plants have salt tolerance.

the seedling stage started. There are clear indications that mutation occurs in two directions —increase in sensitivity and increase in tolerance. Several salt-tolerant mutant plants from Taichung 65 were identified (Fig. 33).

Somaclonal variation induced by seed-derived-callus culture

Somatic tissue culture offers a new avenue of research to generate a wide range of genetic variability. Tissue culture *per se* appears to induce genetic variation.

Many unusual plant traits have been observed in two generations (R_1 and R_2) of plants regenerated from callus. Visible changes included reduced plant height, early maturity, tetraploidy, large grain with normal fertility, awns, dwarfism, albinoism, rolled leaves, white or yellow stripes, open spikelets, and sterility.

Occurrence of such abnormal traits is not always observed in all the plants regenerated from one callus line or among the different shoots of the same plant. These observations suggest that plants from one callus line are heterogenic and some regenerated plants are chimeric. Occurrence of mutation in the visible plant traits suggests that mutation would also occur in physiological and biochemical traits.

Progress in anther culture research

A limitation of anther culture research is that only a limited number of pollen grains have the capacity to produce plants. In 1981, we concentrated on search for factors that would allow us to overcome that problem.

A liquid medium with the capacity to stimulate a larger number of pollen grains to develop into callus was devised. With that medium, efficiencies of up to 600% (callus production per number of anthers plated) were obtained.

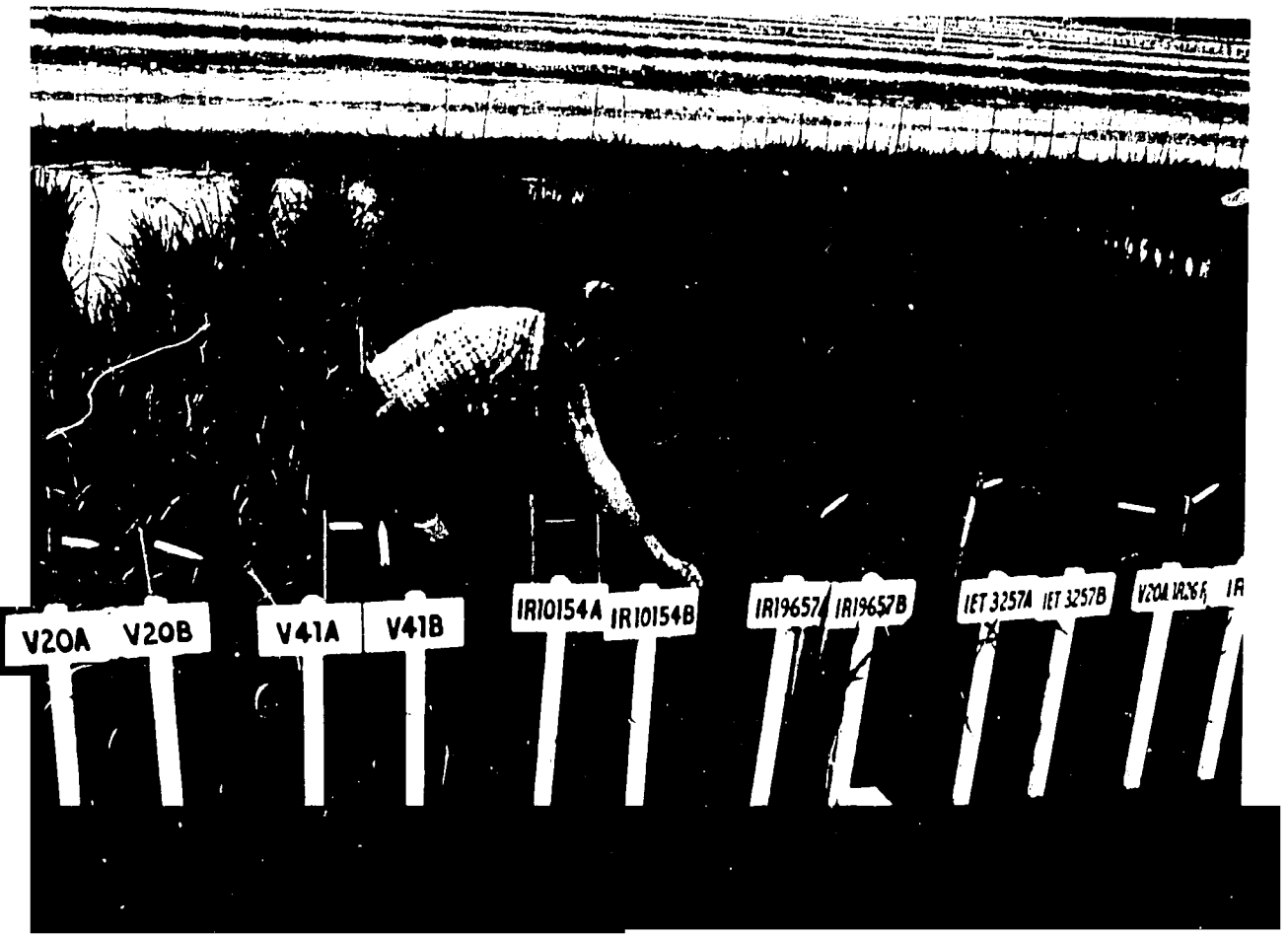
Taipei 309 — a japonica type — and Mingolo — an indica type — have been considered model systems for basic anther culture research because of their high callusing and plant regeneration efficiency. So far, anther culture has enabled us to regenerate plants and produce seeds of 21 japonica, 9 indicas, and 6 F_1 hybrids. We continued research on transferring the regeneration capacity of varieties that are high callus producers to varieties with more desirable agronomic characteristics.

Hybrid rice potential stays high

Our work with hybrid rice continues to indicate that hybrid rice has the potential to increase farmers' rice yields by 20-25%. An experimental hybrid at IRRI yielded 10.4 t/ha in the 1981 dry season — 2.4 t/ha higher than the popular modern variety IR36 in the same trial.

The potential for hybrid rice goes beyond farms with irrigation. An experimental hybrid in a rainfed (nonirrigated) wetland field in Pangasinan Province, Philippines, yielded 5 t/ha. IR52, a drought-resistant variety especially bred for rainfed wetland fields, yielded 4.2 t/ha in the same field.

S. S. Virmani, IRRI plant breeder, works at IRRI with cytoplasmic male-sterile lines (IR10154A, IR19657A, IET3257A), which we adapted to tropical conditions, from cytoplasmic male-sterile lines Er-Jiu-Nan 1A, V20A, and V41A introduced from China.



34. Hybrid seed production, seen here in IRRI plots, requires planting a restorer row between every 5 rows of male-sterile plants. The male-sterile female plants can be fertilized only by the restorer plants.

Insect and disease susceptibility of the available stable male-sterile lines, which we introduced from China, is the major constraint to development of commercial F_1 rice hybrids for the tropics. Therefore, we are transferring the male sterility of these lines into the elite breeding lines adapted to the tropics. Stable male-sterile lines with disease and insect resistance should be available during 1983.

With hybrid seed production techniques developed in China (Fig. 34) we obtained as high as a 30% seed set on male-sterile lines and a hybrid seed yield of 1.5 t/ha in the dry season. That compares favorably with commercial hybrid seed yield in China.

We continued to collaborate with Chinese scientists in developing and improving hybrid rice breeding technology. A number of elite restorer lines used as male parents in the F_1 hybrids have already been identified and some of them are being used to develop new hybrid rices in China. With the Chinese Academy of Agricultural Sciences we jointly organized a second training program on hybrid rice at the Hunan Academy of Agricultural Sciences at Changsha. To date, 19 rice breeders from IRRI and 6 Asian countries (Bangladesh, India, Indonesia, Philippines, Sri Lanka, and Thailand) have been trained in hybrid rice breeding.

Variability for breeding photoperiod-sensitive rices

Breeders of rainfed wetland rices usually have to deal with more traits than for irrigated rice. The rainfed crop may need photoperiod sensitivity as well as drought resistance, deepwater adapt-

ation, tolerance for adverse soils, and other associated traits. The many characters required cannot be combined, even in 4-parent complex crosses, in one cycle of selection.

We developed methods to recombine more than four parents in composite crosses by:

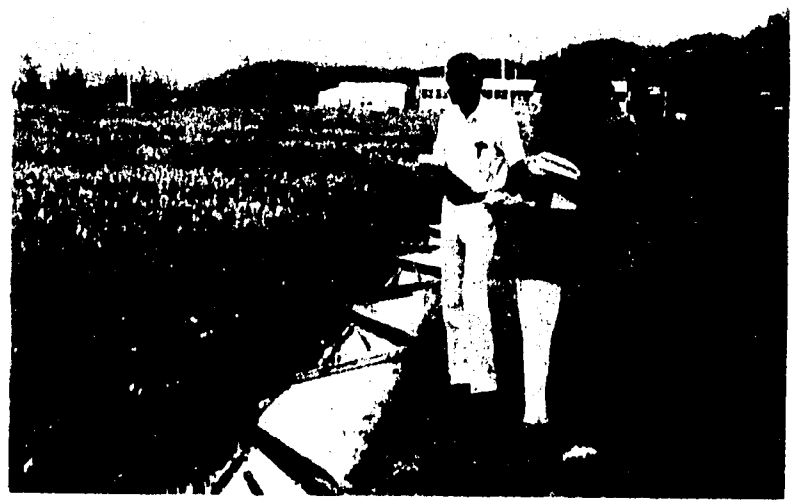
- temporarily converting rice into a cross-pollinator using genetic (recessive) male sterility from IR36 (MS);
- synchronizing the flowering dates among parents with different flowering behavior by giving 40 days of long-day treatment prior to treating the population with flowering-inducing short days; and
- increasing random mating by handling the population at close spacings — more than 1,000 plants/m^2.

Our rapid generation advance facilities in 1981 handled IR38497-CP 101 (6 parents) and IR38498-CP 102 (40 parents). These will have four generations of random mating, in which crosses from self-sterile plants will be selected, and three generations of fixation in which self-fertile plants will be selected. Finally, field selection will be made in different environments.

INTERNATIONAL RICE TESTING PROGRAM

Our International Rice Testing Program (IRTP) completed its seventh year in 1981. This international activity has effectively linked national and regional rice improvement programs with our Genetic Evaluation and Utilization (GEU) program.

The strength of the network comes from rice scientists who collaborate in the evaluation of elite germplasm, varieties, and



Korean Office of Rural Development scientists Kim Tong Jin, branch chief at Chuncheon, and Yea Jong Do, plant breeder (right), and IRRI Plant Breeder-IRTP coordinator V. Seshu Durvasula (left), make notes on performance of rice in the 1981 International Rice Cold Tolerance Nursery planted at Chuncheon.

advanced breeding lines as part of the worldwide effort to develop better rice varieties. Emphasis of IRTP in 1981 continued to be on strengthening those international linkages through its nurseries and on organizing monitoring tours and workshops. During these events the participating scientists identify problems of mutual interest.

International nurseries

IRTP nursery work expanded in 1981. We assembled more than 1,500 nursery sets, which went to 52 countries in the network. Almost simultaneously we analyzed 1980 trial results from more than 500 sites and published nursery reports.

A number of 1980 nursery entries continued to do well and many new promising entries were identified (Table 9). All of

Table 9. This list includes more than 150 rices that showed good performance at many sites in 1980 IRTP tests. Data from the tests were submitted by scientists at test sites and analyzed and summarized at IRRI.

Nursery	Promising entries
	Yield — irrigated
IRYN-VE (very early)	• IR9729-67-3, IR19746-28-2-2, BG367-7, IR19743-25-2-2
IRYN-E (early)	• IR9828-91-2-3, IR36, IR50, IR13429-196-1, Chianung sen yu 13
IRYN-M (medium)	• BR51-282-8, IR54, IR13540-56-3-2-1, IR15318-2-2-2-2, BG400-1, BR168-2B-23, IR42
IRYN-L (late)	• RP1064-14-2-2, MTU7029, RP975-109-2, CR1006, Mahsuri
	Yield — rainfed
IURYN (upland)	• IR5931-110-1, BG35-2, B733c-167-3-2, CR156-5021-207, IR52, IR6115-1-1-1, IR9560-2-6-3-1, IR995-96-2
	Observational — irrigated
IRON	• AD9246, IR4744-295-2-3, IR52, IR8608-82-1-3-1-3, IR9209-217-1-2-2, IR9224-140-3-2-2-3, IR9698-16-3-3-2, IR9782-111-2-1-2, IR9784-142-1-3-3, IR9852-22-3
IRARON (arid regions)	• B459b-Pn-32-3-5, C633 (IET3268), IR9761-1-2, MRC603-383, PAU14-2-2-B-9-2-1-1-1, PK178, Pusa 2-21, Rasht 507, SKL17-67-11 (IET6507), IR50, GZ864-2-1-1, CR410-1-3-4, CR547-1-2-3, CR547-1-2-5, CR581-6-1-1, GZ809-4-1-2, GZ916-3-1-1-2, Sakhai
	Observational — rainfed
IURON (upland)	• BG35-2, CR156-5021-207, IR3880-29, KMP34, ARC10372, C924-9
IRLRON (lowland)	• Mahsuri, IR13146-45-2, BR10, BR51-282-8, Pelita I-1, IR4819-77-3-2, IR4829-89-2, IR10781-75-3-2, IR10781-75-3-2-2, IR13146-41-3, IR13564-95-1
IRDWON (deepwater)	• RD19, SPR7233-1-24-2-2-2-3, SPR7292-151-2-1-B-B, Chamara, FRRS43/3, Khama

Continued on next page

Table 9 continued

Nursery	Promising entries
	Stress screening
Temperature	
IRCTN (cold)	• Fuzi 102, Olbyeo, China 1039, Deog-Jeog-Jodo, Hwanghaedo, Eiko (Acc9417), IR8455-K2, IR9099-K1, K78-13, IR9129-K1, IR9202-5-2-2-2, K39-96-1-1-1-2
Problem soils	
IRSATON (salinity and alkalinity)	• *Salinity:* Vegetative: C23-3-1, Getu Mutant 2735, IR36, IR2307-247-2-2-3, IR4595-4-1-15, IR4630-22-2-5-1-3, IR4630-22-2-17, Rok 8, Rok 9, Pokkali Maturity: IR36, IR4432-28-5, IR4595-4-1-15, IR4630-22-2-5-1-3, IR4630-22-2-17, IR9852-19-2, Rok 8, Rok 9, TNAU17069, Pokkali *Alkalinity:* CSR1, Getu, IR2058-78-3-2-3 (IR46), IR4432-28-5, IR4462-22A-2-10, IR8236-B-B-359-2-2, IR11418-19-2-3, Pokkali
Diseases	
IRBN (blast)	• IR1416-128-5-8, IR1905-81-3-1, IR4227-18-3-2, IR4547-4-1-2, IR4547-6-2-5, IR5533-PP850-1, IR5533-PP854-1, IR13149-19-1, Tetep, Carreon, Ta-poo-cho-z, Tres Marias, C46-15, 5287
IRTN (tungro)	• AC4236, ARC10342, ARC10495, ARC11353, ARC11554, Utri Merah, Utri Rajapan, BR51-66-3, IR9209-249-1-2-3-2, RD6-516-29-1-4-1-1
Insects	
IRBPHN (brown planthopper)	• IR13427-45-2-3-3, IR17496-2-25-1
IRSBN (stem borer)	• IR9828-23-1, IR13639-34, IR13635-38, IR19735-30-3-3

these superior entries are freely available to national rice improvement programs.

Monitoring tours and workshops

Monitoring tours in Asia focused on diseases in China, problem soils in India, and deepwater problems in Bangladesh, India, and Thailand. A regional monitoring program in West Africa covered rice research and testing activities in Senegal, Liberia, Ivory Coast, and Nigeria.

A regional workshop for Latin America, held in Colombia, attracted scientists from 22 countries. A deepwater rice workshop in Thailand served as a focal point for the deepwater monitoring tour. The first of a series of workshops on dryland rice was held in Brazil.

CONTROL AND MANAGEMENT OF PESTS

We continued research to develop low-cost ways to control rice pests — diseases, insects, and weeds — in farmers' fields. The relative seriousness of the pests changes among rice culture types and may be complicated by disease and insect interaction. For example:

- Weeds, which contribute a small portion of the yield gap in irrigated rice, become more serious in rainfed rice where water may be inadequate and can seriously cut yields in dryland rice fields.
- Insects carry and spread rice diseases, with the green leafhopper as a vector of tungro virus disease as a prime example.
- Rice blast usually does minor damage in wetland rice but can devastate a dryland rice crop.

Emphasis remains on development of pest control techniques that are safe for the farmer as well as for those who share the environment. We know that natural parasites and predators can play an important role in rice insect control. We also know that natural, cultural, and chemical control of rice pests can be integrated to reduce pest-control costs over wide areas.

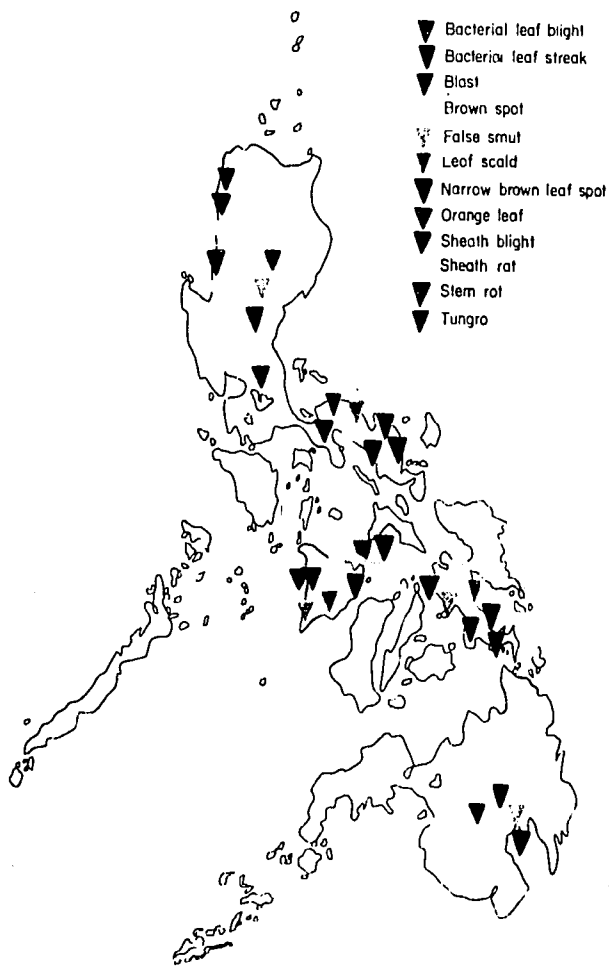
IRRI entomologists check a field of hopperburned rice. Hopperburn may occur in small spots where hopper populations increase rapidly or can spread to kill a farmer's entire rice crop. Integration of varietal resistance and natural, cultural, and chemical control practices can eliminate situations like this.

DISEASE CONTROL

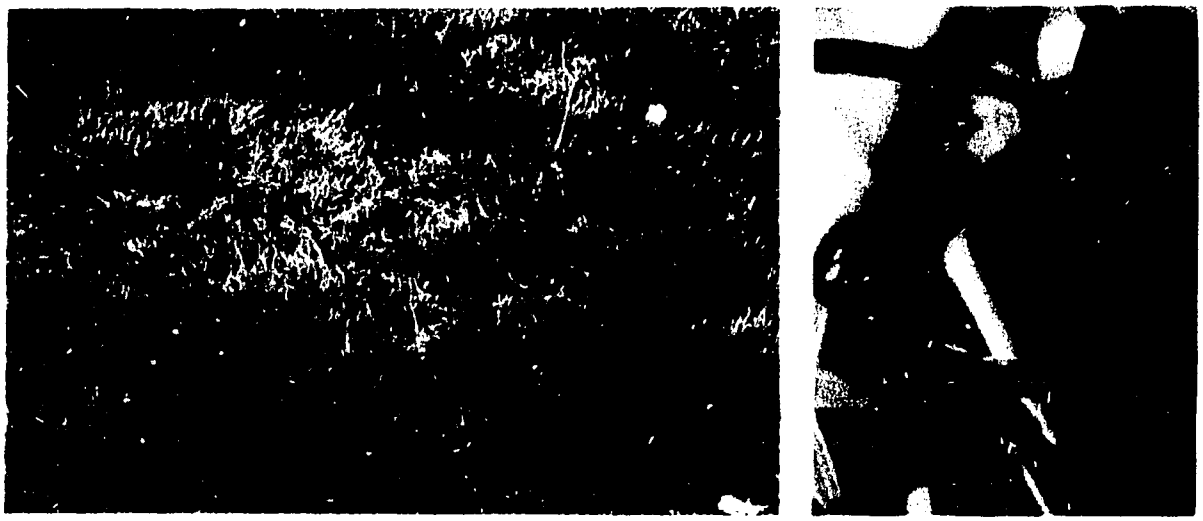
Despite an increasing number of disease-resistant modern rices grown by farmers throughout Asia, the diseases — and their potential to strike the rice crop — remain. Our plant pathologists continue to monitor and investigate diseases, and develop and test cultural and chemical control methods.

Monitoring rice diseases

We initiated monitoring of rice crops in the Philippines to determine occurrence and severity of diseases. During November-December 1981 we visited 75 sites in 15 provinces and found 12 diseases on 15 varieties. Bacterial leaf blight, narrow brown leaf spot, and sheath blight were more prevalent than bacterial leaf streak, blast, brown spot, false smut, leaf scald, orange leaf, sheath rot, stem rot, and tungro (Fig. 1).



1. Twelve rice diseases were found in 15 Philippine provinces during a November-December 1981 survey.



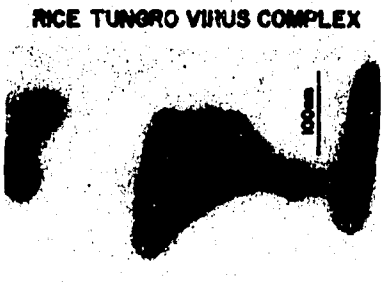
2. Bacterial stripe severely damaged rice seedlings in a seedbed at IRRI. The rice leaf (right) shows typical bacterial stripe symptoms.

Bacterial stripe

Bacterial stripe damage on rice seedlings was recognized recently at IRRI (Fig. 2). The disease had been observed earlier in the Philippines.

The characteristic symptoms are brown stripes on leaves and rotting of the seedlings in severe cases. The stripes vary in width and length and may cover the entire leaf sheath and almost the whole leaf blade.

We found that the disease is caused by *Pseudomonas setariae* and is apparently seed-transmitted — infected seedlings were obtained from seeds of 6 rice varieties planted in sterile soil even after the seeds were dipped in 5% calcium hypochlorite. Infection was also obtained from seeds inoculated by soaking in bacterial suspension for one day, from seeds harvested from plants inoculated by injection at the booting stage, and from plants inoculated by spraying at flowering stage.



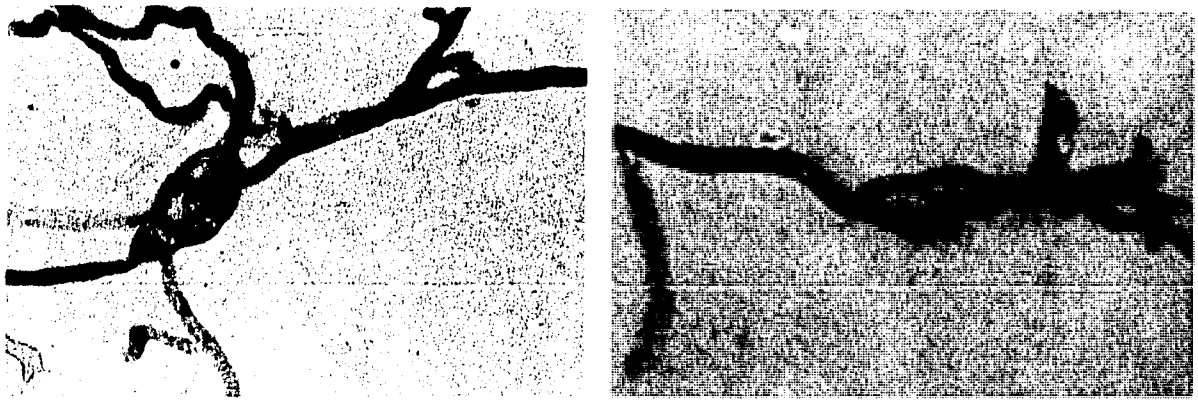
3. Two kinds of virus particles are known to be associated with rice tungro disease. Particles shown here were observed by Italian collaborators by electron microscopy.

Tungro virus complex

Two kinds of virus particles are known to be associated with rice tungro disease. Collaborators in Italy observed distinct isometric and bacilliform particles of rice tungro virus (Fig. 3). Collaborators in Japan developed an electron microscopy technique for observing both kinds of particles in dry infected leaves.

Cytology of the blast fungus

The pathogenic variability of the blast fungus *Pyricularia oryzae* may be related to its chromosomal behavior. In four races (IA65, ID14, ID16, and II-1) studied by HCl-Giemsa technique, we found that almost all of the mycelia, conidiophores, conidia, and



4. A germinated conidium of *Pyricularia oryzae* (left) shows one nucleus in each cell. A portion of mycelium of *Pyricularia oryzae* (right) shows 5 chromosomes at metaphase.

appressoria were uninucleate (Fig. 4). Nucleus division was by typical mitosis. At metaphase the chromosomes were generally five in the isolates studied.

Bacterial leaf blight toxins

Production of a toxin or toxins may play an important role in the pathogenic variability and virulence of the bacterial blight bacterium. In investigations of the association between toxins produced by *Xanthomonas campestris* pv. *oryzae* and symptoms of bacterial leaf blight, we found that culture filtrates of the organism caused wilting and yellowing on seedlings of IR8 with partially excised roots. Hence toxins were present in the cultures; however, the amount in the filtrates varied among strains of the bacteria, ages of cultures, and methods of cultivation.

Chemical disease control

Research continued on chemical control of blast, sheath blight, and bakanae.

Blast. Blast remains a major constraint in rice production. We used the compound CGA49104 as a seed soak for 24 hours at the rate of 1.5 g formulation/1.5 liter water per kg seed. Plants from treated seeds exposed to high blast pressure showed remarkable reduction in disease severity until the end of the test, which was 8 weeks after seeding.

Sheath blight. We continued to test fungicides and compounds for their effectiveness in controlling sheath blight at the seedling stage of a susceptible variety. In greenhouse tests we found Serinal (50% WP) and NTN19701 (25% WP) applied as foliar sprays of 0.5 kg formulation/liter 3 times at weekly intervals reduced disease severity. The compound PP296JF7168 was more effective in controlling sheath blight but suppressed plant height.

Bakanae. Bakanae is a common disease in rice fields, and we

have emphasized its control by chemical seed treatment. Seed soaking is more convenient and economical than slurry and dust methods, but is as effective.

Benomyl and thiophanate-methyl used for seed soaking for 24 hours at a concentration of 1 g formulation/liter of water per kg seeds effectively reduced bakanae incidence. Increasing the rate of the compounds to 3 g also increased their effectiveness.

Monitoring of tungro

Tungro is an endemic disease that can become epidemic. Its incidence is a function of the vector insect, virus source, host plant, environment, and time. It is essential to monitor these factors, especially at the early stages of rice growth, because when the factors strike a favorable combination tungro outbreak can occur.

With the Philippine Bureau of Plant Industry (BPI) we initiated a collaborative project on rice tungro monitoring. The first phase of the project emphasized training of eight regional crop protection officers in all aspects of tungro monitoring (Fig. 5). Phase two involved actual monitoring of the disease factors in the eight regions.

The tungro monitoring gave a negative prediction of tungro outbreak and no tungro outbreak occurred in the eight regions in 1981.

We believe tungro monitoring is essential to the prevention of tungro outbreaks. We will continue and strengthen collaboration with national organizations to assist them in control of the disease.

5. Regional crop protection workers undergo field training in tungro monitoring. Monitoring insect populations is an effective approach to preventing tungro disease outbreak.

The threat of the destruction of a rice crop by one or more insect pests remains real. At the same time the potential for reducing or controlling insect damage by careful management has increased. Our research on insect control and management adds emphasis to both statements.

Brown planthopper migration

Detailed monitoring in farmers' fields showed seasonal abundance of the brown planthopper to be closely related to local cropping patterns. Peaks of flight activity occurred during the wet and dry seasons and activity was greatest when a major part of the plantings were approaching harvest.

It appears that many of the potential brown planthopper migrants remain within the locality in which they are produced. Studies at a number of sites suggest that the rate of immigration early in the crop does not bear any relationship to the size of the

Brown planthopper movement was monitored at Liliw, Laguna Province, Philippines, by Center for Overseas Pest Research (COPR) scientists in collaboration with SEARCA and IRRI. Green or yellow water pan traps are seen on posts in the paddies. A 12-m suction trap is visible in the background. The tent-like structures are emigration traps, which catch hoppers as they fly out of the paddy.

6. IR20 (foreground), an intermediate-duration variety, was hopperburned. IR19735-30-3-3-2-2, which matured 3 weeks earlier than IR20, was undamaged. The early line yielded 5.8 t/ha; IR20 yield was 1.7 t/ha. A resurgence-inducing insecticide was applied to both cultivars to increase the brown planthopper populations.

subsequent population. Factors within a field, such as predation and parasitism, are thus more important determinants of population size than the levels of initial immigration.

Insect catches with nets and sticky traps were made during eight interisland sea voyages in the Philippine archipelago. The catches show highest insect activity during the wet season. That suggests that long-range migration is prevalent at that time and is associated with warm, moist, southwest monsoonal winds.

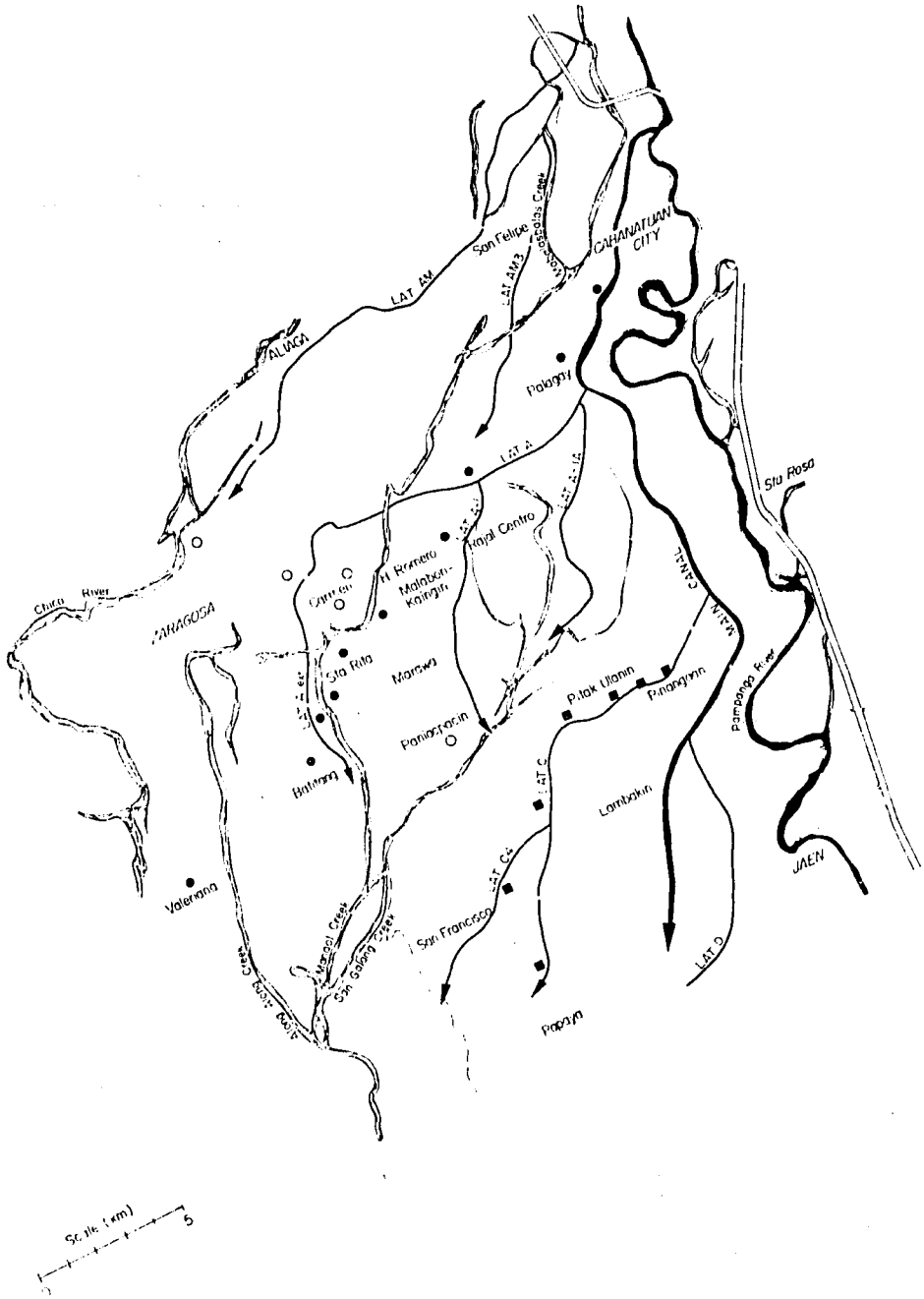
Early-maturing rices escape brown planthopper damage

IRRI plant breeders have developed breeding lines with a growth duration of 75 days from transplanting to harvest. In field studies we found that early lines susceptible to brown planthopper escape injury because they begin maturing and are unsuitable for the brown planthoppers before the insect can build up to a damaging level (Fig. 6).

Cultural insect control by synchronous planting

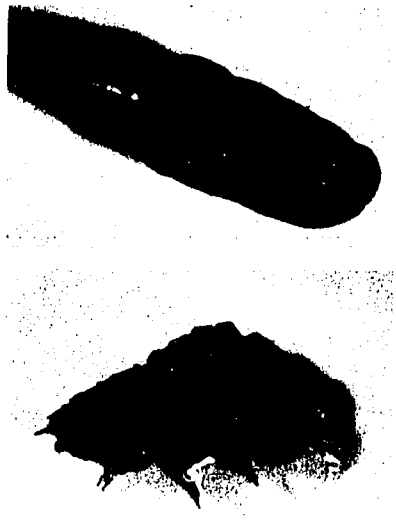
We studied insect populations in a large irrigation system to determine the potential of community-wide management of rice insect pests through all farmers planting at the same time — synchronous planting. Three transects (Fig. 7) of paired kerosene-burning light traps were established in an irrigated area, portions of which were more or less nonsynchronous. Information on planting dates was gathered by irrigation ditch tenders from the National Irrigation Authority.

Total light trap catches of insect pests during the 1981 dry season and variances in planting dates within 400-m and 1,000-m radii for 9 sites in transect 1 showed that insect species behaved



7. Pairs of kerosene-burning light traps were used to trap rice insect pests along 3 long transects in the Upper Pampanga River Integrated Irrigation System in 1981. The transects covered a rice-growing area of 20,000 ha.

differently. Green semilooper *(Naranga aenescens)* responded to nonsynchronous planting within a radius of 400 m but was unaffected by nonsynchronous planting over a radius of 1,000 m. Seasonal totals of caseworm *Nymphula depunctalis*, yellow stem borer *Scirpophaga incertulas*, and brown planthopper *Nilapar-*



8. The pupa of the rice ear-cutting caterpillar (top) is normal. The pupa at bottom was treated topically with 12.5 μg neem oil.

vata lugens were more closely related to nonsynchronous planting over 1,000 m.

Our results showed that nonsynchronous planting was positively related to increased insect pest abundance, and therefore supported synchronous planting as a control method.

Synchronous planting requires coordination between farmers, hired transplanters, custom tillage services, banks, and the irrigation authority. This tactic may prove particularly feasible for rice-growing communities that have suffered pest epidemics in the past, which would motivate them to provide the necessary organization to carry out this strategy.

Plant derivatives for management of rice insect pests

Neem oil's effects against the brown planthopper and rice leaffolder were reported in 1979-80. In 1981 we applied neem oil topically to the early 5th-instar larvae of the ear-cutting caterpillar. The treatment caused abnormalities during pupation and eclosion (Fig. 8). Hatchability was totally impaired when freshly laid eggs were dipped once in neem oil formulations.

Rice plants sprayed with azadirachtin, the active ingredient derived from neem seed, showed measurably less feeding damage by last-instar rice ear-cutting caterpillar larvae than was observed in control plants (Fig. 9).

Growth and development of first-instar brown planthopper, whitebacked planthopper, and green leafhopper nymphs were significantly reduced when the insects were caged on rice plants grown in soil in which about 1 mg azadirachtin/pot had been incorporated. The result indicated a systemic activity (Table 1).

These are neem trees, which grow widely in South Asia as well as in Africa. Seed of the neem tree is crushed for its oil. Both the neem oil and the resulting neem-oil cake are known to have insecticidal and antifeedant effects on many rice insect pests.

9. The rice plant on the right was sprayed with a solution containing 200 ppm (wettable powder) of the neem seed derivative azadirachtin. The plant on the left was a nontreated control in the test. Difference in feeding by last-instar larvae of the rice ear-cutting caterpillar is obvious.

Table 1. A neem derivative, azadirachtin, had a systemic effect on growth of brown planthopper (biotype 2). Nymphs caged on TN1 plants grown in soil in which azadirachtin had been incorporated developed significantly fewer adults in 1981 tests at IRRI.

Application (mg/5 tillers)	Nymphs becoming adults[a] (%)		
	1st infestation (1-18 Sep)	2d infestation (21 Sep-8 Oct)	3d infestation (9-24 Oct)
0	85 a	80 a	93
1	58 a	40 b	80
5	18 b	28 b	80
10	0 b	0 c	63

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

The systemic effect, which lasted for more than a month, reduced feeding. Nymphs failed to become adults on plants treated with the neem-seed derivative, even when infested repeatedly (Fig. 10).

Custard apple oil

The oil of custard apple *Annona reticulata* L., a widely grown fruit tree in the Philippines and many other rice-growing countries in Asia, was highly toxic to leafhoppers and planthoppers. Topical application of the oil at 5 μg/insect caused 90-100% mortality of brown planthopper and whitebacked planthopper females. Green leafhopper mortality was high at the dose of 50 μg/female (Table 2).

Stem borer control through mating disruption

Insecticides tend to kill more kinds of organisms than intended, and pose hazards to the environment. Sex pheromones or attractants, when applied over an area, disrupt mating behavior because male moths cannot locate female moths, and little or no

10. Azadirachtin, a neem seed derivative, had a systemic effect when applied to the soil. All the 9 brown planthopper nymphs (left) grew normally and became adults on rice plants grown in soil without azadirachtin. Few nymphs, if any, survived to adult stage on plants grown in soil treated with azadirachtin (right).

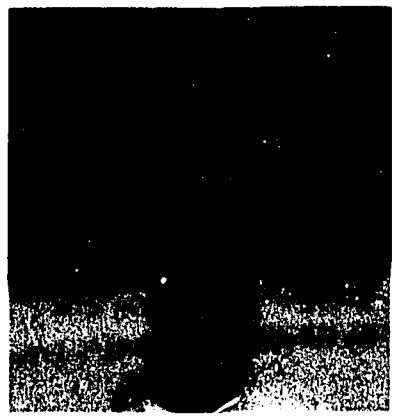


Table 2. Topical application of custard-apple-seed oil gave control of brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper (GLH) females in tests at IRRI, 1981.

Dose (μg/female)	Mortality[a] (%) after 24 h		
	BPH	WBPH	GLH
0	20 a	6 a	0 a
5	98 b	90 b	2 a
10	100 b	98 b	14 b
20	98 b	96 b	56 c
50	98 b	100 b	94 d

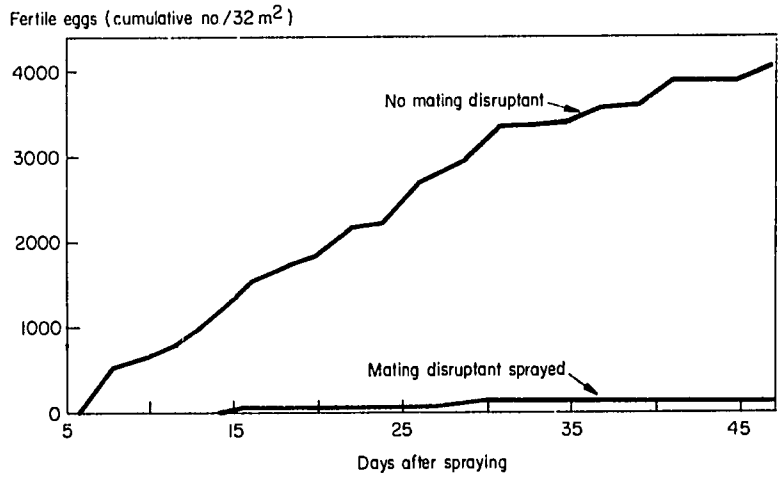
[a] In a column, means followed by a common letter are not significantly different at the 5% level.

egg laying occurs. That gives pest control with only the target species affected.

In collaboration with the Tropical Products Institute, London, we sprayed rice in cages with the striped borer pheromone in a stabilized microcapsule formulation. Striped borer moths released in the cages laid virtually no eggs (Fig. 11) and 96% mating disruption was achieved over a 47-day period. Similar results were obtained with yellow borer moths.

Natural control of green leafhoppers

To predict pest densities more accurately, we observed green leafhopper populations in a series of flooded rice crops. Three generations developed during one crop period; the second had the highest density. Natural mortality, caused primarily by egg parasites and nymphal predators, was high. Only 7% of first generation eggs, 4% of second generation eggs, and 1% of third generation eggs became adults. This high mortality suppressed the pest population, which declined after the second generation.

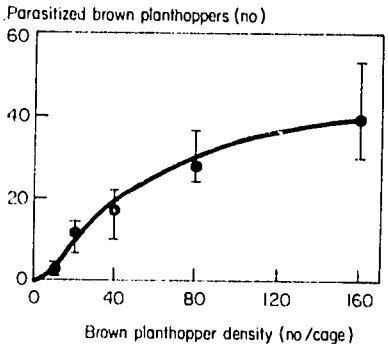


11. Egg laying by striped stem borer *Chilo suppressalis* moths was almost eliminated when rice plants in field cages were sprayed with a microencapsulated mating disruptant. IRRI, 1981 dry season.

12. A wasp parasite attacks and lays an egg inside a brown planthopper nymph. The egg hatches to produce a new parasite, which kills the planthopper.

Biological control of brown planthopper with parasites

Parasites kill insect pests, and contribute substantially to pest control (Fig. 12). Parasites that increase their killing activity when more pests are present are especially beneficial. When we caged brown planthopper with a naturally occurring wasp parasite *Pseudogonatopus flavifemur*, the parasite's activity increased as the brown planthopper density increased (Fig. 13). This is an excellent behavioral characteristic of the parasite, and shows the great potential such beneficial insects have for suppressing insect pest populations.

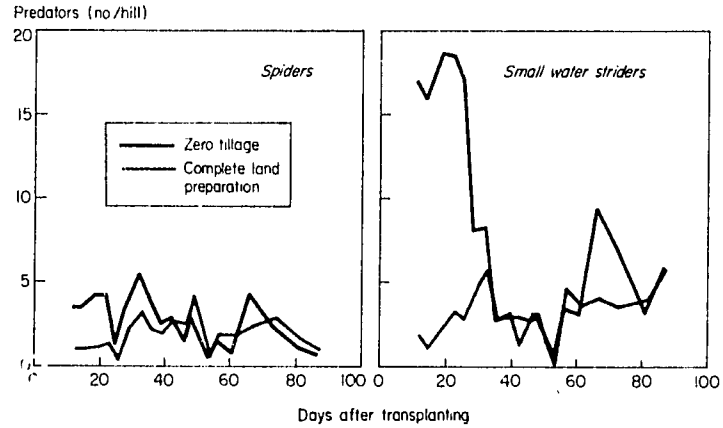


13. In a 1981 study, a female wasp parasite increased parasitization of brown planthopper nymphs to an average of 40 in 1 day as more nymphs became available.

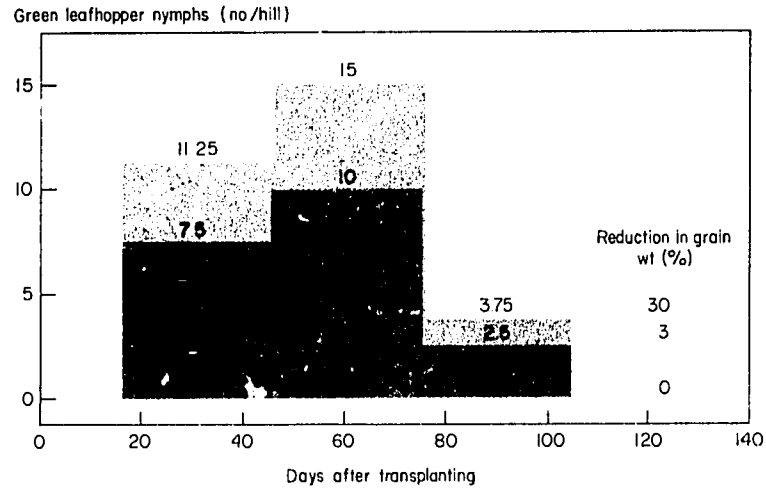
Conserving beneficial predators through zero tillage

Land preparation before transplanting rice disturbs insects and other small animals living in the field. Many beneficial predators

14. Beneficial predators were conserved in zero tillage plots (left), but complete land preparation (right) reduced the initial densities of predators. The early stage of the crop was more vulnerable to insect pest attack.



15. Beneficial predators — spiders and small water striders *Microvelia* — were more abundant at the beginning of a crop period if zero tillage was practiced than if land preparation was complete.



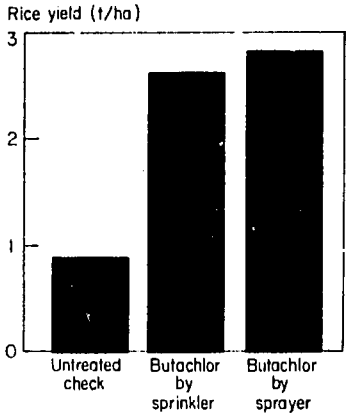
16. Green leafhopper *Nephotettix virescens* nymphs were caged on IR42 plants at different crop ages in the field. Insect density varied, following a typical population growth pattern. There was significant reduction in grain weight only when insect density was more than 10/hill during the early and middle crop growth stages. IRRI, 1981 dry season.

require several weeks after transplanting for populations to return to their levels in the previous crop. Therefore pests that infest a crop soon after transplanting multiply rapidly at the beginning of the crop period. We found that zero tillage (Fig. 14) conserves several predatory animals such as spiders and small water striders (Fig. 15).

This conservation of predators has important implications for green leafhopper control and tungro virus incidence. A separate study with IR42 showed a 30% grain weight reduction when green leafhopper density was high during early and middle crop growth stages (Fig. 16).

WEEDS

Dry seeding of rice continues to grow in popularity, particularly as rainfed rice growers seek to grow two crops of modern rices in



17. Rice yield when butachlor was applied with a sprinkler bottle was similar to that when butachlor was diluted with water and applied with a sprayer.

18. A combination of pendimethalin and propanil, each at 1.5 kg active ingredient/ha, gave excellent control of weeds in dry-seeded wetland rice. Weeds completely took over the unweeded plot (right).

the wet season. The dryland culture at the early stages of a rainfed crop gives weeds an early start — often well ahead of the rice seedlings.

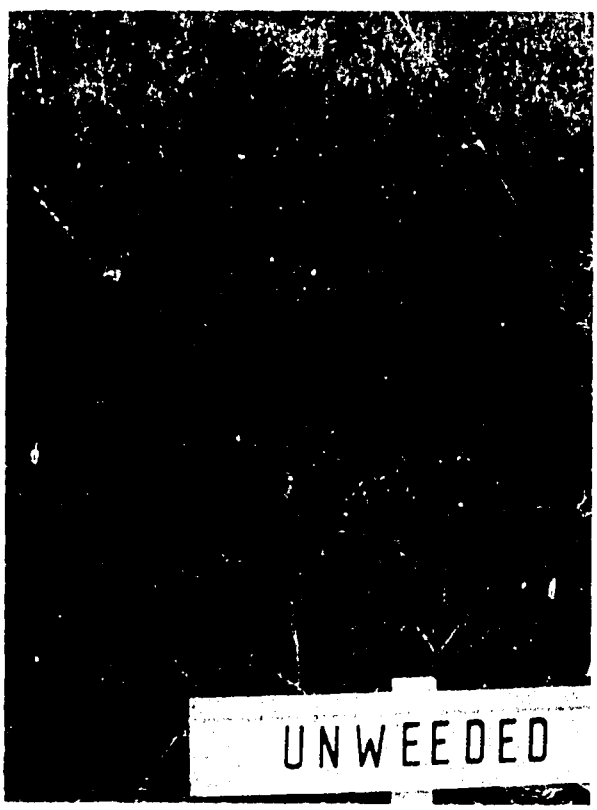
We continued to seek effective, low-cost ways to use herbicides on rainfed wetland and dryland rice farms.

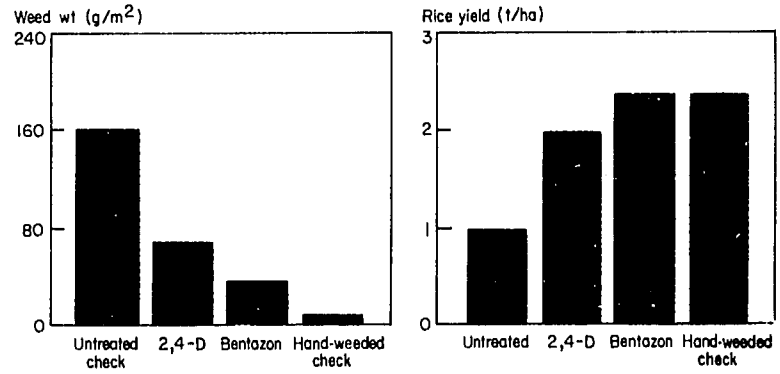
Herbicides applied by sprinkler bottle

Sprinkler bottle application of herbicides, a relatively new technique, allows use of herbicides in wetland rice fields without addition of water during spraying. We initiated sprinkler bottle trials with herbicides, such as butachlor, which is formulated for use as a diluted spray. Butachlor gave the same weed control and grain yield when applied without dilution as when sprayed with water added (Fig. 17).

Weed control in dry-seeded bunded rice

Herbicide combinations applied at preemergence, soon after emergence, and sequentially continued to provide good weed control and produce yields equivalent to those obtained from hand weeding of dry-seeded rice. The best 1981 herbicide treatments were thiobencarb + oxadiazon applied preemergence,





19. A single application of either bentazon (0.5 kg a.i./ha) or 2,4-D (1 kg a.i./ha) adequately controlled *Cyperus rotundus* in dryland rice. Note that as weed stand decreased because of herbicide treatment, rice yield increased.

pendimethalin + propanil applied soon after emergence, and pendimethalin applied preemergence followed by 2,4-D applied postemergence. Figure 18 shows weed control with application of pendimethalin + propanil soon after emergence.

Control of *Cyperus rotundus* with herbicides in dryland rice

We continued our search for chemicals to control *Cyperus rotundus* in dryland rice. One application of either 2,4-D or bentazon 3 weeks after weed emergence provided sufficient control to give rice yield increases of 1 t/ha or more (Fig. 19).

IRRIGATION WATER MANAGEMENT

The word irrigation can inspire a vision of big dams storing large quantities of water, broad irrigation canals snaking across the countryside, farmers turning water into small farm ditches, and year-round rice production. The fulfillment of such visions is rare. Much can go wrong between dam and farm in the best of irrigation systems and the rice farmer fails to get water when he needs it.

We know that the problems of water availability and distribution within the service area of a tertiary irrigation canal or a common turnout can be improved if appropriate facilities within that area are provided and if those facilities are properly used.

Effect of structural upgrading on water distribution

We completed a study of the effects of upgrading water allocation and distribution facilities in two irrigation systems.

Irrigation water allocation and distribution facilities such as these are costly and their proper design and use are vital to efficient irrigation of the rice crop.

- The Jatiluhur Irrigation System, a reservoir-type system in West Java, Indonesia, had a tertiary improvement program that provided each service area of 100-150 ha an upgraded tertiary canal with a control gate, a flow measuring device, and new or improved quaternary canals branching out from the tertiary to deliver water to the farms.
- The Camiling River Irrigation System, a run-of-the-river system in Tarlac, Philippines, had intensive structural upgrading made for each 40-50 ha served from a common turnout. The facilities provided included a gated turnout with a measuring device, a main farm ditch, 4-5 supplementary farm ditches, division boxes, and drainage ditches designed for once-in-5-days rotational allocation of water for each of 5 units of about 10 ha in the service area.

The Jatiluhur system. In the Jatiluhur system, we found that upgraded facilities improved the allocation and distribution of water. Farmers in the improved areas had better water supply in the critical dry season and obtained higher yields than farmers in the unimproved areas (Table 1).

Our survey in the improved areas indicated a significant positive development in farmers' satisfaction over the irrigation facili-

Table 1. Water availability and yields differed greatly in areas with and without improved tertiary facilities in the Jatiluhur Irrigation System, Indonesia, 1981 dry season. A relative water supply of 0.7 indicates that farmers did not get enough water for a normal rice crop.

	Improved tertiary area	Unimproved tertiary area
Relative water supply	1.1	0.7
Days without standing water in paddies during reproductive period	13	27
Yield (t/ha)	4.4	3.5

ties provided and water distribution to their farms. More than 85% of farmers indicated that the upgraded facilities made it easier for them to match their own cropping schedule with the system's irrigation water delivery schedule. We also found that farmers in unimproved areas of the system would agree to cooperate in future improvement programs.

The Camiling System. In the Camiling system the dry season river flow is low and water is delivered only a fraction of the time. The designed rotational water allocation procedure, which required continuous water supply to the turnout, could not be followed.

In the part of the area where ditches ran parallel to the supply canal farmers constructed many extra turnouts to get added water in the designated service area of a common turnout and most of the expensive structural facilities originally provided were removed by farmers or remained nonfunctional.

Farmers in the part of the system where ditches had been made perpendicular to the supply canal made better use of the turnouts and maintained the main farm ditch better. Construction of extra turnouts was difficult for farms far from the supply canal. We calculated that the optimal area serviceable from a common turnout in such a situation was 47 ha, whereas only about 20 ha could be effectively served if the main farm ditch was parallel to the supply canal.

In the parallel situation extra turnouts are easy to construct; therefore maintenance of the main farm ditch is generally neglected. Designers of irrigation systems should exploit all opportunities to provide main farm ditches perpendicular to their supply canals.

Returns to investments on various types of irrigation systems

Results of our study on the costs of different types and sizes of 12 irrigation projects in Central Luzon, Philippines, showed that the annualized costs vary significantly among the systems. Gravity

Table 2. The benefit-cost ratio and internal rate of returns were estimated for 12 irrigation systems in Central Luzon, Philippines, during 1981. Computations were based on 12% interest rate, 60 years life span for the dam, 30 years for canals, and 15 years for pump and engine. Cost and net benefits are at 1980 prices.

System	Annualized total cost (US$/ha)	Annual farmers' net benefit (US$/ha)	Benefit-cost ratio
Gravity diversion system			
Sibul	26.50	192.75	7.3
Salapungan	63.13	405.12	6.4
SFRIS	93.88	317.62	3.1
Prenza	110.88	-41.75	—
Combination pump-gravity			
Caingin	73.38	33.88	0.5
Surface pumps			
BPIP	187.50	429.00	2.2
Small pumps	187.50	291.50	2.1
Safari	89.13	135.50	1.8
Halina	235.12	216.87	0.9
Deep well pumps			
GP-4	312.62	291.75	0.9
GP-3	403.62	313.38	0.7
GP-19	400.37	154.12	0.4

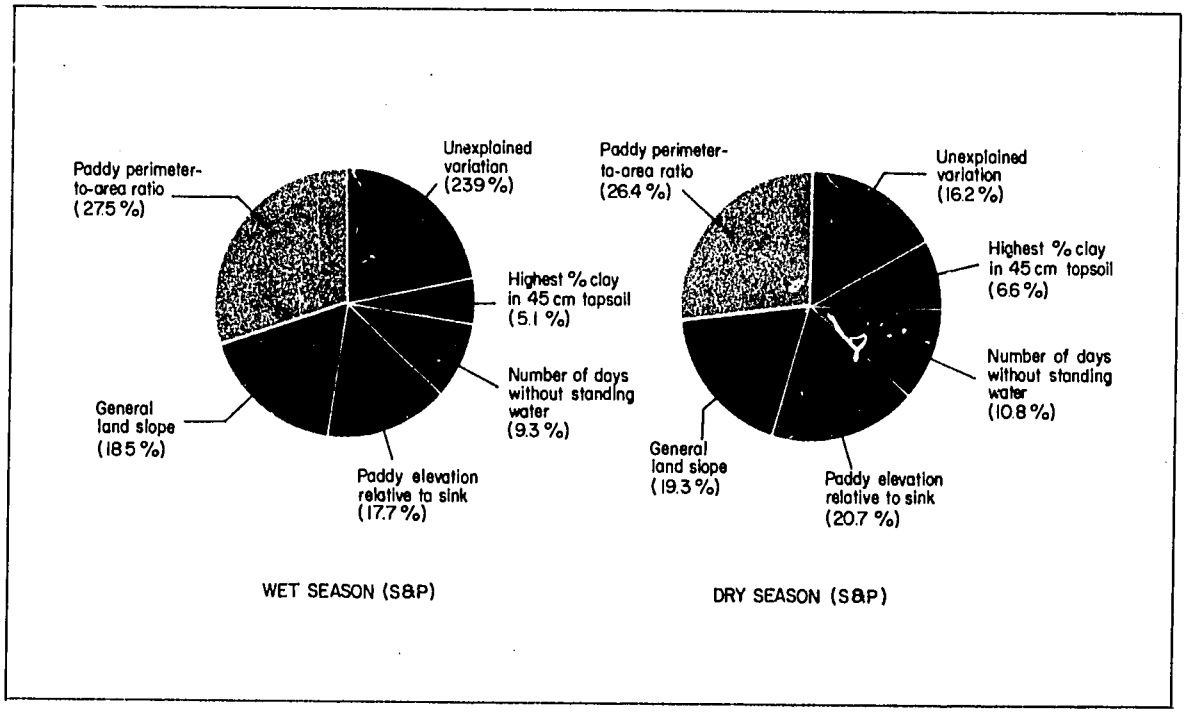
systems incurred the lowest costs, surface pumps were intermediate in cost, and deep well costs were highest (Table 2).

We calculated benefits from irrigation by determining the difference between the gross margin from crop production of the farms within the project and that of a corresponding sample of rainfed farms outside the project, assuming all other factors constant. Farmers' annual net benefits were similar for all types of systems. Our analysis suggests that as far as relative economic efficiency is concerned:

- Gravity systems with their low annualized cost were generally more lucrative investments than other types.
- Surface pumps of appropriate size and capacity appeared to be relatively efficient.
- Large (BPIP), medium (Safari), and small pumps yielded relatively high internal rates of return.
- None of the deep well pump systems gave an economic return.

We found that conditions unique to each area resulted in substantial variations in the cost and benefit data. Furthermore, we recognize that decisions in irrigation development projects are not made on economic considerations alone.

Our findings are therefore useful for the purpose of setting a general order of magnitude of differences in costs and benefits among types of systems in the Philippines.



1. The ratio of paddy perimeter to paddy area affected seepage and percolation most in both seasons of 1981. A portion of the losses were, however, unexplainable in our study and will be scrutinized during phase II of the research in 1982.

Prediction of seepage and percolation

Seepage and percolation is a land component of the total irrigation requirement and is highly variable among sites. In 1981 we finished field work on major research to define patterns and develop models to predict seepage and percolation.

As part of our irrigation system management research, seepage and percolation were observed on a grid sample of 60 sites in a a 2,500-ha system. The effects of landscape and profile factors affecting seepage and percolation were observed.

The most important factor was ratio of paddy perimeters to area (Fig. 1). This is simply the length of boundary relative to the

When used properly, control structures and farm ditches help allocate and distribute the farmers' share of water effectively.

Table 3. Seasonal water use efficiency in Lower Talavera River Irrigation System, 1975-81.

Year	Use efficiency (%)	
	Wet season	Dry season
1975	—	43
1976	51	—
1977	—	60
1978	60	50
1979	73	70
1980	69	50
1981	75	65

size of paddy as it influences opportunity for water to be lost from the field. Of the explainable factors general land slope and paddy surface elevation relative to the nearest sink were the second and third most important factors. Water adequacy was fourth, and highest clay percentage in the top 45 cm of the soil profile was fifth in importance.

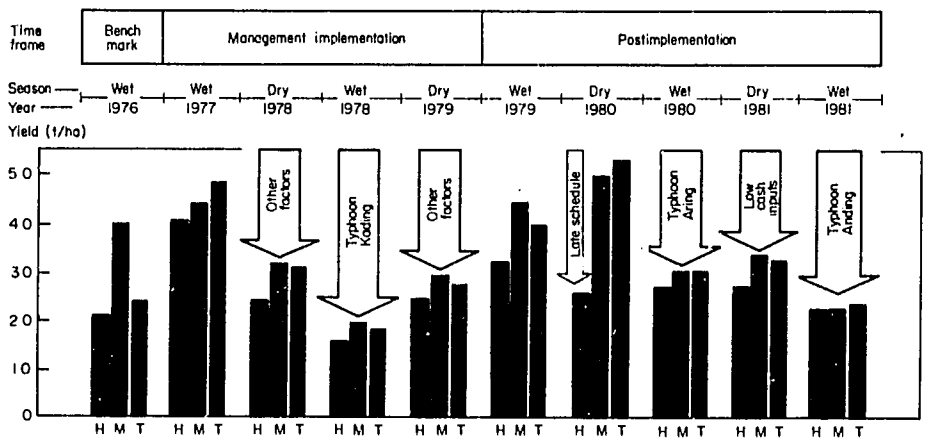
We found that the regression model accounts for 84% of the dry season variability in seepage and percolation rate; in the wet season it accounts for 78%.

Intensive irrigation system management

We continued to monitor intensive system management in the Philippines' Lower Talavera River Irrigation System. The 1981 seasonal water use efficiencies were among the highest observed to date (Table 3).

System performance in terms of average crop yield for the 2,500 ha included in the system remained about 3 t/ha. This low yield was due largely to major weather disturbances and low cash inputs by farmers in the season after a major crop disaster (Fig. 2).

2. Water use efficiency (see Table 3) in the Lower Talavera River Irrigation System has increased for the 5 seasons following implementation of intensive management, but yields have remained low because of typhoons and related factors. H = head, M = middle, T = tail.



SOIL AND CROP MANAGEMENT

Increases in rice yields mean increased removal of plant nutrients from the soil. Those nutrients must come from the natural supply in the soil, from nutrients added by the rice farmer, or from both. Dependence on the natural supply leads to decreasing yields; use of purchased fertilizer leads to increasing costs.

The best payoff from modern rice technology currently comes where the efficiency of purchased fertilizers added to the soil is highest. But there is also good potential for providing significant amounts of biologically fixed nitrogen for the rice plant.

Our research in 1981 concentrated on ways to increase efficiency in all areas of soil and crop management.

Jenny Calabio, IRRI research assistant in agronomy, checks a plot of early-maturing rice in 1981 fertilizer management studies at IRRI.

Nutrient deficiencies and soil toxicities limiting rice yields were identified and characterized during 1981.

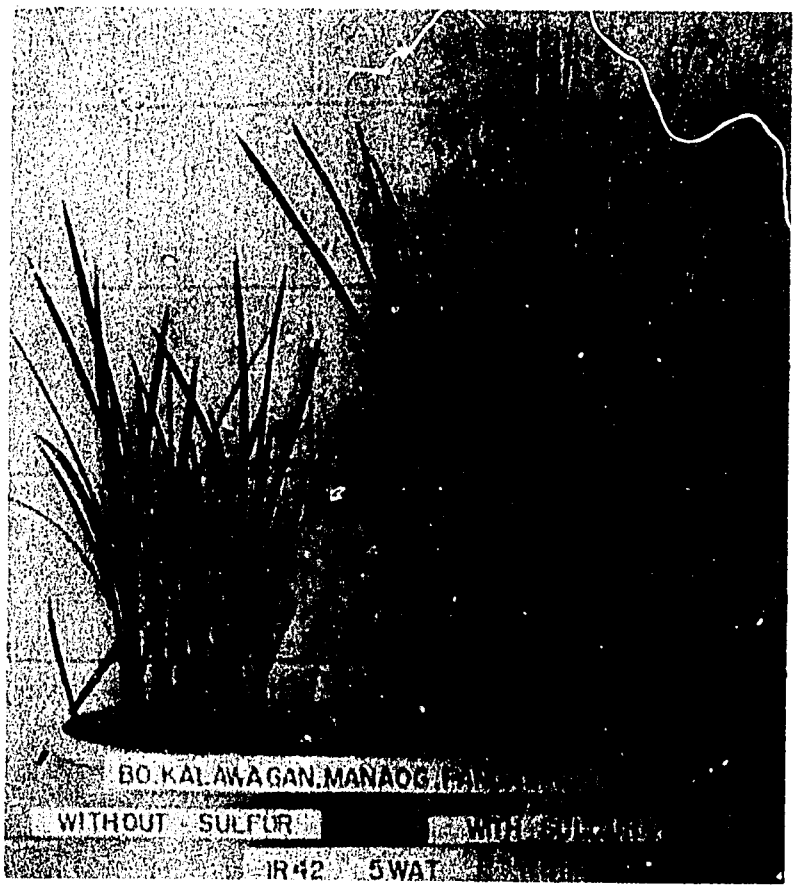
Sulfur deficiency

The incidence of sulfur deficiency in wetland rice is increasing but we have had no suitable soil or plant tests for the disorder. In tests (calcium phosphate method) of soils where rice was yellow and stunted and responded to sulfur application, we found less than 9 ppm available sulfur.

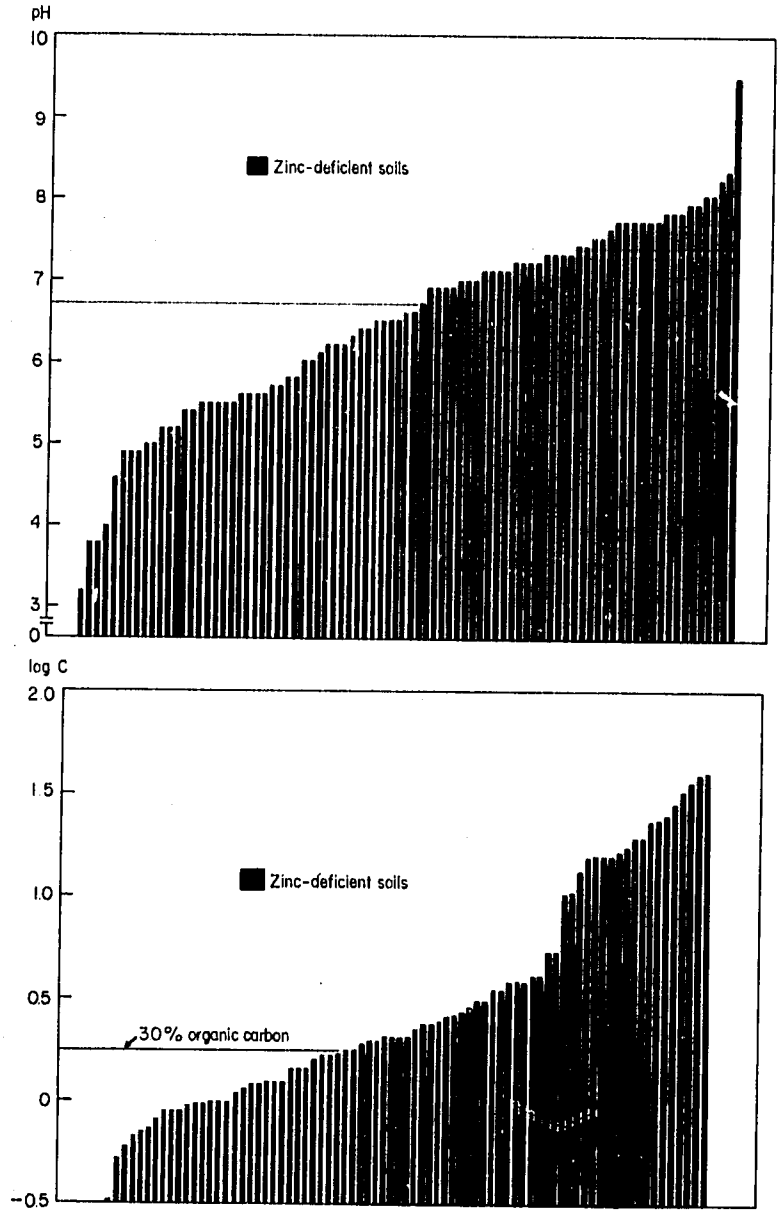
A sulfur-deficient plant is seen in Figure 1. The critical total sulfur limits in the plant were 0.11% in the shoot, 0.055% in the straw, and 0.065% in the grain. The corresponding critical ratios of nitrogen to sulfur were 15, 14, and 26.

Zinc deficiency

Zinc deficiency in wetland rice is widespread. We studied more than 300 Philippine soils and found that zinc deficiency is asso-



1. These IR42 plants at 5 weeks after transplanting illustrate the effects of sulfur deficiency on wetland rice.



2. Zinc-deficient soils in 1981 tests are concentrated at the higher pH and organic matter contents. Note the pH line at 6.8 and the carbon line at 3%.

ciated with one or more of these characteristics:

- pH higher than 6.8
- organic carbon higher than 3.0%
- available zinc less than 1.0 ppm
- water-soluble silicon more than 100 ppm
- magnesium-calcium ratio greater than 1
- total chromium greater than 0.1%

Soil pH and carbon content, which are routinely measured in all soil testing laboratories, are simple and reliable indicators of where zinc deficiency may be expected in wetland rice (Fig. 2).

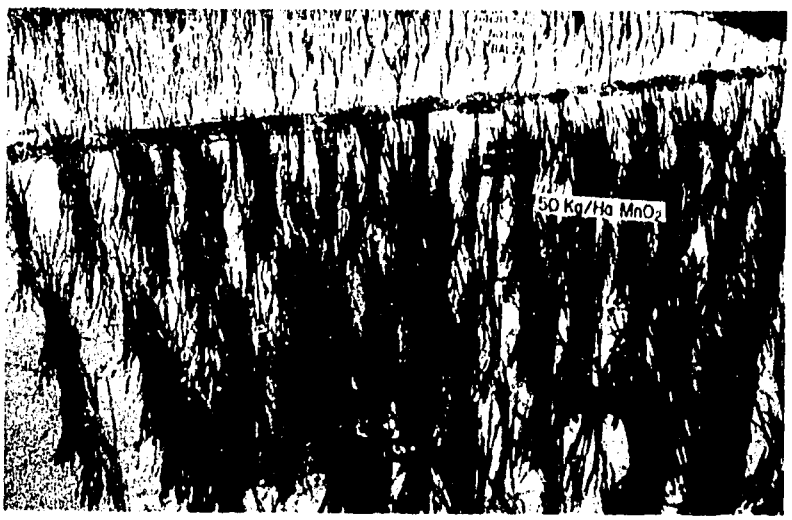
3. IR4683-54-2-2-3 showed marked response to liming (background) in 1981 field tests on acid sulfate soils in the Philippines.

Amelioration of acid sulfate soils

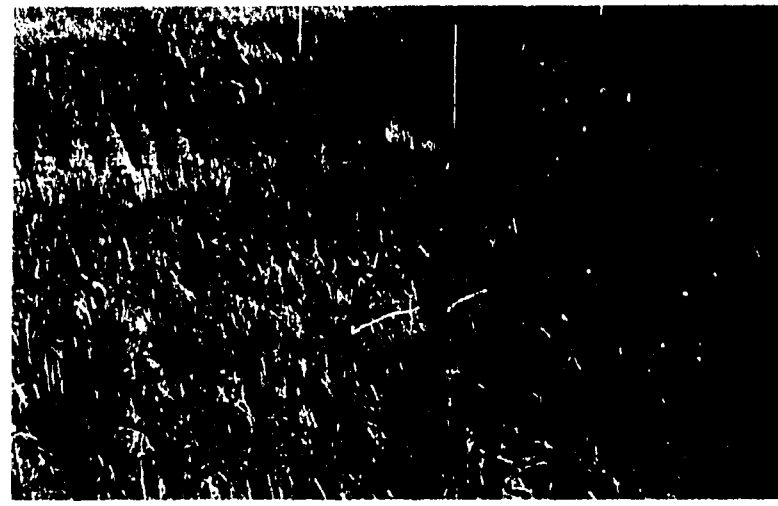
Most of the 5 million hectares of acid sulfate lands in South and Southeast Asia is not cultivated largely because of aluminum and iron toxicities.

We found that those toxicities can be alleviated by liming, prolonged submergence, use of manganese dioxide, and transplanting (instead of direct-seeding) tolerant varieties (Fig. 3, 4).

In 13 experiments at 7 acid sulfate soil sites in the Philippines,



4. Manganese dioxide applied at 50 kg/ha improved the stand of IR4683-54-2-2-3 where no lime was used.



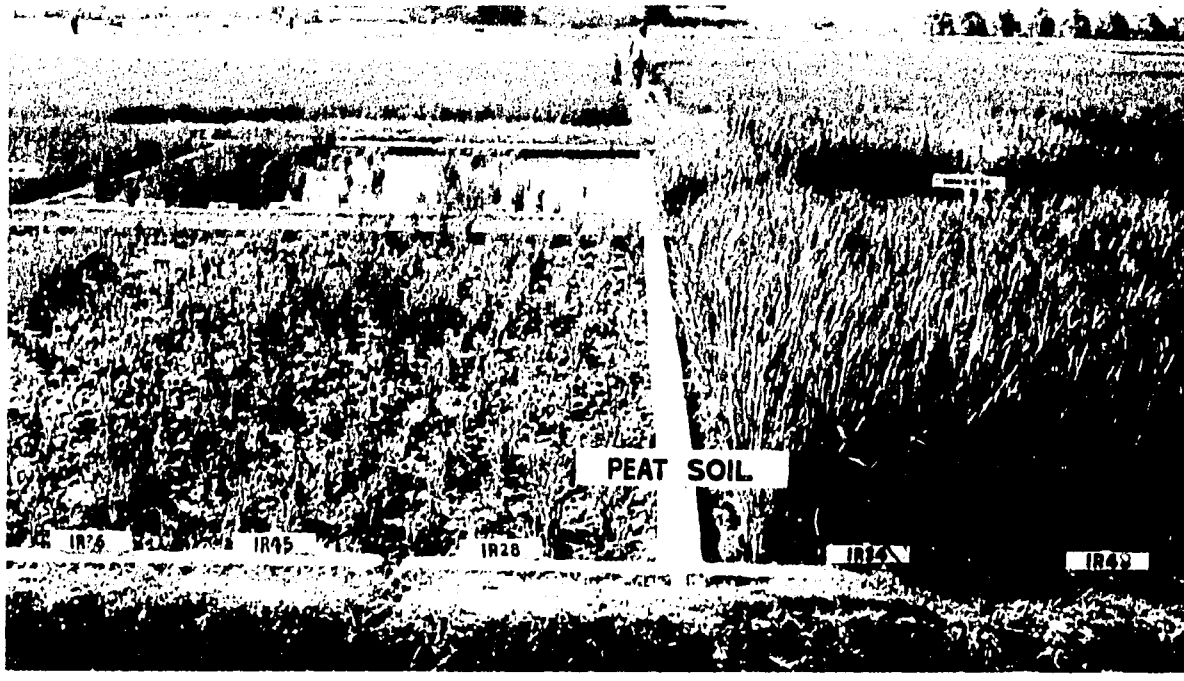
5. Rices with tolerance for an iron toxic acid sulfate soil are seen in yield trials at the back of this farmer's field in Albay Province, Philippines, 1981. The farmer's rice (foreground) shows severe toxicity symptoms.

we found that any one of these methods produced rice yields exceeding 4 t/ha (Fig. 5).

Peat soil problems

The growth-limiting factors in an acid peat soil in a volcanic area were identified as zinc deficiency and boron toxicity. On another peat soil the problems were deficiencies of nitrogen, phosphorus, potassium, and zinc (Fig. 6). A third peat produced the highest grain yield in the treatment that combined complete (NPK) fertilizers with zinc, copper, and molybdenum.

6. A peat soil from Laguna Province, Philippines, was put in concrete beds at IRRI during 1981. The bed on the right received complete NPK fertilizer and zinc; the bed on the left was not treated.



Decomposition of organic matter in wetland soils

Organic manures are assuming increasing importance in rice production but there is little information on organic matter decomposition in flooded soils in the tropics and on its influence on the rice plant.

We used straw labeled with radioactive carbon in field studies and found that large amounts of carbon dioxide and methane are produced within 2 weeks of straw incorporation. Surprisingly most of the methane came from soil organic matter.

Laboratory experiments showed that soil properties, temperature, and the type of organic matter influenced the rate of formation and the concentration of organic acids. Five phenolic acids and six volatile acids, some of which are toxic to rice, were identified. Low temperature and low pH favored acid accumulation.

Classifying Asian dryland rice environments

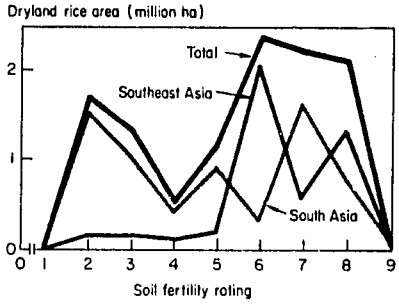
The rainfed rice-growing environments of the world are extremely diverse. As we become increasingly involved in varietal improvement and more intensive cropping in rainfed areas, it is clear that this environmental diversity is a major constraint to technology development and diffusion. There is need to identify and quantify the environmental diversity within each of the major rice culture types — dryland, shallow wetland, waterlogged, and the deepwater and floating rice areas.

We selected dryland rice in Asia for initial classification work. The largest area of dryland rice occurs on Acrisols. The Orthic Acrisols are highly dominant in Southeast Asia (Table 1). They are chemically poor, strongly acid, and low in organic matter. They are most important in Thailand (0.5 million ha), Burma (0.4 million ha), and Indonesia, Vietnam, and Laos (0.5 million ha each). In those countries, between 30% and 60% of the dryland rice is produced on Orthic Acrisols.

In South Asia the dominant soils are different from those of Southeast Asia and no one soil has such importance as that exhibited by Orthic Acrisols in Southeast Asia.

Each of the soil units was given a rating indicative of its inherent fertility status (Table 1). Asian dryland rice tends to be distributed into favorable or unfavorable categories, with relatively little with intermediate ratings (Fig. 7).

The distribution of the dryland rice area is distinctly different between South and Southeast Asia. South Asia has more dryland rice on favorable soils. Southeast Asian dryland rice is predominantly on relatively unfavorable soils.



7. Asian dryland rice area distributed by inherent fertility status (1 = highly favorable, 9 = highly unfavorable). In Southeast Asia, most of the dryland rice is grown on the poorer soils.

Table 1. The dominant soils for dryland rice differ greatly between South and Southeast Asia.

Soil unit	Dryland rice area (ha)	Percentage of dryland rice (within the region)	Inherent fertility status[a]
Southeast Asia	4,670,000		
Orthic Acrisols *(Tropudults)*	1,967,700	42	6
Ferric Acrisols *(Tropudults)*	603,300	13	8
Gleyic Acrisols *(Aquults)*	466,300	10	8
Dystric Nitosols *(Rhodudults)*	439,300	9	7
Ochric Andosols *(Andepts)*	109,100	2	4
South Asia	6,925,000		
Ferric Luvisols *(Ustalfs)*	1,132,800	16	7
Eutric Cambisols *(Tropepts, Tropaquepts)*	886,000	13	2
Calcic Luvisols *(Ustalfs)*	681,500	10	2
Eutric Gleysols *(Tropaquepts)*	603,000	9	5
Chromic Vertisols *(Vertisols)*	539,300	7	3

[a]Rating scale: 1-2 highly favorable, 3-4 favorable, 5-7 unfavorable, 8-9 highly unfavorable.

When dryland rice distribution maps were overlaid on climatic maps a marked contrast was again observed between the two regions. The growing season is less than 5 months in most of the South Asian dryland rice area, and exceeds 5 months in 76% of the Southeast Asian dryland rice area. Thus, although the dryland rice soils of South Asia are generally superior to those of Southeast Asia, the growing season is shorter and earlier-maturing cultivars are required. Early maturity is not critical in Southeast Asia but adaptation to infertile soils is required. Thus, different approaches to dryland rice improvement are needed for these two regions.

MANAGEMENT OF SOIL AND FERTILIZER NITROGEN

Technology to improve fertilizer nitrogen efficiency

There are indications that high prices of nitrogen fertilizers — and reduction of fertilizer subsidy in some countries — will affect rice yields and production. We continued looking for better techniques of applying fertilizer nitrogen. In collaboration with the International Fertilizer Development Center (IFDC), we

Table 2. The farmers' method of splitting urea applied to rice is significantly less efficient than the researchers' split. Slow release (SCU) and deep placement added another 0.4-0.5 t/ha to researchers' yields. IRRI, 1981 dry season.

Nitrogen treatment	IR36 yield[a] (t/ha)	Total nitrogen uptake at harvest (kg N/ha)
No fertilizer nitrogen	2.4 d	38 d
Urea, farmers' split[b]	4.6 c	76 c
Urea, researchers' split[c]	5.4 b	84 b
Sulfur-coated urea (SCU)[d]	5.9 a	101 a
Placement (10-cm deep) of urea supergranules	5.8 a	100 a

[a]Av of 3 replications and 3 rates (58, 87, and 116 kg N/ha). Means followed by a common letter are not significantly different at the 5% level. [b]Equal applications 10 days after transplanting and 5-7 days after panicle initiation. [c]Two-thirds applied basally and incorporated and one-third topdressed 5-7 days before panicle initiation. [d]Broadcast and incorporated before transplanting.

continued testing new fertilizer forms.

Evaluation of alternatives. We compared farmers' method and timing of urea application with improved timing, slow-release sulfur-coated urea (SCU), and deep soil placement of urea supergranules.

There was a 2 t/ha yield increase due to urea applied by the farmers' method; in addition there was a 0.8 t/ha increase from timing that we consider better than the farmers' timing. Slow-release SCU and deep-placed supergranules both gave significantly higher yields than did our research timing of urea (Table 2).

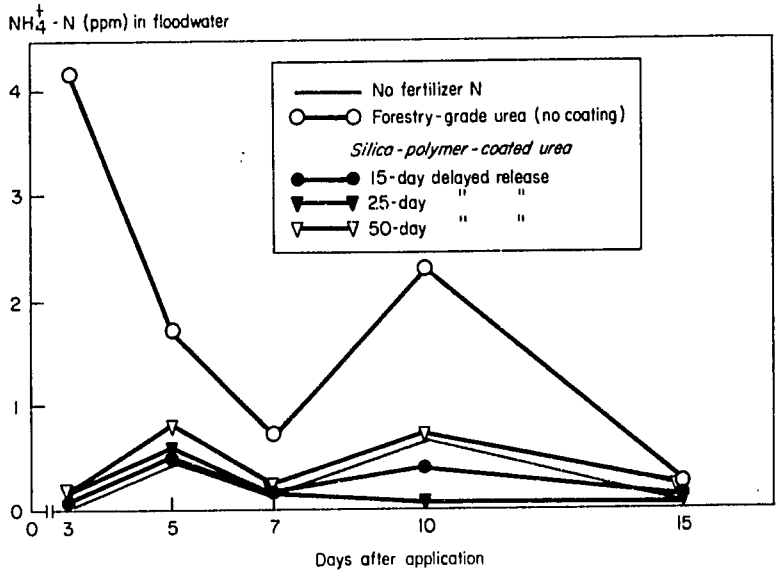
Effectiveness of silica-polymer-coated urea. IFDC, in collaboration with the Korean Institute of Technology (KIST), has developed silica-polymer-coated urea (PCU) as a slow-release fertilizer. PCU with release delays of 15, 25, or 50 days is available.

We tested the slow-release fertilizers and found all gave significantly higher yield than noncoated urea (Table 3). When we used noncoated urea at 100 kg N/ha, we detected more than 4 ppm of ammonium in floodwater 3 days after application (Fig. 8). With PCU fertilizer, the concentration of ammonium in floodwater was negligible. A high concentration of ammonium in floodwater

Table 3. Tests of noncoated and silica-polymer-coated urea (PCU with different release times) showed the 25-day delayed PCU was best. 1981 dry season.

Treatment	IR36 yield[a] (t/ha)
No fertilizer nitrogen	3.8 d
Forestry grade urea (no coating)	5.2 c
PCU, 15-day delayed release	5.8 ab
PCU, 25-day delayed release	6.1 a
PCU, 50-day delayed release	5.7 b

[a]Av of 3 replications and 4 rates (25, 50, 75, and 100 kg N/ha). Yields followed by a common letter are not significantly different at the 5% level.



8. Ammonium found in floodwater after application of silica-polymer-coated forestry grade urea (100 kg N/ha) was negligible in the 1981 dry season.

results in ammonia volatilization and denitrification losses.

Placement method and recovery of ^{15}N-labeled urea. To develop fertilizer placement techniques relevant to on-farm conditions, we compared alternative techniques. Point placement of urea supergranules and uniform placement of prilled urea (by topsoil removal, fertilizer application, and replacement of topsoil) both

Cao Zhi-hong, an IRRI research scholar from China, checks a plant from a plot in which he tested fertilizer placement methods.

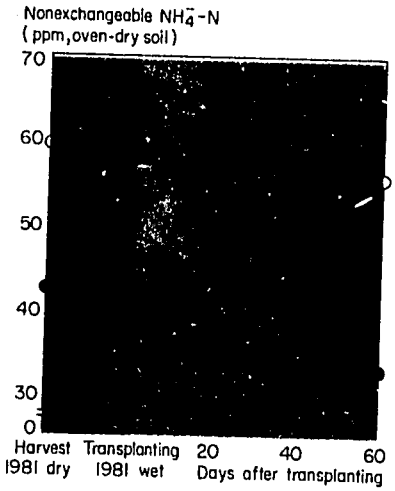
Table 4. Recovery at harvest of ^{15}N-labeled urea (87 kg N/ha) applied to IR36 was highest when the urea was uniformly placed 10 cm deep. 1981 dry season.

Treatment	Applied ^{15}N recovered (%)		
	Straw	Grain	Total
Uniformly placed at 10-cm depth	20 a	69 a	89 a
Band placed at 10-cm depth	13 c	48 c	60 c
Placement (10-cm deep) of urea supergranules	19 ab	54 b	73 b
Researchers' split application[a]	9 d	24 d	33 d
CV %	12	7	5

[a]Two-thirds basal and incorporated, 1/3 5-7 days before panicle initiation.

gave significantly higher yield than band placement or split application of prilled urea.

In the placement study we found that recovery of ^{15}N-labeled urea was significantly higher with uniformly placed urea than with point-placed urea (Table 4). The considerable amount of nitrogen in floodwater when urea was applied in a band or in split doses explained the lower recovery for those techniques.



9. Nonexchangeable ammonium in wetland soils in replicated experiments during the 1981 wet season indicated a need to study ways to tap this nitrogen pool.

The role of nonexchangeable ammonium in wetland rice soils

Ammonium fixation reduces the effectiveness of applied nitrogen fertilizer. On the other hand, its release contributes to plant nutrition. The problem of ammonium fixation and release by clay minerals has not been studied adequately in wetland rice soils. We need to know the role of this pool, known as nonexchangeable ammonium, in nitrogen availability in wetland rice soils.

We studied the mobility of nonexchangeable ammonium during the 1981 wet season at two sites in the Philippines. The clay minerals on both soils were smectite and vermiculite but smectite was dominant in the Guadalupe clay and vermiculite dominant in the Maligaya silty clay loam.

Figure 9 illustrates the changes in nonexchangeable ammonium content of nitrogen-fertilized soils at the sites. In Maligaya silty clay loam the nonexchangeable ammonium content increased during the period between harvest in the dry season and transplanting in the wet. This soil, with vermiculite as the major clay, might be expected to fix more ammonium because vermiculite has a better ability to fix ammonium than smectite clay minerals. Therefore we assumed that part of nitrogen fertilizer applied to this soil was fixed by the vermiculite.

Our results indicate different patterns of fixation and release of ammonium from the nonexchangeable ammonium fraction in the two soils. Changes in this pool of ammonium influence the available nitrogen status of a soil and the mobility of this fraction

Snails, such as these in an IRRI rice plot, graze on blue-green algae. Because these algae are nitrogen fixers, grazing reduces the source of a free supply of nitrogen for the rice crop.

should be considered in developing management practices to get maximum use from applied nitrogen.

BIOLOGICAL NITROGEN FIXATION

Nitrogen is needed for even modest rice yields but most of the world's small rice farmers — who are also among the poorest of rice farmers — buy little nitrogen for their crop.

Those farmers know the value of nitrogen but they do not buy it because of lack of cash or credit or because chances of crop damage — drought, weeds, flash floods, pests — make cash spent for fertilizer a high risk.

There is growing evidence, however, that biologically fixed nitrogen — nitrogen pulled from the air by microbes and made available to a rice crop — may give rice farmers a low-cost source of nitrogen. Algae living in association with the water fern azolla have provided the soil more than 400 kg N/ha in a year in experiments in IRRI rice paddies. In 1981 we started to develop ways for small farmers to use azolla as an on-farm nitrogen source.

We also gathered added evidence that blue-green algae provide nitrogen for the deepwater rice crop. There is the possibility that

rice varieties that promote nitrogen fixation better than others can be identified.

Nitrogen-fixing algae on deepwater rice

Blue-green algae grow on the surface of roots and the submerged leaf sheaths, and on the culm of deepwater rice. The algae are found on the tissue surface and also in the air cavities of the leaves.

We found that autotrophic (self-nourishing) nitrogen fixation by algae associated with deepwater rice provides nitrogen for the rice crop. To determine the amount of algal nitrogen fixation and to see if the fixed nitrogen becomes available to the aerial parts of the deepwater rice plant, we exposed deepwater rice to a traceable $^{15}N_2$ gas for 9 days at the heading stage.

At crop maturity 8 mg of nitrogen had been fixed for each plant and 40% of that nitrogen was transferred to the grain and upper shoots.

Under fluorescent microscopy, blue-green algae showed red on this rice root. The red broken line is a chain of algae in the water surrounding the root (magnification 100x).

Colonies of nitrogen-fixing blue-green algae grow on the surface of tillers of wetland rice. Nitrogen fixed by such colonies is used by the rice plant.

Stimulation of nitrogen fixation by rice

We know that the rice plant can stimulate development of an increase in nitrogen in a flooded soil.

About 100 rice varieties and wild rices were studied to see if there are differences in the ability of the rice plant to stimulate such a nitrogen gain. For 3 crops of rice, the nitrogen gain ranged from 538 mg/pot for Peta and 485 mg/pot for Mahsuri to 191 mg/pot for a fallow soil and 188 mg/pot for Pokkali.

We hope to correlate this characteristic with other plant characteristics. The next step will be to develop a simpler system for screening many more varieties for high nitrogen gainers and to investigate the genetic heritability of the trait.

Neem boosts nitrogen fixation

Cheap indigenous materials may help increase nitrogen fixed in a rice field.

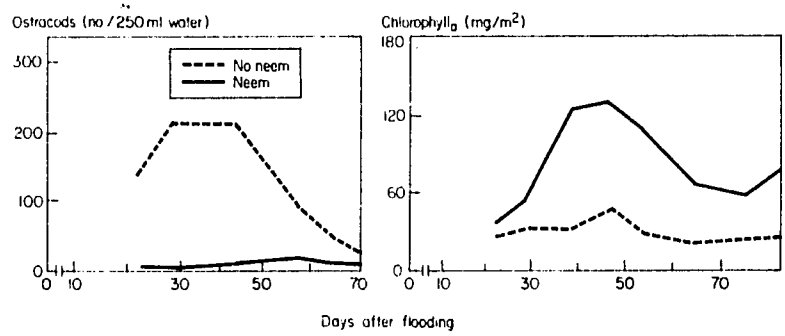
In past experiments, IRRI entomologists have found the seeds of the neem tree — or neem cake after oil extraction — to be an insecticidal antifeedant, that is, they caused insects to stop feeding on rice plants.

Neem seed and cake also stimulated growth of nitrogen-fixing blue-green algae. A study of algal biomass and the ostracods that graze on algae showed that neem applied at 100 kg/ha depressed growth of the grazers and increased algal growth (Fig. 10).

Microbial iron reduction in soil

Bronzing — purplish-brown or orange discoloration of rice leaves — is usually considered a symptom of iron toxicity. Bronzing may occur in rice grown in nutritionally poor soils, even where iron content is low.

A 1981 study showed that soil microbes also play a part in iron toxicity. In experiments with soils that caused iron toxicity, we



10. Seeds of neem (*Azadirachta indica*), or the neem cake after oil extraction, applied at 100 kg/ha, reduced the small aquatic invertebrates (Ostracods) grazing on blue-green algae. The reduction in grazing resulted in increased growth of the nitrogen-fixing blue-green algae.

Rice straw plowed into the paddy significantly improves soil nutrient content. Farmers in many areas, however, burn their rice straw in the field.

found that iron toxicity in rice grown in poor soils is triggered by microbial iron reduction in the root zone at the maximum tillering stage of the crop. Analysis of leaves from plants that showed bronzing indicated that the plants were poor in essential elements, particularly potassium and sometimes zinc.

MANAGEMENT OF ORGANIC MANURES

Rice straw as a nutrient source

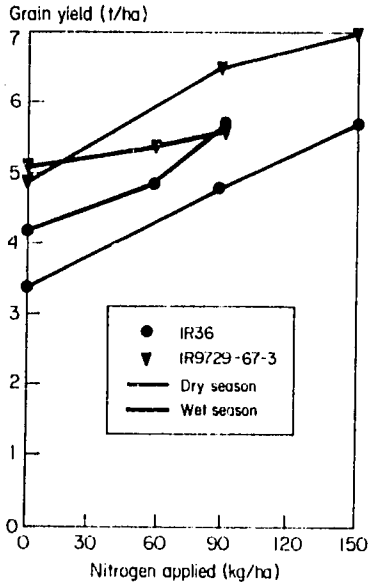
The high cost of fertilizers and the possibility of conserving nutrients by recycling them focus attention on readily available organic materials such as rice straw. In a long-term trial we found that, compared with straw removal, straw plowed into the soil significantly increases the content of organic carbon, nitrogen, and potassium in the soil but decreases zinc (Table 5).

On a neutral IRRI soil that received no nitrogen fertilizer for the past 7 seasons, straw plowed in gave, in the 18th season, a

Table 5. The plowing in of rice straw for 7 years affected average nutrient content of 3 soils.

Straw	Organic carbon (%)	Total nitrogen (%)	Phosphorus (Olsen ppm)	Potassium (meq/100 g)	Zinc available (ppm)
Removed	1.27	0.145	7	0.28	5.1
Plowed in	1.53	0.175	8.4	0.76	2
Difference[a]	0.26**	0.030**	0.7	0.48**	-2.9**

[a]** indicate significant difference at 1% level.



11. IR9729-67-3, a promising early-maturing line, yielded more than IR36 at almost all levels of nitrogen applied. It matures 8-10 days earlier.

yield of 2.9 t/ha. Yield was 2.2 t/ha where straw was removed. The corresponding yields on an unfertilized acid soil in a farmer's field in the 4th season were 2.1 t/ha for straw plowed in and 1.7 t/ha where straw was removed. All plots appeared to be nitrogen-deficient, but the straw-treated plots were greener than the untreated ones. For higher yields, those soils still need fertilizer nitrogen.

RICE CROP CULTURAL PRACTICES

Increasing productivity of early-maturing rices

There is considerable demand to increase productivity of rice (kg rice produced/ha per day) by reducing growth duration. We compared several early-maturing elite breeding lines with IR36 at various nitrogen management practices. IR9729-67-3 produced 80 kg/ha per day in the dry season and 65 kg/ha per day in the wet season.

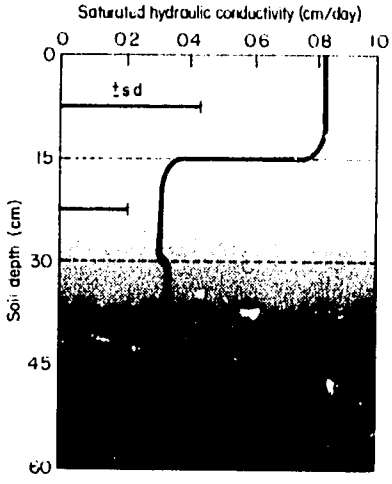
IR9729-67-3 also produced higher yields at IRRI than IR36 rice, even without fertilizer nitrogen (Fig. 11). This trait was exhibited earlier by IR42.

TILLAGE AND MANAGEMENT OF SOIL PHYSICAL CONDITIONS

Water transmission in wetland soil profiles

Accurate estimates of percolation losses in flooded rice require field measurement within the soil profile. Using improved field techniques, we monitored hydraulic gradients and soil-water conductivities in water-saturated and unsaturated soil profiles. Subsoil conductivities in a flooded field were less than 0.4 cm/day, which indicates slow drainage (Fig. 12).

Knowledge of unsaturated soil-water conductivities is required in characterizing water movement and hydrologic water balance in dryland rice and other dryland crops. The relationship of conductivity to energy state of soil water is shown in Figure 13. The values can be used to quantify soil-water movement in the root zone, drainage beyond the root zone, and capillary contribution from shallow water tables. These are important for the assessment of the availability of water left in the soil profile (after flooded rice) for subsequent use of a dryland crop.

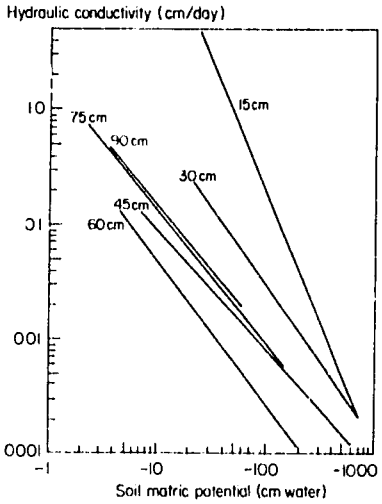


12. Measurement of saturated vertical hydraulic conductivity in the profile of a puddled wetland paddy at IRRI in the 1981 wet season showed slow drainage (low percolation loss) below 15 cm.

Soil water extraction by dryland crops

During the 1981 dry season we recorded actual soil water extracted by sorghum and mungbean in the field and compared

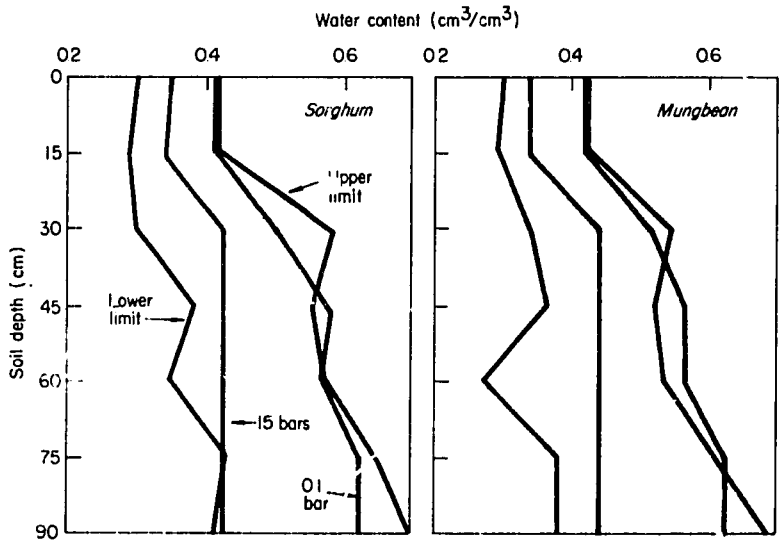
S. S. Hundal, IRRI postdoctoral fellow in agronomy, uses a neutron moisture meter to monitor soil moisture at different depths for determination of unsaturated soil conductivity in IRRI plots.



13. These unsaturated hydraulic conductivities at various depths in a soil profile are based on *in situ* measurements. These relationships can help provide accurate estimates of root zone water balance in a soil.

the data with empirical available water limits based on 0.1 and 15 bars moisture determinations in the laboratory (Fig. 14). Both crops extracted significantly greater amounts of soil water than predicted by laboratory data. This observation reflects the need for field determination of water extraction by crops.

In addition, our experiments showed that even though both crops extracted similar amounts of soil water, a short-duration crop of mungbean avoided late season drought and gave optimum yield whereas sorghum yields remained below optimum.



14. These soil-water content profiles show the water availability for sorghum and mungbean grown after wetland rice at IRRI in the 1981 dry season. Upper and lower limits represent soil moisture status at the beginning and end of the crop season.

Water table depth and crop root growth

Root growth of dryland crops following rainfed wetland rice is restricted by unfavorable soil moisture and aeration in the presence of receding water tables that prevail during the dry season. We found that root extension in mungbean and sorghum crops was restricted more by lack of adequate soil moisture than by soil aeration during the 1981 dry season.

A thorough understanding of such edaphic factors is needed for fitting crops to existing physical and hydrological environments.

ENVIRONMENT AND ITS INFLUENCE

The environment in which a rice crop must grow represents a complex of factors that can change suddenly and provide a constant threat of crop damage in farmers' fields. We continue to seek ways to help the rice plant adapt to its environment.

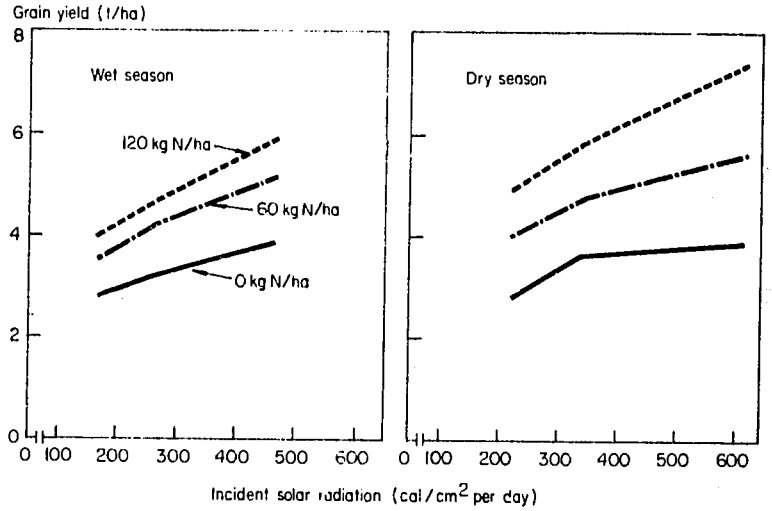
Sunlight nitrogen interaction

In the past when we studied the effect of sunlight on grain yield, other factors, including nitrogen level, were optimal. The amount of nitrogen farmers apply to rice, however, varies from farm to farm. Therefore, it is important to understand how nitrogen interacts with sunlight in rice yield formation if we wish to explain variation in farmers' rice yields in terms of sunlight effect.

Rice yield is sensitive to variation in solar radiation during the reproductive and ripening stages. Our 1981 research examined the effect of sunlight-nitrogen interaction on rice yield during ripening. At the same level of solar radiation, yields were always higher at higher levels of nitrogen, and at each level of nitrogen grain yield increased with increasing level of solar radiation (Fig. 1). Yield increase with increasing level of solar radiation is steeper at higher nitrogen levels.

Nitrogen-potassium interaction in low-temperature-induced sterility

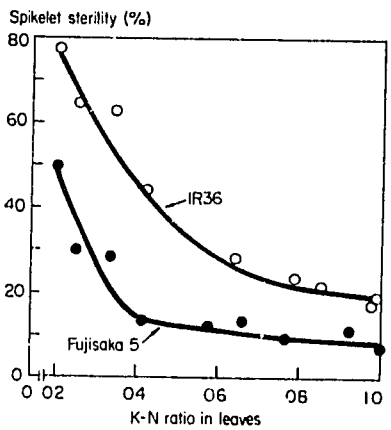
In 1981 we examined the interaction between nitrogen and potassium in low-temperature-induced sterility at the booting stage. There was a clear interaction between nitrogen and potassium. Increased supply of nitrogen increased spikelet sterility of both



1. The greatest yield effect of increased application of nitrogen to a rice crop (IR36) was obtained at highest levels of solar radiation. IRRI, 1981.

cold-tolerant Fujisaka 5 and cold-susceptible IR36. Increased supply of potassium counteracted the nitrogen effect in decreasing spikelet sterility.

When the relationship between potassium content in leaves and spikelet sterility was examined, a loose correlation was obtained. However, the correlation was greatly improved when the K-N ratio in leaves was plotted against spikelet sterility (Fig. 2). In both varieties, spikelet sterility was inversely correlated with K-N ratio in leaves. In Fujisaka 5, a K-N ratio of 0.4 is considered critical. Below that, the percentage of spikelet sterility increases with decrease in K-N ratio. In IR36, however, a K-N ratio of 0.8 appears to be needed to maintain a low percentage of spikelet sterility. In other words, cold-susceptible IR36 requires more potassium supply than Fujisaka 5 to tolerate low-temperature damage.



2. In a study of the relationship between spikelet sterility and potassium-nitrogen ratio, IR36 required more potassium than Fujisaka 5 to tolerate low temperature (15°/15°C for 3 days) damage.

Calcium peroxide as an oxygen supplier

Rice does not require oxygen for germination but needs it for seedling growth until an air passage system from shoot to root is established. Calcium peroxide coating of seeds was earlier found effective to release oxygen around the rice seedling and ensure a good crop establishment when seeding in a wet paddy. In 1981, we examined factors affecting the effectiveness of calcium peroxide for seedling emergence and grain yield.

For traditional direct seeding of rice, seeding rates are usually 120-150 kg/ha. Such high rates compensate for seed losses to rats and birds and for poor emergence. Drainage of the field at seeding time stimulates weed growth.

In 1981 tests with a calcium peroxide coating technique, we

Table 1. High yields were obtained when IR36 seed was coated with calcium peroxide and broadcast-seeded at 20 kg seed/ha. The traditional farmer seeding rate for broadcast seeding is 120-150 kg/ha. IRRI, 1981 dry season.

Seeding rate (kg/ha)	Grain yield (t/ha)[a]
10	5.13 b
20	5.62 ab
30	5.50 ab
50	6.22 a

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

placed seeds about 1 cm deep in the soil. This minimized losses to rats and birds. Flooding the field at seeding time minimized weed growth. The experiment showed that seeding rate can be reduced to 20 kg/ha without any reduction in yield (Table 1). Even at seeding rate of 10 kg/ha, the grain yield was reasonably high. In addition to low seeding rates, we used a high tillering variety and assured the even distribution of seeds.

CONSTRAINTS TO HIGH RICE YIELDS

Researchers on constraints on rice yield put increased focus on rainfed rice in 1981. Our bias within rainfed environments is the shallow flooded rainfed crop, which covers about 25% of the world's rice lands.

Cracking of this rainfed wetland rice field reflects the constant risk of moisture stress when rainfall is irregular. In 1981 trials, rice yields at high-stress sites — more than 20 days of moisture stress during the crop period — were significantly lower than yields from low-stress sites.

Intensive study of constraints to higher rainfed rice yields started in crop year 1980-81. We chose Camarines Sur in the Bicol region of the Philippines as the initial site because:

- farmers now grow two rainfed crops of modern rices each year;
- Bicol is one of the major rice-growing regions of the Philippines and yields are low — reported as 1.7 t/ha; and
- an institution is in place — the Bicol River Basin Development Authority — to extend benefits emerging from the research.

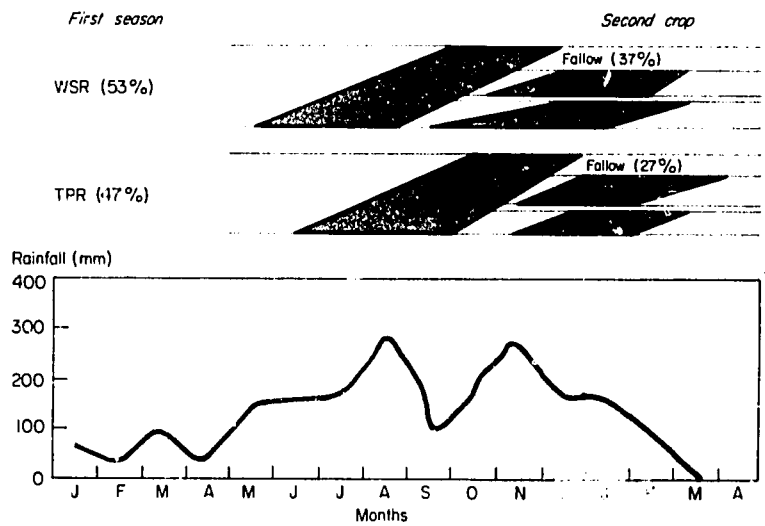
Rainfed rice production in Bicol

We did farm surveys to provide information on existing systems of rice production in the Bicol region:

- About half the farmers surveyed were owner-operators; half were tenant-operators.
- Rice farms are small by Philippine standards — the average size is 0.6 ha.

Dominant cropping patterns are shown in Figure 1. Overall, 68% of the land is double-cropped to rice — the dominant variety is IR36 and IR42 is the second most important variety. Whether farmers wet-seeded or transplanted was largely determined by the water status of individual paddies at planting time.

Of the surveyed farmers, 12% applied fertilizer to the first rice crop but only 5% to the second crop. The quantity of fertilizer applied was low — an average 19 kg/ha for the first crop and 15 kg/ha for the second. Pesticides were more frequently applied by farmers than was the case for fertilizer; however, the rates of



1. The rice cropping pattern observed at our Camarines Sur (Philippines) field site in 1980-81 was almost equally divided between a wet-seeded (WSR) and transplanted (TPR) first crop.

application of pesticides were some 30% of those recommended.

Three operations — land preparation, transplanting, and harvesting and threshing — accounted for more than 80% of labor use. Farmers' rice yields were recorded as 2.4 t/ha for the first crop, and 1.8 t/ha for the second.

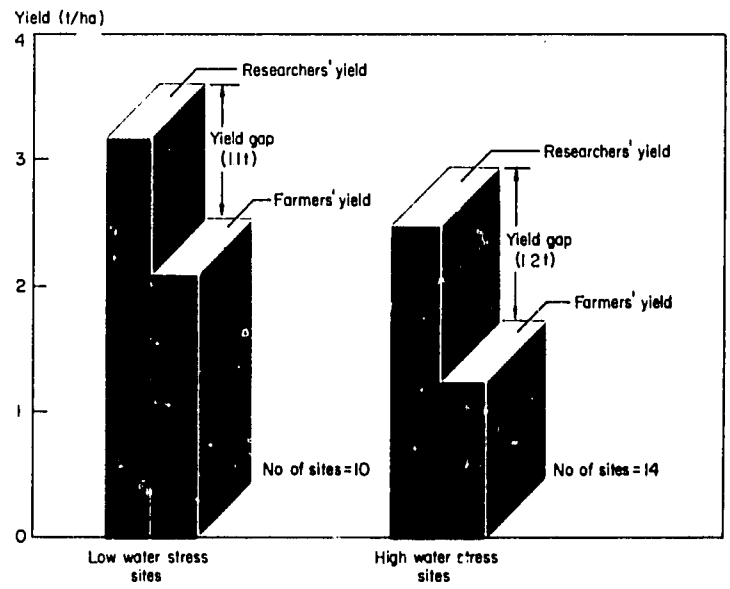
Thus, although farmers in Bicol grow modern rice varieties they use low levels of purchased inputs and get relatively low yields. The region provides us a challenging case study to develop further procedures to examine and ameliorate constraints to high rice yields in rainfed environments.

The yield gap

The procedures used in 1980-81 on-farm constraints trials were those developed and tested since 1974. We had 24 constraints experiments in the Bicol area during the second crop season. Sites were established across landscapes to provide areas subjected to a range of moisture stress. Sites that had less than 20 days of stress over the cropping season were designated low-stress sites, and those with more than 20 days of stress as high-stress sites.

Yields differed significantly between low- and high-stress sites. The second crop gave a significant response to researchers' fertilizer and insect control when compared to farmers' current practices, but not to weed control.

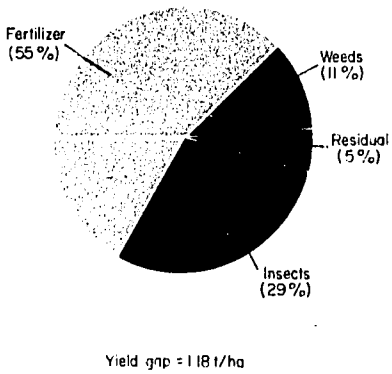
The mean yield of farmers' treatment was 2.1 t/ha for the low-stress sites and 1.3 t/ha for the high-stress sites (Fig. 2). Researchers' yields were also significantly higher at the favorable



2. The relative contribution of the combined effects of fertilizer, insect control, and weed control to the improvement of rice yields was calculated in farmers' field with low and moderate moisture stress in Bicol, Philippines, 1980. The yield gap was nearly the same for both stresses.

low-stress (3.2 t/ha) than at the high-stress sites (2.1 t/ha).

Difference in level of fertilizer contributed most to difference between researchers' and farmers' rice yields — across sites fertilizer accounted for 55% of the gap (Fig. 3).



3. The contributions of fertilizer and insects to the yield gap were highest in rainfed rice yield constraints experiments in Bicol, Philippines, 1980-81.

Yield variability between sites

We combined the managed experimental data with site-related factors to relate the variability between treatments to managed and site-determined factors. A production function was estimated:

$$Y = f(N, I, W, CEC, SD, N.SD, SH, VD)$$

where

- Y is yield in kg/ha;
- N is nitrogen input in kg/ha;
- I is expenditure on insecticides in $/ha;
- W is investment in herbicides in $/ha;
- CEC is the cation exchange capacity in meq/100 g;
- SD is moisture stress days during crop growth;
- $N.SD$ is an interaction term between nitrogen and stress;
- SH is the average hours of sunshine per day in the 45-day period before crop maturity; and
- VD is a variety dummy to allow for the 5 sites where short-season "Speed 70" (IR747) was planted by farmers as opposed to IR36.

All variables were significant at the 5% level or better (Table 1). In addition to the direct interpretation of the regression coefficients, the marginal R^2 shows that nitrogen level, the cation exchange capacity of the soil, and moisture status in the paddy

Table 1. Least squares regression estimates of response function fitted to rainfed rice yield constraints experiments, Bicol, Philippines, 1980-81.

Variable	Unit	Regression coefficient	Marginal R^2
Constant	kg/ha	992.29	
Nitrogen	kg/ha	24.69	0.14
Nitrogen square	kg/ha	−0.21	0.01
Insecticide	$/ha	0.12	0.04
Herbicide	$/ha	0.18	0.01
Cation exchange capacity	meq/100 g	12.80	0.12
Stress	days	−41.23	0.13
Sunshine	h/day	5.98	0.07
Variety dummy	0, 1	−413.66	0.04
R^2		0.56	
F-ratio		36.43	
Standard error of Y	kg/ha	584.77	

Table 2. Owners had higher net benefits and marginal benefit-cost ratios than tenants when costs of researchers' practices and the package of technology were estimated in a rainfed rice constraints experiment, Bicol, Philippines, 1980-81.

	Individual test factor			Package of technology
	Fertilizer	Insect	Weeds	
Yield increment (t/ha)	0.64	0.34	0.13	1.18
Harvester's share[a] (t)	0.07	0.04	0.01	0.13
Net yield:				
Owner (t/ha)	0.57	0.30	0.12	1.05
Tenant[b] (t/ha)	0.38	0.20	0.08	0.70
Value of net yield[c] ($/ha)				
Owner	73	38	15	135
Tenant	48	26	10	90
Incremental cost ($/ha)	67	49	11	127
Incremental benefit-cost ratio				
Owner	1.09	0.78	1.36	1.06
Tenant	0.72	0.53	0.91	0.71

[a]Harvester's share is one-ninth of threshed crop. [b]Tenants pay landlord one-third of yield after harvester's share is deducted. [c]Effective price of rough rice in research site was $128/t.

were the principal determinants of within-site and between-site variability in rice yields.

Profitability of recommended practices

The incremental benefits of the researchers' technology, the incremental benefit-cost ratios (B:C) of components of the technology and for the technology as a whole when compared to farmers' practices are reported in Table 2.

- The operator's tenure has a substantial impact on the profitability of adjusting from current to recommended practices.
- The incremental B:C values for a tenant were all less than 1.0. It would not be profitable, therefore, for tenants to adopt the recommended practice, given present technology, prices, and tenure arrangements.
- The incremental B:C exceeded 1.0 for fertilizer and weed management for owner-operators. However, it is unlikely that such low values would be attractive to low-resource farmers.

In our own 1980-81 work, we were able to add a little more than 1 t/ha to the farmer's yields — at a cost of nearly $125/ha. At current prices, added returns and added costs were similar. From a profit viewpoint the technology we tested was not superior to that of the farmers.

Thus with present rice varieties, the farmers' decision to use low levels of inputs for rainfed rice areas of Bicol appears to be justified. Detailed studies were initiated to identify the reasons for low productivity of modern rice varieties in the region.

CONSEQUENCES OF NEW TECHNOLOGY

A highly visible consequence of the widespread adoption of modern rice technology by farmers has been criticism of that technology in nonagricultural circles. Much of that criticism comes from those who lack information about changes that have occurred on rice farms and among rice consumers.

Research to determine the consequences of using the new rices and their accompanying technology started in 1966 and has continued.

Farmers surveyed in Laguna Province, Philippines, reached 100% adoption of modern rice varieties and fertilizer in 1978. Use of threshers went from none in 1975 to 72% in 1978. Most of the threshers are the IRRI-designed portable model.

Changes on Filipino rice farms

We have studied two sets of farms in the Philippines since 1966. Almost all farms have become complete adopters of modern varieties, have increased fertilizer use, have undergone land

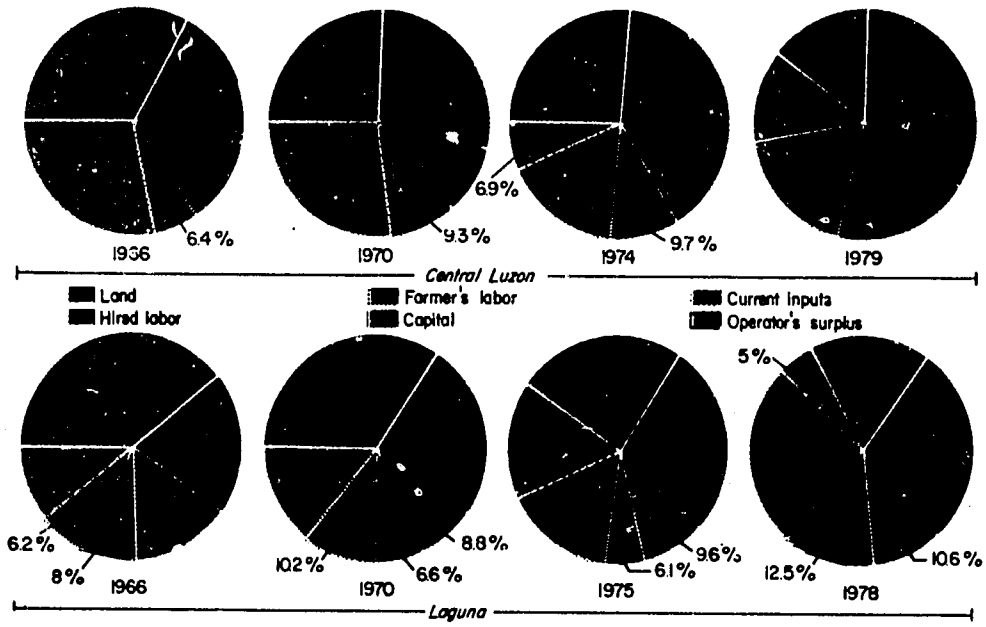
Table 1. Changes on rice farms in Central Luzon and Laguna Province, Philippines, 1966-79. Note that almost all farmers have adopted modern varieties and practice fertilizer use.

	Central Luzon				Laguna			
	1966	1970	1974	1979	1966	1970	1975	1978
Farmers studied (no.)	92	62	58	149	155	151	67	96
Share-tenants (%)	73	55	24	7	42	82	36	6
Grow modern varieties (%)	0	68	78	95	0	95	100	100
Apply fertilizer (%)	62	92	93	95	75	98	98	100
Use power tillers (%)	0	2	10	48	38	76	87	98
Use threshing machine (%)	76	71	50	51	0	0	0	72

reform, and have adopted use of small machines. Rice yields increased from 2.2 to 3.4 t/ha in the Central Luzon set and from 2.2 to 3.7 t/ha in that of Laguna Province. Table 1 provides details through 1979.

The Filipino farmers increased use of purchased inputs as well as the share of output going to pay for purchased inputs (Fig. 1). At the same time, the share of output for hired labor increased despite increased use of machinery.

One of the most dramatic on-farm changes was the reduction in the share of output going to land. The increase in yield brought by new technology after the declaration of land reform remained with the farmers instead of going to landlords as it would have under the share-tenant system. As a result the return to land declined 45% in both areas. Operators' surplus also declined but



1. Changes on Filipino rice farms as a consequence of using new rice technology are seen in the allocation of rice output among various factors of production. Detailed surveys of farmers started in 1966.

because total output was much greater, the advantage to the farmer tended to increase.

Profitability of tractor and tiller ownership

In a 1981 survey in Central Luzon, as a followup to work in the area in 1972, we concluded that the profitability of owning a large tractor had declined markedly. This is largely explained by a decline in the demand for custom tractor work, brought about by the rapid spread of small tillers. In contrast, the profitability of tillers, which are used predominantly for land preparation, has remained fairly constant.

Economics of the reaper

Previous mechanization studies have indicated that there may be certain times during each season when farmers contend with a shortage in the availability of casual labor. Often, harvesting is such a critical period that a lack of harvesters can lead to significant grain losses.

One solution is to mechanize reaping in the labor-scarce areas. We studied the use of small reapers (1.0 m and 1.6 m) and found they had enormous potential because they enable the farmer to reduce his labor input drastically (Table 2). However, three points were noted:

- the corners of fields still remain the preserve of manual reapers;
- the machines are suitable only for rice harvesting; and
- social considerations necessitate selective introduction of this new technique.

Energy for rice production

High fuel prices continue to emphasize the importance of efficient energy use in rice production. We studied energy used to provide water for rice on selected farms in Nueva Ecija Province,

Table 2. A 1981 comparison of manual reaping and reaping with 2 sizes of IRRI-Chinese reapers showed a distinct cost advantage for the small mechanical reaper.

	Manual reaping	IRRI-Chinese reaper	
		1.0 m	1.6 m
Labor input (h/ha)	70	16.6[a]	14[a]
Cost of reaping (US$/ha)			
Machine owner	47.60	19.60[b]	20.10[b]
Machine user	47.60	36.80[c]	36.80[c]

[a]Assuming 10 h/ha for manual harvesting of field corners. [b]Assuming an annual use of 40 ha for the 1-m reaper and 80 ha for the 1.6-m reaper. [c]Assuming a custom fee of US$30/ha and $0.68/h for manual reaping of field corners.

Philippines. The source of water was rainfall, shallow pump (6 m to water table), deep pump (14 m to water table), or gravity flow. We found that energy use per hectare was greatest for the shallow-pump irrigated farm and lowest for the rainfed farm, but output per unit of fuel energy was highest in the gravity irrigated fields, and lowest in the rainfed fields.

Consequences of mechanization

Data we have analyzed on the consequence of mechanization have little evidence to support any change in yield or cropping intensity arising from mechanical land preparation. We found that differences in fertilizer use explained any apparent yield differences. The isolation of such contributory factors is our next task.

It is also evident that much of the reduction in labor use resulting from mechanization can be attributed to a reduction in the use of family labor.

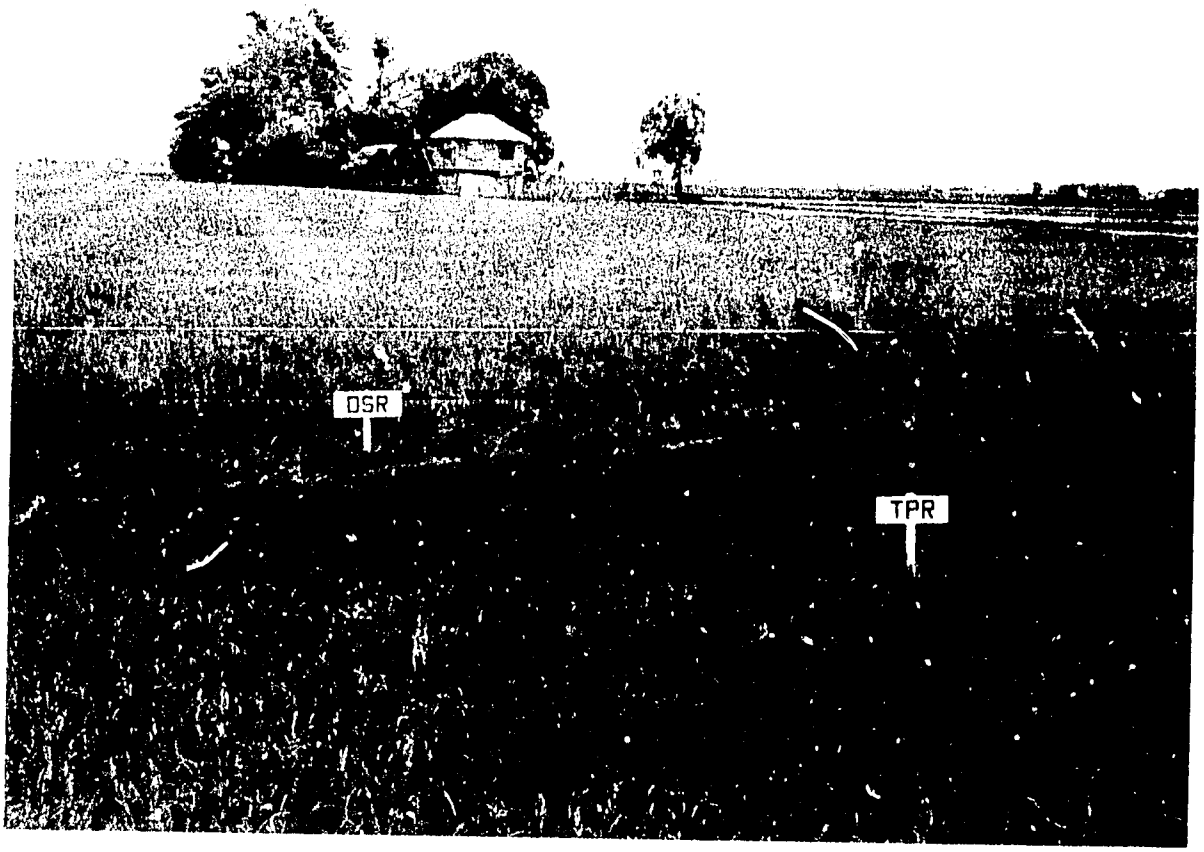
CROPPING SYSTEMS

Farmer adoption of cropping patterns built around modern rices continued at an increasing rate throughout Asia in 1981. Patterns with two rice crops spread rapidly in Indonesia, Philippines, and Sri Lanka. Farmers generally combined short-duration modern varieties with dry seeding of the first crop to obtain two crops instead of one and more than double rice production in some rainfed areas. In irrigated areas some farmers used 90-day rices such as IR36 in continuous rice production systems that gave 3-4 crops a year and 25-30 t/ha annual yields.

But not all areas can count on two rainfed rice crops while other rainfed areas easily make two rice crops and have enough soil moisture left to grow a dryland third crop. For both types of area, our search concentrates on better dryland crops and dryland crop practices to add profit to the rice-based cropping systems.

The cropping systems researchers' handbook, *A methodology for on-farm cropping systems research,* was released in 1981. It will help strengthen research throughout the Asian Cropping Systems Network — and beyond.

Publication of the handbook marked the completion of the phase of activity that gave primary attention to the development



Rice in these 2 farmers' fields in Iloilo Province, Philippines, is dramatic evidence of the time gained by dry seeding (DSR) an early-maturing modern variety as the first crop in a rice-rice cropping pattern. The DSR crop (background) was ripening while the transplanted crop (TPR) was at the early vegetative stage. The farmer with the DSR crop had his second crop planted before the farmer with the TPR harvested his first — and only — crop.

of the cropping systems methodology. In the immediate future we expect to increase research devoted to the improvement

- of technology to increase the productivity of rice-based cropping systems, and
- of methods for preproduction testing of cropping systems.

ANALYSIS OF THE SOCIAL AND ECONOMIC ENVIRONMENT

Cross-site analysis of cropping patterns

If major relationships between the acceptability of cropping patterns and their respective physical-economic environments can be specified — and even measured — researchers can increase their efficiency in designing and testing new cropping patterns and their component technologies.

During 1981 we tested the feasibility of comparative analysis at 14 sites in 4 major agroclimatic zones of the Philippines. We focused exclusively on rainfed areas where cropping systems research is concentrated. Multivariate statistical techniques such

as factor analysis and discriminant analysis were applied with promising results:

- Among the farm-level variables, farm size (and implicitly the man-land ratio) appeared to have a major influence on cropping systems characteristics, particularly those related to input use.
- Sociodemographic variables such as farmers' age, education, and farming experience did not appear to influence cropping systems.

We believe it may be advantageous that most farm-level variables were insignificant in explaining cropping systems characteristics. Many socioeconomic variables are much harder to measure than physical parameters. This early outcome of cross-site studies suggests that only a few socioeconomic variables may need to be considered in cropping systems design. However, we will do more extensive cross-site analysis within the Asian Cropping Systems Network.

Credit and adoption of new cropping systems

New cropping technologies usually required larger amounts of cash inputs than farmers use in their traditional systems and lack of credit is often identified as a constraint to adoption of new technologies.

Governments and development agencies have devoted massive amounts of resources to developing large-scale rural credit schemes to facilitate new technology adoption.

We studied technology adoption and the role of credit in villages in Iloilo Province where cropping systems research had demonstrated added productivity of double-cropping systems,

Filipino farmers in a double rice crop program discuss credit needs with their banker (center). Credit helped stimulate early adoption of the new rice technology. But as farmers stayed in the program, their capacity to finance their inputs without credit increased.

which replaced the traditional single rice-crop system. In some of the villages a pilot production program (KABSAKA), which incorporates a credit component, had been operating. We found that:

- Irrespective of whether a formal credit scheme operated, widespread adoption of the new technology took place in all study villages.
- Of a sample of 77 farmers who participated in KABSAKA in 1977, 36 did not participate in 1980. However, nearly all of them continued to practice the major elements of the KABSAKA technology package.
- Often the real cost of institutional credit was high — time spent traveling, filling forms, obtaining clearances, etc. — and timing of credit was less than satisfactory.
- There was increased capacity for farmers to self-finance their inputs because of higher incomes.
- A major expansion had occurred in the informal credit sector. Fertilizer was available on credit, to be paid back in kind after harvest in every one of the villages with no formal credit scheme. The fertilizer was available in the village at the needed time and the interest cost compared favorably with the real cost of institutional credit.

Our findings suggest that although institutional credit schemes may help stimulate early adoption, they may not be necessary for sustaining adoption if the production technology is indeed appropriate.

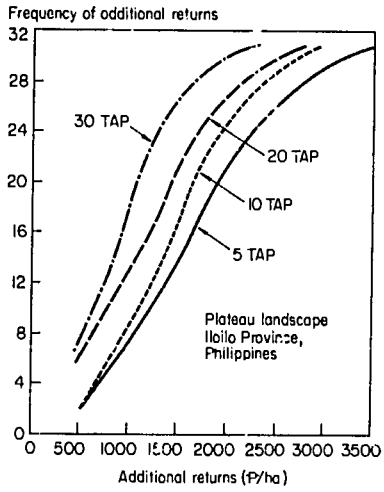
Economics of shorter turnaround periods

Early crop establishment and shorter turnaround period between crops increase cropping intensity in rainfed environments. Direct-seeding techniques achieve the former in rice-based systems and increased use of animal power or machinery helps achieve the latter.

The net economic benefits from such practices are affected by many factors. Erratic early rains make early crop establishment more risky; higher power requirements increase costs and reduce economic benefits from higher yields of subsequent crops.

In the Oton-Tigbauan area in Iloilo, we found that the average turnaround period between rice crops was 23 days. Long turnaround periods resulted in lower second crop yields and sometimes complete crop failure.

We used a rainfed crop simulation model, developed earlier for the site, to analyze the economics of reducing turnaround period with greater use of animals or machinery. We examined the



1. The cumulative frequency distribution of additional returns from a dry-seeded rice - transplanted rice - mungbean pattern using carabao shows that returns increase as turnaround period (TAP) decreases. The returns are based on a simulation model, which used weather data for 1949-79.

performance of three intensive cropping patterns on the plateau, plain, and side slope landscape positions. The selected patterns were: wet-seeded rice (WSR) – transplanted rice (TPR) – mungbean, dry-seeded rice – TPR – mungbean, and WSR – WSR – mungbean.

We analyzed the net economic benefits from turnaround periods of 5, 10, 20, and 30 days with animal power and 7 days with a power tiller. The results were used to develop cumulative frequency distributions (CFDs) of net benefit.

Figure 1 shows the CFDs for the four times with animal power on the highest landscape (plateau) sites. The study results showed that:

- shorter turnaround times are more profitable and less risky in all landscape positions for each pattern; and
- use of a power tiller is attractive in all cases except when sufficient animal power at prevailing hiring rates can be obtained to reduce turnaround time to 5 days.

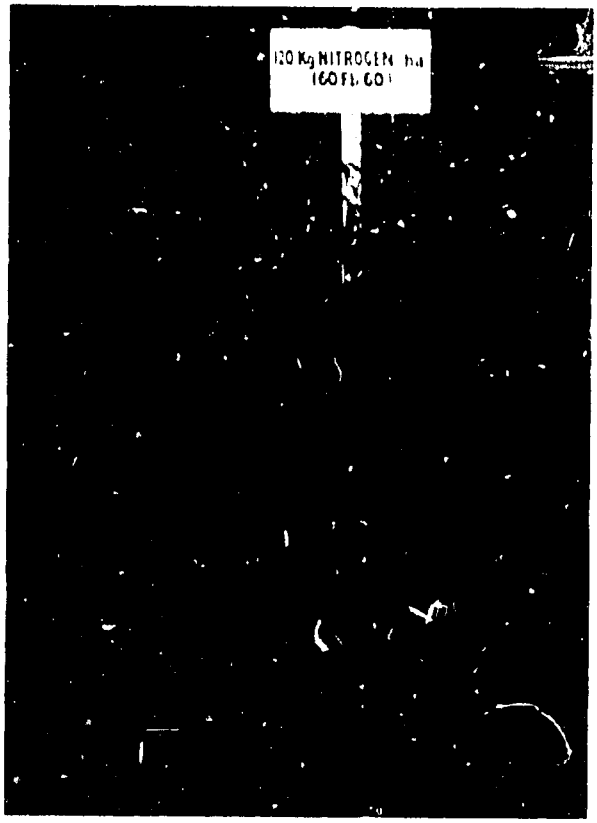
Our results also indicated that for the Iloilo site environment, patterns where the first crop was dry-seeded gave slightly higher profits on the average, but wet-seeding the first crop was less risky. Farmers there preferred wet seeding.

PEST CONTROL IN RICE-BASED CROPPING SYSTEMS

Weeds in rice cropping patterns

The weed populations that grow in association with rice vary greatly among cropping patterns.

Relatively low dosages of 2,4-D at pre-emergence and propanil 15 days after transplanting gave weed control that was as good as hand weeding in rainfed wetland trials.



Increases in level of nitrogen fertilizer caused greater weed problems in 1981 trials in a cropping pattern of continuously transplanted rice.

We noted:

- In the transplanted continuous rice cropping pattern, yield losses to weeds increased as the level of applied fertilizer increased.
- When one crop of transplanted rice was grown, hand weeding alone or in combination with herbicides resulted in good weed control.
- When dry-seeded rice was followed by transplanted rice, good weed control was achieved by hand weeding, butachlor combined with propanil, and butachlor followed by hand weeding, but not by butachlor applied alone.
- Excellent weed control was obtained in transplanted rice with one hand weeding, 2,4-D followed by propanil, and 2,4-D and butachlor followed by hand weeding. Weed control with butachlor decreased as the level of applied fertilizer increased.

Competitive ability of rice cultivars against weeds

Tall traditional and short modern rice cultivars were tested as a transplanted crop for competitive abilities against a weed com-

Table 1. Tall cultivars Peta and Binato were competitive against weeds and showed no significant yield differences between weeding and no weeding treatments in the 1981 dry season. When weeded, the short modern cultivars IR32 and IR52 gave highly significant yield increases. Note that the modern rices had yields nearly double those of the tall cultivars when both types were weeded.

Cultivar	Grain yield (t/ha)[a]		
	Hand weeding	No weeding	Difference
Peta	2.05 b	1.62 ab	0.44[ns]
Binato	2.67 b	2.05 a	0.61[ns]
IR32	4.32 a	0.80 b	3.52**
IR52	4.57 a	1.45 ab	3.12**

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. **Significant at the 1% level, ns = not significant.

munity dominated by *E. glabrescens.*

The greatest increase in crop growth rate of all cultivars occurred between 6 and 9 weeks after transplanting, which was the same time maximum weed weight was recorded.

Even though there were no significant differences in the weed weights or the composition of the weed flora among cultivars, weeds caused a significant yield reduction in the modern cultivars but not in the traditional cultivars (Table 1). The traditional cultivars were above the weed canopy and did not suffer from shading, but the short modern cultivars were affected by shading. Because the modern cultivars matured earlier they had weed competition for a proportionately longer part of crop life than the tall cultivars.

Interaction between weeds and rats

Rat damage in transplanted rice is more severe in weedy than in weed-free plots. We found a highly significant correlation between percentage of rat damage and dry weed weight at harvest. Rats damaged weedy plots first and moved to adjacent weeded plots when the food supply in the first was exhausted.

Disease control by chemicals

Several fungicides available to farmers were tested in 1981. At IRRI, we found that commercially available soil fungicide PCNB, applied as seed treatment, was effective against preemergence damping-off of mungbean. Metalaxyl, a fungicide for downy mildew of maize, was excellent against preemergence damping-off caused by *Pythium* but ineffective against *Sclerotium.* PCNB + thiadiazole, carboxin + captan, and the commercially available fungicides thiophanate methyl, PCNB, and iprodione applied as foliar spray were effective against *Rhizoctonia* postemergence damping-off of mungbean and cowpea. Carboxin + captan and PCNB were also promising against *Sclerotium* postemergence damping-off.

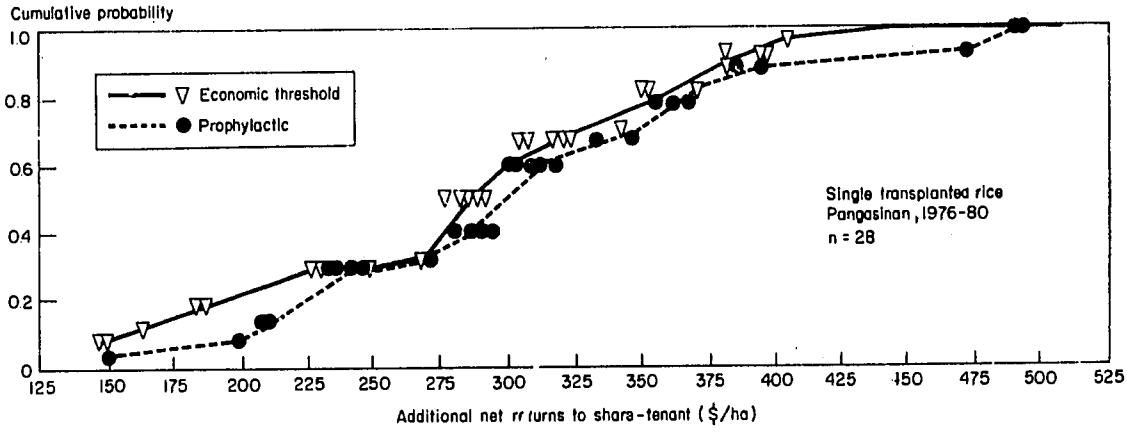
Mancozeb + benomyl and chlorothalonil, applied as foliar spray at recommended rates, effectively controlled Cercospora leaf spot, powdery mildew, and rust of mungbean planted after rice. The disease control by mancozeb + benomyl 1 (Delsene) was significantly correlated with yield but the less expensive fungicide chlorothalonil gave a better benefit-cost ratio. There was significant control of powdery mildew and Cercospora leaf spot when the application rates were reduced by one-half.

Cropping systems and soil-borne diseases

We previously observed that there was a shift from *Rhizoctonia* to *Fusarium* in the pathogens isolated from infected cowpea plants grown in a dryland field during the first crop and that the incidence of *Rhizoctonia* infection on cowpea was not reduced by planting rice as the first crop.

In the third crop (1981) of continuous cowpea, *Fusarium* disease increased and progressed until severe stunting occurred (Fig. 2). With rice as the first crop, the disease was greatly reduced. Addition of compost did not affect the soil-borne diseases.

2. The incidence of the soil-borne pathogen *Fusarium* increased with continuous cropping of cowpea in cropping pattern trials. The plots with stunted plants had continuous cowpea; the plots with better growth had rice - cowpea.



3. When cumulative probability for added net returns was plotted for economic threshold and prophylactic chemical insect practices for 1976-80, the prophylactic practice showed consistently higher probability of obtaining greater returns.

Insect control for transplanted rice

We analyzed data for 1976-80 on chemical insect control practices for single-crop transplanted rice in Pangasinan Province, Philippines. Two potential practices have been tested:

- insecticide application only when economic thresholds for insects were surpassed, and
- prophylactic use of soil-incorporated carbofuran granules before transplanting to protect the vegetative stage, and application of additional insecticides at other growth stages when economic thresholds were surpassed.

The practice with prophylactic carbofuran gave a significant yield increase over the treatment at economic threshold alone in 3 of the 4 years. Yields were reflected in net returns, which were higher for the prophylactic practice in the same 3 years.

When net returns for each practice were plotted over all years as a cumulative frequency distribution reflecting the probability of a share-tenant obtaining greater profit, the prophylactic practice was superior to economic threshold (Fig. 3). The prophylactic carbofuran treatment was chosen as the recommended practice for provincewide testing.

Yield loss from insect pests

Yield losses measured as the difference between insecticide-protected and unprotected plots during the 1981 crop year in Cagayan Province, Philippines, showed a remarkable absence of insect pest infestations. Low insect infestations reflected the detrimental effect of a 5-month rice-free period (March-July) enforced by the long dry season.

CES 1D-21 mungbean planted in April with the first rains showed insignificant yield differences between protected (1.2 t/ha) and unprotected (1.1 t/ha) plots, even though all of the key

insect species known to attack mungbean in the Philippines were present. CES 1D-21 had more than 80% yield losses in Pangasinan and Iloilo.

IR52 dry-seeded bunded rice planted in June did not show significant loss of stand from ant damage in 1981 as it had the year before, and there was no yield difference between protected (3.3 t/ha) and unprotected (3.5 t/ha) treatments.

Single-crop rice transplanted in August was not significantly affected by insect damage: IR52 yielded 3.6 t/ha with protection and 3.1 t/ha without protection; a traditional photoperiod-sensitive variety yielded 3.2 t/ha with protection and 3.4 t/ha without protection.

Rice stubble and mungbean insect control

Mungbean, grown after rice where rice stubble is plowed under, sits in a bare soil and is attractive to beanfly, thrips, aphid, and leafhopper. We know that abundance of these early crop colonizers is reduced if rice stubble is left standing and mungbean is planted after minimum tillage.

Preflowering insecticide is still required for mungbean, however, because other insects such as flea beetle are not affected by the stubble. In 1981 tests in Pangasinan, the recommended insecticide practice of 0.25 kg a.i. + 0.75 kg a.i. monocrotophos/ha applied 2 and 12 days after crop emergence + 0.75 kg a.i. endosulfan/ha 30 and 40 days after crop emergence gave higher yield with stubble present (minimum tillage) than with no stubble (Table 2).

It is apparent that sowing mungbean into stubble after rice harvest increases yield from insect control. Yield reduction caused by preflowering insect pests can be seen in the postflowering insecticide treatment where mungbean yield in stubble was twice the yield without. The higher yield in the recommended practice with stubble is believed to be from better thrips control.

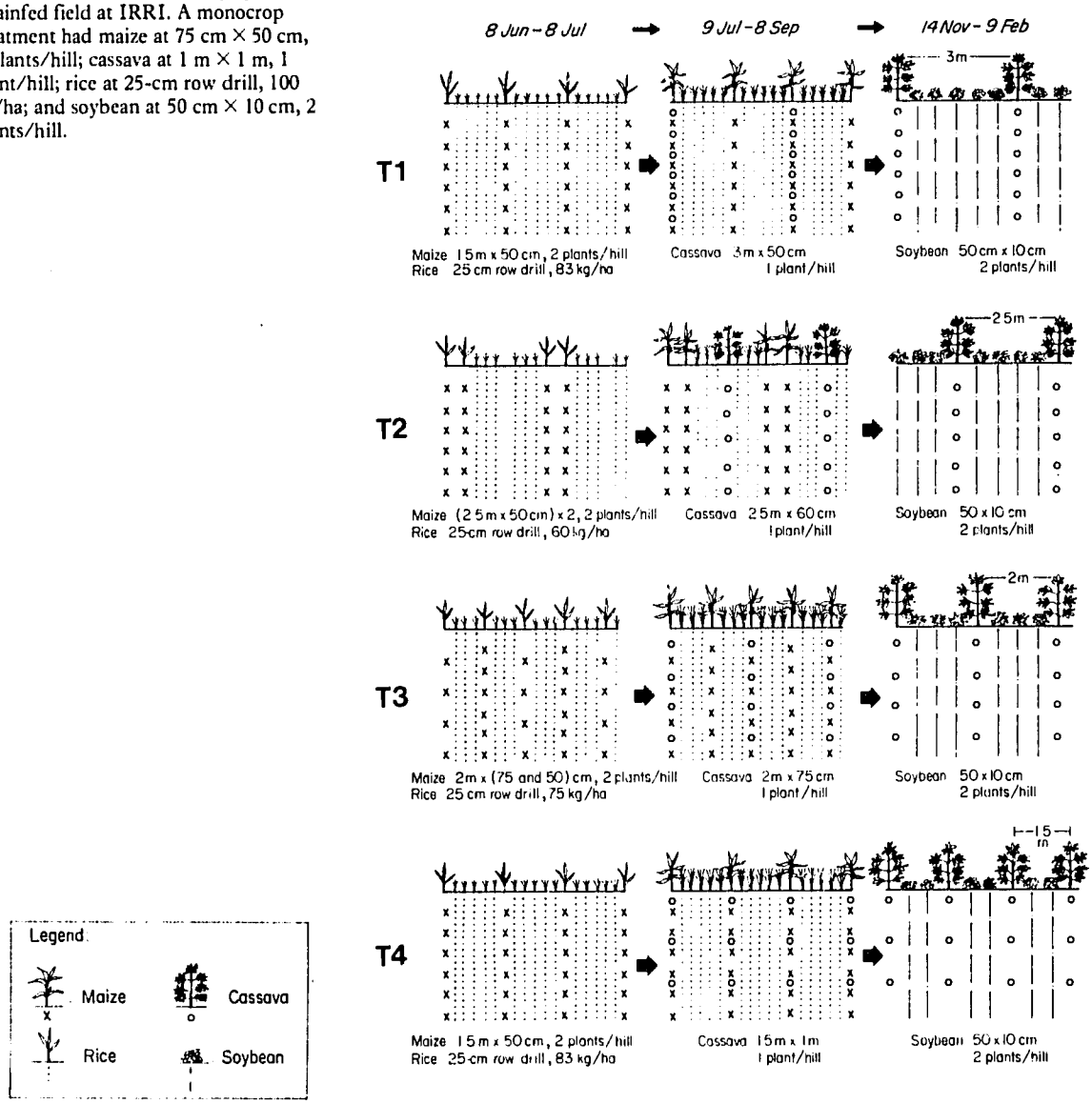
Table 2. In 1981 tests in Pangasinan, mungbean planted in standing rice stubble with zero tillage (ZT) was less attacked by insects and gave generally higher yields than mungbean planted after high tillage (HT, no stubble).

Insecticide protection	Beanfly infested plants (%) 25 DE[1]		Thrips (no./35 terminals) 25 DE		Aphid infestation (grade) 25 DE		Leafhoppers (no./35 plants) 25 DE		Yield (t/ha)	
	ZT	HT	ZT	HT	ZT	HT	ZT	HT	ZT	HT
Complete	0 a	0 a	18 a	23 b	1 a	1 a	0 a	0 a	0.73 a	0.53 ab
Postflowering	4 b	19 c	24 b	122 c	1 a	1 a	0 a	3 c	0.48 bc	0.24 de
Untreated	5 b	19 c	26 b	127 c	4 b	4 b	0 a	3 c	0.23 de	0.09 e
Recommended	0 a	0 a	15 a	26 b	1 a	1 a	0 a	1 b	0.54 ab	0.34 cd

[1]DE = days after crop emergence. In paired columns (tillage methods), means followed by a common letter are not significantly different at the 5% level.

A 4-crop system for rainfed areas

We continue to explore the role of intercropping in rainfed rice-based cropping systems. In 1981 we completed tests with four crops (rice, maize, cassava, and soybean) in four planting arrangements (Fig. 4). Varieties, planting and harvesting dates, and fertilization practices were the same for all treatments. Intercrop competition lowered the yield of all crops (Table 3), but



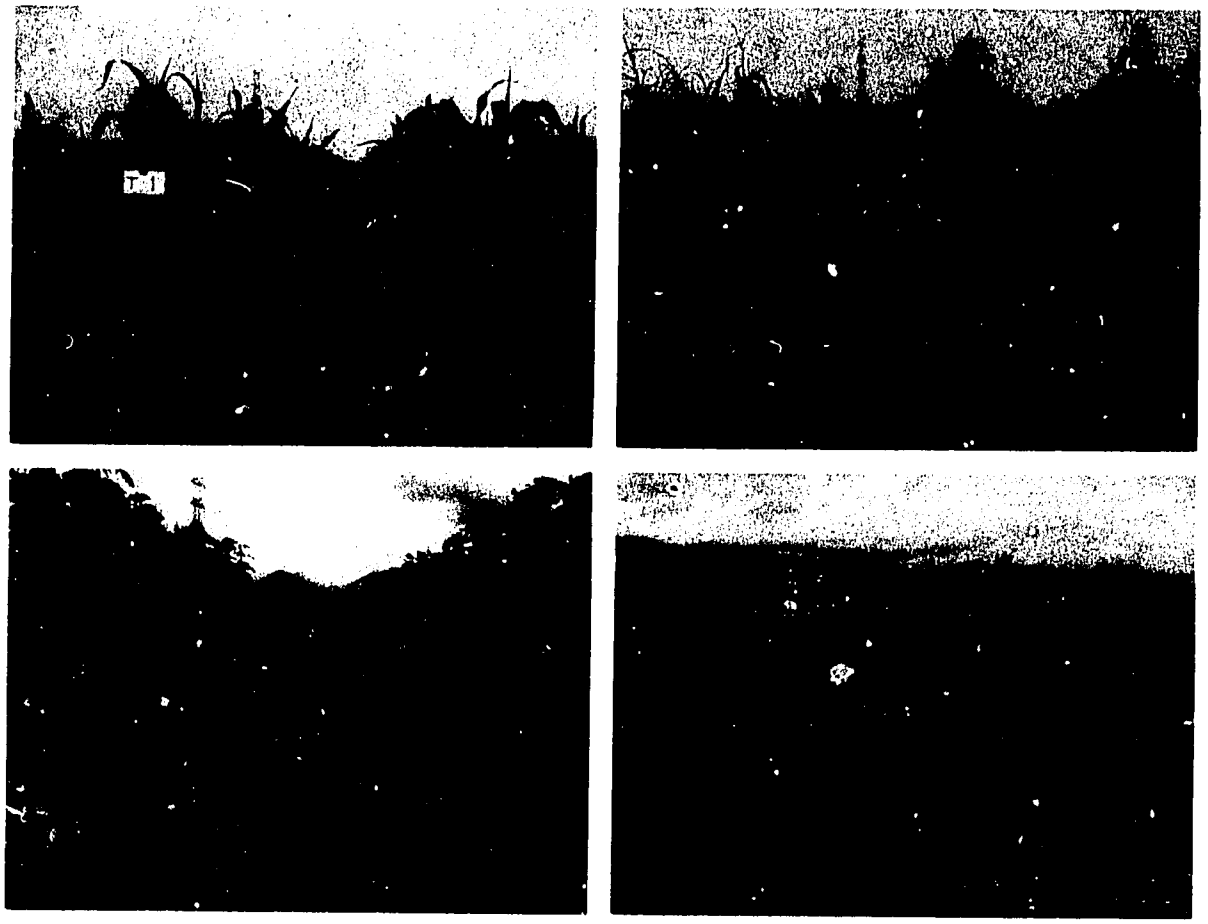
4. Row arrangements and plant spacing used in a 1981 test of a 4-crop system in a rainfed field at IRRI. A monocrop treatment had maize at 75 cm × 50 cm, 2 plants/hill; cassava at 1 m × 1 m, 1 plant/hill; rice at 25-cm row drill, 100 kg/ha; and soybean at 50 cm × 10 cm, 2 plants/hill.

Table 3. Crop yield and gross return from 4 crops with treatments as diagrammed in Figure 4.

Row and space arrangement	Intercropped cassava variety	Yield (t/ha)				Gross return[a] (₱/ha)
		Maize	Rice	Soybean	Cassava	
T1	Tall	1.4	1.8	2.5	11.1	7,675
	Short	1.4	1.8	2.8	8.6	7,123
T2	Tall	1.5	1.6	2.2	6.6	6,153
	Short	1.5	1.5	2.5	4.9	5,697
T3	Tall	1.8	1.6	1.9	9.3	6,950
	Short	1 7	1.4	2.2	8.1	6,548
T4	Tall	1.5	1.6	1.4	11.7	7,036
	Short	1.5	1.6	1.6	9.1	6,521
Monoculture		2.7	3.5	4.0	20.9 (tall)	5,225
					27.9 (short)	6,975

[a]Prices used were maize ₱0.9/kg; rice, ₱1.3/kg; soybean, ₱5/kg; cassava, ₱250/t.

gross return per hectare was greater than for monocrop systems when the tall cassava variety was used. Figure 5 shows treatment 1 at 4 stages.



5. Treatment 1 of the 4-crop system in a rainfed field at different times after cassava planting.

Cropping pattern studies for dryland areas

During the development of the IRRI dryland research area in 1975-76, one block (UD) was carefully divided into many small plots according to topography and some were bunded for rainfed rice culture. During 1977-80 various cropping patterns were designed and tested to identify adapted and productive patterns in fields with different elevations and water regimes. The cropping patterns in these experiments included:

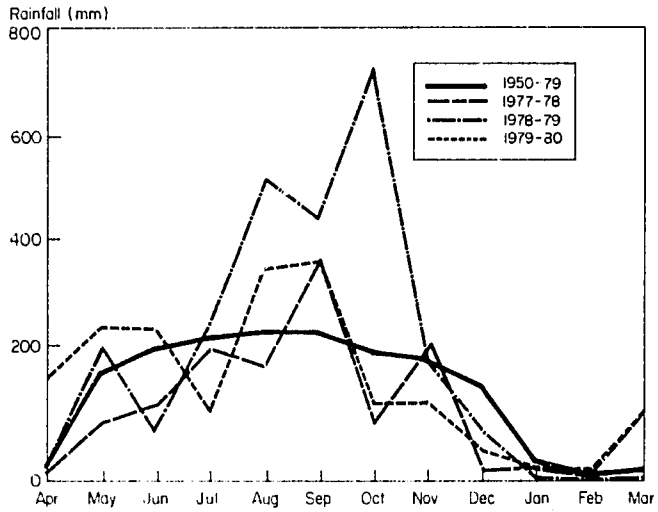
- a group with dryland patterns, which consisted of crops and management without wetland rice or soil puddling, and
- a group with wetland patterns, which involved at least one crop of wetland rice with soil puddling.

The design of the various patterns was based on previous knowledge of crop combinations and on judgment of the research staff.

Monthly rainfall distribution for 1977-80 is in Figure 6. These data were compared with the 29-year average using a simple regression model. Only the 1977-78 rainfall was similar to the long-term rainfall distribution.

The length of the growing season was calculated each year by using the rainfall accumulation criteria of 100 mm for dryland crops and 200 mm for wetland rice. The 3-year study indicated the following patterns to be most feasible and profitable:

1. On dryland, unbunded fields (those not including dryland rice)
   - Grain legume – maize – sweet potato
   - Grain legume – maize – grain legume
   - Grain legume – sorghum – sorghum (ratoon)



6. Monthly rainfall distribution of 1977-80 crop years compared with the 29-year average. Block UD, IRRI.

2. On wetland, bunded fields
   - Dry-seeded rice – transplanted rice – grain legume
   - Grain legume – transplanted rice – grain legume
   - Maize – transplanted rice – grain legume
3. The best intercrop combinations on the dryland unbunded area were grain legumes + maize or sorghum

Pattern studies in Cagayan Valley

In 1980 we identified three land strata on a rice-growing plain near Solana, Cagayan, where both drought and flooding were prevalent. The strata (A, B, and C) were separated on the basis of depth of flooding following heavy rainfall. Stratum A had one 3-day flood period; three serious flood periods occurred in stratum C.

In 1981, 25 farmers' fields at 3 sites near Solana were planted to mungbean (MG) as the first crop in MG – TPR – MG and MG – TPR patterns. Seventeen trials were on stratum A and eight on stratum B. The grain yields and economic analysis of our technology vs farmer practice are shown in Table 4. Despite much higher expenses, our trials showed greater gross returns and returns to variable costs than farmer practices. It was safer and more profitable to plant mungbean before rice on stratum A than on stratum B.

The 1981 results indicated that introduction of an improved variety such as CES 1D-21, an increase of present seeding rates from 13 to 25 kg/ha, and pest protection will help make mungbean before rice a profitable crop in the Cagayan Valley.

Table 4. Yield and economic performance of mungbean was higher with new technology than with traditional practices at Solana, Cagayan, Philippines, 1981. Fields that gave no yield because of storms and soil waterlogging are included in cost computations.

	New technology[a]		Traditional technology[b]	
	Stratum A	Stratum B	Stratum A	Stratum B
Plots (no.)	16	9	34	34
Yield (kg/ha)	523	234	82	34
Requirements:				
Material cost	360	315	97	90
Labor cost	1298	636	220	164
Total variable cost	1658	951	317	254
Returns:				
Gross	2531	1,213	302	175
To variable cost	873	262	−15	−17
To labor	3.0	2.4	1.4	0.7
To material cost	2.4	0.8	− 0.1	− 0.8

[a]Five fields in stratum A and 3 in stratum B that failed (0 yield) because of severe waterlogging are included in the computations. [b]Eight fields in stratum A and 13 in stratum B were total failures (0 yield), but are included in the cost and returns computations.

Sweet sorghums such as this did well in 1981 trials at IRRI.

Sorghum potential for droughty rainfall areas

Many rainfed areas of Asia have been unable to adopt a cropping pattern with two rice crops because of the frequency with which drought hits the second crop. Tests of cropping patterns in some areas have shown good potential for sorghum because of its drought resistance. Sorghum has not, however, been a highly marketable crop.

Because of increasing fuel costs and the universal search for alternate fuels, we started tests with sweet sorghums in 1981 to see if a profitable cropping pattern with rice and sorghum could be developed. Sorghum could be converted to fuel alcohol, with a high-protein animal feed as a by-product.

Our tests indicate that a cropping pattern with sweet sorghum has promise for many rainfed areas.

Soybean phenotype × environment studies

The soybean is of interest in rice-based cropping systems because of its relatively short growth duration and high oil and protein contents. The soybean, which originated in North China, has higher and more stable yields in temperate regions than in the tropics.

There is a wide range of morphological differences among soybean cultivars and breeding lines. To better understand the tropical genotype × environment interaction by factor analysis we grew 25 cultivars from 12 countries before rice at IRRI and Tuguegarao, Cagayan. Trials were planted in March and the means and ranges of values of plant characteristics and climate at the two sites were recorded.

Cultivars Pb-1, Fitzroy, Clark 63, Tunia, and Improved Pelican were among the top 10 yielders at both sites. The low yielders were late-maturing cultivars such as IGH23, L-114, and Jupiter.

We continued studies with the 25 cultivars during the postrice season at different sites in the Philippines and additional plant characteristics will be observed. Knowing a cultivar's phenological and growth characteristics will improve our ability to predict its yield performance in a given environment.

Screening seed legumes for hypocotyl length

One major problem in growing grain legumes in a rice-based cropping system is getting good crop stands. The small farmer often simply plants by hand and covers the seed using simple implements or his foot. Thus, seeding depth varies and the

7. Hypocotyl length of selected soybean seedlings in 1981 tests at IRRI. The mean length of SJ4 was 191 mm. Wayne had a mean length of 147 mm and UPL-SY 2, 91 mm. Tests of the 3 types were started to see which would emerge best with farmers' planting method and seedbed conditions.

hypocotyl may have an effect on seedling emergence. We screened locally available cultivars and some advanced tropical lines of soybean, mungbean, and cowpea for hypocotyl length.

A total of 56 soybean, 45 mungbean, and 63 cowpea entries were germinated on paper towels in closed chambers. The range in hypocotyl lengths after 8 days was 83-191 mm for soybean, 78-125 mm for mungbean, and 96-128 for cowpea. Figure 7 shows short, intermediate, and long hypocotyl type for soybean.

Testing grain legume cultivars for rice-based cropping systems

Promising mungbean and peanut cultivars as dryland crops in cropping patterns were identified in 1981 tests.

Mungbean. Pagasa 1 (CES 1D-21) is an outstanding mungbean for planting before rainfed wetland rice. In 3 years of testing, it outyielded 9 other early promising entries at IRRI and at cropping systems research sites in Pangasinan, Iloilo, and Cagayan. Yields ranged from 0.61 to 1.50 t/ha and 75% of the dry pods were harvested during the first priming.

Pagasa 1 did not lodge even with heavy rainfall at flowering and harvesting, and was tolerant of Cercospora leaf spot, a major disease during the rainy season. Even after the last harvest, Pagasa 1 remained green for green manure or forage.

CES 1T-2 was identified as a promising variety when grown with zero tillage after wetland rice. Yields ranged from 0.76 to 1.88 t/ha. CES 1T-2 is tolerant of powdery mildew disease — a major problem when mungbean is grown after rice — is taller than Pagasa 1, and matures in 68 days.

Both varieties were developed by the Institute of Plant Breed-

ing, University of the Philippines at Los Baños.

Peanut. Tests of peanut cultivars after rainfed wetland rice with zero tillage were planted at IRRI and at Iguig, Cagayan, during the 1980 and 1981 dry seasons. The trials showed the possibility of establishing a good peanut crop without cultivation if sufficient soil moisture is available at least until flowering.

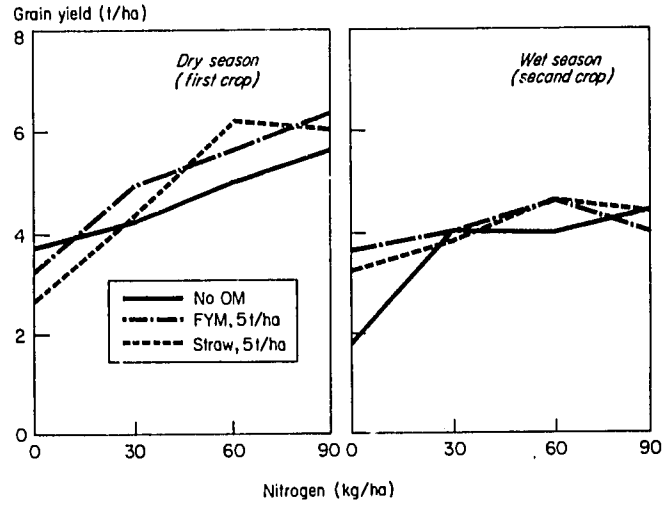
The two most outstanding varieties were CES 2-25 and Accession 12, which were developed by the Institute of Plant Breeding at Los Baños. CES 2-25 yields averaged 1.3 t/ha and was only moderately susceptible to Cercospora leaf spot. Accession 12 was resistant to Cercospora leaf spot and average yield was 1.3 t/ha.

AGRONOMIC MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

Organic and inorganic combinations of nitrogen and nitrogen uptake of IR36

To determine how much of the nitrogen requirements in a rice–rice cropping pattern may be met by incorporating organic materials before planting, we did field experiments at IRRI to study the effect of rate and time of nitrogen application in paddies treated with rice straw and farmyard manure.

Nitrogen application increased grain yield in the dry season but not in the wet season (Fig. 8). In the dry season, incorporation of the organic materials generally complemented the nitrogen fertilizer. The carryover effects or new additions of the organic materials, or both, increased second crop (wet season) yields appreciably only on the plots receiving no fertilizer nitrogen.



8. In trials with different nitrogen rates and organic manures on IR36 in IRRI paddies, the greatest effect of organic matter (OM) was at high levels of nitrogen in the dry season first crop and with no nitrogen in the wet season second crop. FYM = farmyard manure.

Table 5. Total dry matter, percent nitrogen, and nitrogen yield of mungbean green manure at various growth stages. IRRI, 1981 wet season.[a]

Green manure growth stage[b] (DE)	Total dry matter (t/ha)	Nitrogen (%)	Nitrogen yield (kg/ha)
20	0.33 a	3.96 a	13.2 a
30	1.63 b	3.05 b	49.7 b
40	3.45 c	2.32 c	80.0 c
Mean	1.85	3.11	47.6
CV (%)	5.7	6.5	11.3

[a]In a column, all treatment means are significantly different from each other at the 5% level. [b]DE = days after crop emergence.

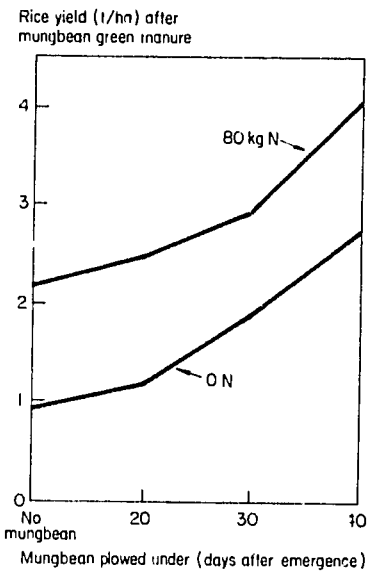
Response of transplanted rice to nitrogen and a mungbean green-manure crop

We continued to seek ways of reducing nitrogen fertilizer requirements without sacrificing grain yield.

Mungbean was seeded at 10-day intervals as the 1981 wet season started. IR36 rice was transplanted 40 days after emergence of the first mungbean planting. Two nitrogen treatments were used for the rice.

The total dry matter, nitrogen content, and nitrogen in the mungbean crops are shown in Table 5. Rice yields were increased by either adding nitrogen or growing a mungbean crop. The longer the growth of the preceding mungbean crop, the higher the yield of rice at each nitrogen level. Compared to rice yields with no nitrogen (no mungbean), yields with 80 kg N/ha doubled; growing mungbean for 40 days almost tripled yields; and the combination of 40-day mungbean and 80 kg N quadrupled yields (Fig. 9).

The small farmer may prefer growing mungbean as a food crop rather than as green-manure crop. Our data indicate, however, that where rainfall periods are too short for the food crop, a saving on nitrogen fertilizer costs can be realized by using the mungbean as green manure.

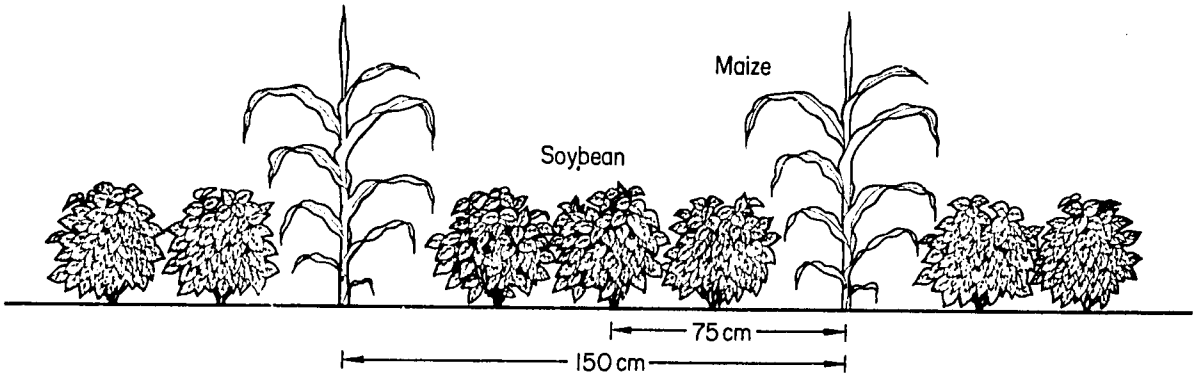


9. In trials of mungbean grown as a green-manure crop before rice, mungbean grown 40 days and plowed under at transplanting more than doubled rice yield. With added nitrogen fertilizer rice yields were more than tripled.

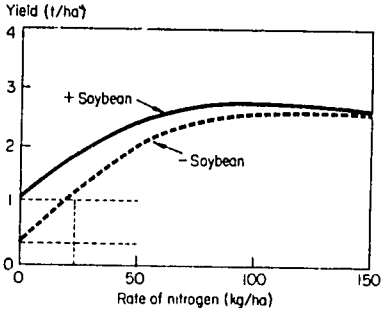
Green manure as a substitute for nitrogen fertilizer

In rainfed areas, where returns are uncertain, the small farmer may not meet the nitrogen requirement of his crops.

We tested the possibility of using fast-growing grain legumes (soybean) as a source of green-manure nitrogen when intercropped with maize. Three rows of soybean were spaced between 2 rows of maize 150 cm apart (Fig. 10). The 2 outside rows of soybean were cut and laid along the maize rows and covered with soil 45 days after planting. The center row of soybean was harvested for grain.



10. Soybean grown as green manure in this system produced an equivalent of 25 kg N/ha (see Fig. 11) when the rows next to the maize were cut, laid beside the maize rows, and covered with soil 45 days after emergence.



11. Effect of nitrogen with and without soybean green manure on yield of maize. See Figure 10.

The incorporation of soybean as green manure increased maize yield by 0.7 t/ha — equivalent to 25 kg N/ha in the control (Fig. 11). A residual effect on the following rice crop is expected.

Increasing efficiency of fertilizer nitrogen in maize

Increasing the efficiency of applied nitrogen in rice-based cropping systems remains a major challenge.

In 1981 trials we sought to increase the nitrogen fertilizer efficiency in maize by applying various rates at different times. The application of a small quantity of fertilizer at weekly intervals during the grand growth period (14 to 70 days after emergence) resulted in yield higher than for basal application at planting, or for 1/3 at planting, 1/3 at 30 days after planting, and 1/3 at tasseling stage.

Hilling of soil at the base of maize increased nitrogen use efficiency and gave a higher grain yield. Hilling is often practiced in areas with high rainfall and on poorly drained soil.

Establishment of mungbean after wetland rice

Mungbean is important as a protein source in the diet of many people in the tropics and is a desirable crop in rice-based cropping systems. The practices of puddling and flooding create soil conditions unfavorable for establishing a succeeding dryland crop, particularly a grain legume. Experiments at IRRI and at Iguig in the Philippines' Cagayan Valley tested establishment of mungbean after wetland rice.

At IRRI the mungbean CES 1D-21 was dibbled (zero tillage) with a pointed stick at 2 seeds/hole and spacing of 46 × 11.5 cm.

The effects of mulching and fertilizer placement on grain yield are seen in Table 6. Fertilizer was most effective when placed deep. Both mulching and fertilizer placement treatments significantly increased mungbean grain yield (Fig. 12). A rice straw

Table 6. Effect of mulch and fertilizer placement on mungbean yield.

Treatment		Grain yield[a] (t/ha)
T1	Check (no mulch and no fertilization)	0.9 e
T2	Rice straw mulch, 5 t/ha 4 days after planting	1.3 bc
T3	Shallow (2-3 cm) interrow cultivation, 8 days after planting	1.1 d
T4	T2 + fertilizer (30 N, 60 P_2O_5, 60 K_2O) surface placed beside row, 4 days after planting	1.3 b
T5	T3 + fertilizer surface placed beside row, 4 days after planting	1.1 cd
T6	T2 + fertilizer deep placed (10 cm) beside row, 4 days after planting	1.5 a
T7	T3 + fertilizer deep placed (10 cm) beside row, 4 days after planting	1.3 bc

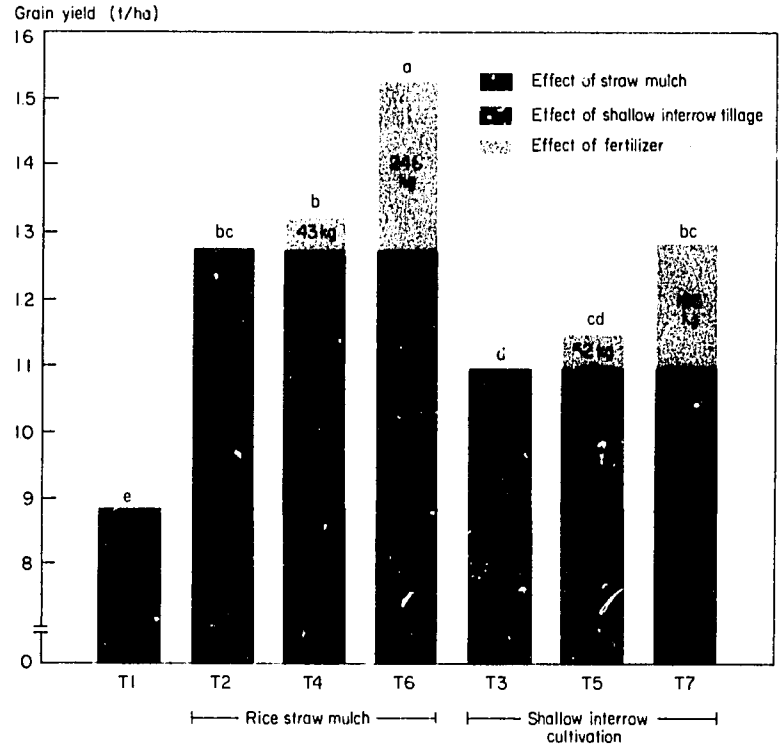
[a]Yield means followed by a common letter are not significantly different at the 5% level.

mulch gave yields superior to those with shallow interrow cultivation.

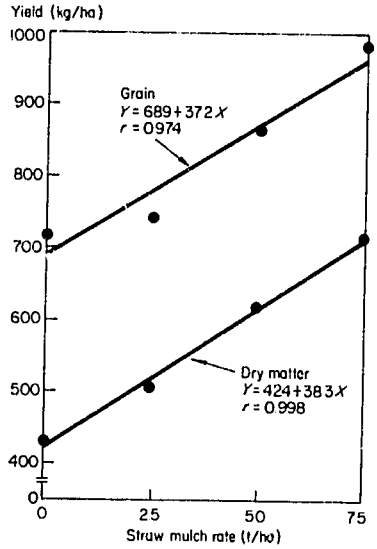
Weed dry weight was significantly higher for the check plots than for the other treatment plots. Rice straw mulch plots had slightly higher weed dry weight than shallow interrow cultivation plots. Fertilizer application, especially deep placement with rice straw mulch, increased weed dry weight.

At Iguig, the trial after dry season wetland rice tested the effectiveness of different amounts of rice straw. All mulch treatments also received chemical protectants.

Previous cropping systems trials had shown mulch to be more



12. Mungbean yield influenced by mulching method and fertilizer treatments. Bars with a common letter are not significantly different at the 5% level.



13. Rice straw mulch increased grain and dry matter yield of mungbean linearly at 55 days after planting at Iguig, Cagayan, Philippines, in 1981.

Rice straw mulch was applied at a rate of 5 t/ha in this mungbean plot at Iguig, Cagayan. Yield increase was more than 200 kg/ha over plots with no mulch.

effective in reducing soil water loss with zero tillage than with high tillage. At Iguig mungbean was dibbled by a pointed stick to make holes 8 cm apart in 40-cm rows immediately after rice harvest.

Soil moisture levels decreased rapidly after planting. The upper soil (0-20 cm) moisture levels were higher under mulch treatments but the lower depths (30-65 cm) were not affected. As the rice straw mulch rate increased, there was a linear increase in dry matter production at 55 days after planting and in grain yield (Fig. 13). All yields were generally low because only 38 mm of rain fell from planting to harvest.

The importance of insects and diseases was indicated by low (124 kg/ha) yields obtained when no chemical protectants were used. The use of rice straw as mulch and pest control appear to be beneficial production practices for mungbean after wetland rice.

Yield effect of skipping or opening up rice rows

Relay planting in dryland rice is sometimes done to get the second crop started and avoid drought damage to it. The relay crop may be established as early as 30 days before the rice harvest. Planting is accomplished by skipped row spacings, by pushing aside paired rows, or by cutting some rows as green feed for animals.

Table 7. In 1981 wet season tests of the effect of skipped rows and row removal at various times on the yield of IR36 and C171-136 as rainfed crops showed small effects of some row removal treatments to allow relay planting of other dryland crops.

Treatment[a]	Yield (t/ha)		
	IR36	C171-136	Mean[b]
Skip row every 1 m in flat bed plantings	2.4	2.1	2.3 ab
Skip row every 1 m in ridge and furrow planting system	2.4	2.2	2.2 bc
Remove row every 1 m at 50 DE (green feed)	2.5	2.2	2.3 ab
Remove row every 1 m at heading	2.2	1.6	1.9 cd
Remove row every 1 m at 10 DH	2.2	1.5	1.8 d
Remove row every 1 m at 20 DH	2.1	1.7	1.9 cd
Lodge or separate 2 rows every 1 m at 20 DH	2.3	2.4	2.6 a
No row removal	2.7	2.0	2.4 ab
Mean	2.4	1.9	

[a]DE = days after emergence, DH = days after heading. [b]Means with the same letters are not significantly different at the 5% level.

A trial in July-October 1981 at IRRI tested how late some rows could be removed without adversely affecting rice grain yields and compared such treatments to solid plantings or skip row plantings.

Paired rows of IR36 (early) and C171-36 (late) varieties were opened up or single rows were cut at ground level at 1-m intervals at predetermined periods. In two treatments, rows were left unplanted.

Grain yields were generally low because of prolonged drought during the maximum tillering stage and cloudy periods during ripening. C171-136 also lodged severely during a typhoon.

Leaving every fourth rice row unplanted, removing rows early (50 days after crop emergence) for green feed, or opening up rows 20 days after harvest resulted in rice yields almost equal to those from solid plantings (Table 7).

Potential for sorghum ratooning

Sorghum plant population did not significantly affect the grain yield of ratoon crops in two 1981 trials. This confirmed previous findings that sorghum will compensate for variations in plant density.

Harvesting or cutting height of the main sorghum crop had significant influence on the grain yield and other agronomic characters of the ratoon crop although maturity dates did not change. One variety tested had a grain yield of 2.54 t/ha when the main crop was cut to leave 3 nodes above ground level.

Evaluation of mungbean technology

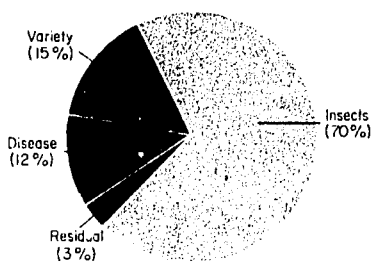
The Asian Cropping Systems Working Group requested increased emphasis on methodology development for preproduc-

In 1981 tests in dryland fields at IRRI sorghum yields remained good through a third ratoon crop.

tion testing of cropping systems.

Late in 1980, we tested a procedure in Pangasinan for monitoring and evaluating pilot production programs. The test was in a pilot program, code-named *Manbilayka,* which we conducted jointly with the Philippine Ministry of Agriculture. We focused on the mungbean component of the recommended rice – mungbean pattern for rainfed areas.

We found that recommended technology produced a mungbean yield of 0.8 t/ha, compared to 0.5 t/ha obtained by farmers in the *Manbilayka* program. When we superimposed trials in farmers' fields, we found that insect control was the major contributor to the yield gap (Fig. 14). Partial budget analysis revealed a benefit-cost ratio of 1.9 for using the recommended insect control.



14. Mungbean yields in 24 farmers' fields where recommended practices were followed were compared with farmers' yields in a pilot production area. Farmers got 0.3 t/ha less yield, caused mostly by failure to control insects.

We tried two types of farm survey. One required several visits to a small number of farmers, the other was a single interview on a large number of farms after harvest. The former required more manpower than most national programs could allocate, and the latter tended to give unreliable results because of dependency on the farmer's recall.

The survey component highlighted deficiencies in extension workers' knowledge of the recommended technology, particularly for chemical pest control.

PREPRODUCTION TESTING OF IMPROVED CROPPING SYSTEMS

Field trials with azolla

Applied research with azolla started in 1979 with 10 trials in 6 Philippine provinces. The trials examined the adaptability of

These South Cotabato, Philippines, farmers harvest azolla for use in composting.

On-farm tests of azolla in South Cotabato, Philippines, indicated that about 1 kg azolla/m² was an economical quantity.

azolla species to Philippine conditions and tested management procedures for use of azolla as an organic source of nitrogen for a rice crop.

Our initial work suggested that water is the most convenient transport for moving large quantities of azolla into a rice field. We introduced azolla into an irrigated rice area in South Cotabato, Mindanao, to determine the suitability of the system to grow and dispense azolla. Soil phosphate levels in this area are high and sufficient to ensure good azolla growth without addition of phosphate fertilizer.

We found that azolla grows well in farm ponds connected to an irrigation system and that azolla can be distributed satisfactorily in irrigation water. During 1981 about 5,000 ha of rice lands were inoculated with azolla. About 1,500 ha were covered with an economic quality of about 1 kg/m^2.

The South Cotabato farmers acknowledged the effectiveness of azolla as a source of nitrogen for their rice and also as a means of controlling weeds. But they also noted that dapog seedlings were killed by azolla.

Our data on rice yields are not complete, but 7 farmers in the project area had average yield increases of 1 t/ha in fields where only azolla was the source of nitrogen fertilizer (Table 8).

Table 8. Six of seven farmers interviewed reported rice yield increases after use of azolla. Magsaysay, Koronadal, South Cotabato, Philippines.

Farmer	Yield (t/ha)	
	Before azolla use	After azolla use
1	5.7	5.3
2	4.5	5.7
3	4.8	5.9
4	4.4	4.8
5	5.5	6.3
6	4.4	7.2
7	5.4	7.1
Av	5.0	6.0

ASIAN CROPPING SYSTEMS NETWORK

Cropping systems research in 1981 was active at 106 sites — a fivefold increase since 1979. Cropping patterns tested were for rainfed wetland, partially irrigated, irrigated, rainfed dryland, and deepwater rice areas (Table 9). China joined the network in 1981 and plans to have one research site in the north and another in the south. Vietnam also expressed interest in joining the network and sent 2 trainees to the 6-month cropping systems course.

Work at the Asian sites concentrated on design and testing of cropping patterns. The main focus at each site is to increase cropping intensity to 2 crops/year where one crop is now grown and 3 or more crops/year where 2 are now grown. Where cropping intensity is already high, research teams concentrated on increasing production by using better varieties and management.

Monitoring of cropping pattern performance

Collaborative research continues to be an important activity in the network. We monitored cropping pattern performance and environments at 30 Asian sites.

Table 9. Cropping systems research sites in national programs in Asia have increased fivefold in 2 years. Some country sites include more than one kind of crop culture.

Country	Total sites	Sites (no.) devoted to different cultures				
		Rainfed wetland	Partially irrigated	Irrigated	Rainfed dryland	Deep water
Philippines	19	18	1	—	5	—
Burma	7	2	4	2	2	—
Indonesia	21	6	—	—	16	1
Korea	9	—	—	9	—	—
Nepal	6	5	5	6	—	—
India	1	1	—	—	1	—
Bangladesh	28	11	4	10	3	4
Sri Lanka	7	4	2	1	—	—
Thailand	8	7	—	1	—	—
Total	106	54	17	29	27	5

Analysis of data from the sites revealed that the total calorie, edible food and digestible carbohydrate production, and protein yields per hectare were much higher at irrigated sites than at rainfed sites. When data on the existing dominant cropping pattern and promising cropping patterns at different sites were combined, the total calorie production per pattern per hectare ranged from 688 to 28,552 in the rainfed areas and from 7,102 to 29,824 in the irrigated areas. The yield of total digestible protein per hectare ranged from 131 to 780 kg at rainfed sites and from 135 to 1,399 kg at irrigated sites.

Investment in terms of variable production costs, and net returns per hectare were much higher at the irrigated sites than at the rainfed sites. However, the ranges of benefit-cost ratios were almost similar, indicating a higher efficiency in use of limited resources by farmers in the rainfed areas.

Varietal testing of dryland crops continued in collaborating countries. The Philippines, Indonesia, Bangladesh, and Thailand started experiments to determine yield loss due to insect damage in dryland crops grown after wetland rice.

Network highlights

During 4 years of cropping systems work, researchers at the tank-based village of Walagambahuwa in Sri Lanka's North Central Province developed a system for establishing a rainfed dry-seeded first rice crop. Depending on the water level in the tank, the dry-seeded crop could be followed by another rice crop or a dryland crop, or both.

From the pilot multisite testing phase in 1979-80 in 10 tank-based villages, the system, which is known as the Walagambahuwa Concept, had covered more than 400 tank villages by the 1981-82 crop year. The concept is the basis of a major production program applicable in more than 10,000 tank-based villages.

Double rice crop system gains in Indonesia

One of the first cropping systems research sites in Indonesia was at Nambhadadi village, Bandarjaya, Lampung Province in South Sumatra. At the site there was spontaneous farmer adoption of the two-rice-crop system developed by researchers to replace the traditional single-rice-crop system.

In Nambhadadi the new system was used in more than 500 ha during 1981, and substantial adoption has occurred in adjoining villages. Similar success with the two-rice-crop system was reported from South Sulawesi.

MACHINERY DEVELOPMENT AND TESTING

Farmers' fertilizer costs continue to increase. As a result farmers need more efficient use of fertilizers by their rice crop. Our agronomy research has shown that placement of fertilizer 10 cm deep will give the needed efficiency. The development of fertilizer placement machines had high priority in 1981.

Rice production increases must come from increasing yields and from increasing cropping intensity. The two can go together when farmers adopt higher-yielding, shorter-growth-duration modern rices. But with those rices comes a demand for reducing time between crops — turnaround time — if the best possible intensity is to be realized.

A labor shortage at harvest time remains a problem for some rice farmers. To alleviate it our engineers cooperated with engineers from the Chinese Academy of Agricultural Mechanization Sciences to develop two reapers adapted to IRRI-designed power tillers. The designs were tested in 1981 and were ready for introduction to manufacturers at the end of the year.

These two machines for deep placement of fertilizer were developed and tested at IRRI in 1981. The spring-auger machine (left) is pulled by the operator to put a band of prilled urea at a 10-cm depth in the paddy soil. The plunger device (right) pushes a urea supergranule 10 cm into the soil each time the operator pulls a trigger on the gun handle.

Applicators for deep placement of fertilizer

Even though modern rice varieties respond well to nitrogen fertilization, plant utilization of applied nitrogen is often low — as low as 25% for prilled urea.

We know that placement of fertilizer at 10-cm soil depth can significantly increase the efficiency of fertilizer use by a rice crop. Prototypes of fertilizer applicators were developed and tested for performance efficiency, durability, and ease of operation. A spring-auger implement applies prilled urea in a band 10 cm below the soil surface. The major components consist of a coiled spring wire inserted into a rigid tube, hoppers with mechanical agitators, and drive wheels. The coiled spring wire moves the fertilizer from the hopper into the soil.

Implements developed for applying urea supergranules include the bamboo and injector-gun applicators. The bamboo applicator consists of a hopper, feed tube, plunger, ejector, drop tube, and furrow covering device. All are made from bamboo materials normally available to the farmers.

The plunger-type applicator consists of a hopper with mechanical agitation to prevent bridging, a feed tube, a plunger-granule ejector, and a skid with a furrow opener and covering device. The granule is ejected by the plunger into a furrow and covered by the skid.

We also adapted a peristaltic pump-liquid applicator that attaches to the IRRI mechanical transplanter.

The IRRI-Chinese reapers

In a collaborative work with the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) a reaper was adapted to the IRRI power tiller in 1980. During 1981 our engineers tested

The 1.6-m model of the CAAMS-IRRI reaper (right) was tested in farmers' fields in 6 countries in 1981. The reaper unit mounts on the IRRI 6-hp tiller and will cut 0.5 ha/hour at ground speed of 3 km/hour. The smaller version of the reaper (above) cuts rice with a 1-m head. The reaper mounts on the new 3-hp IRRI-designed tiller and can be carried to inaccessible fields by 2 men.

The rolling injection planter (right) is used to plant through a mulch into non-plowed dryland soil. The closeup above shows bean plants growing through a mulch after planting with the injection planter.

two reaper models with designs that could be manufactured and serviced in local small and medium-scale machine shops. The designs will be available to manufacturers in early 1982.

The 1.6-m reaper has a capacity of up to 3 ha/day, depending upon field and crop condition. The reaper was tested in the Philippines, Pakistan, Thailand, Egypt, Burma, and Indonesia.

The 1.0-m reaper attaches to the small IRRI 3-hp tiller. The gathering header and cutter bar assemblies used in the 1.6-m reaper were used for the 1.0-m reaper design, which gave standardization and interchangeability of parts. Both the tiller and the easily detached reaper can be carried by two men. This is a valuable feature for harvesting of the small inaccessible rice plots frequently encountered in Asia. The small reaper can harvest 2 ha/day.

Rolling injection planter

Reduced or conservation tillage requires two important inputs — first, an appropriate herbicide or mulch of plant residues that inhibit weed growth, and second, specially adapted seed drills to penetrate plant residues and the soil surface.

We tested a rolling injection planter developed at the International Institute of Tropical Agriculture for no-till planting of dryland crops in our rice-based cropping systems. Instead of cutting a continuous slit in the soil into which the seed is dibbled, the tool opens a slot and inserts a seed.

Its rolling movement and the shape of the hole opener of the

This newly designed 3-hp tiller is aimed at putting tillage power within the financial reach of most small farmers. Seen here plowing a wetland field, the tiller can also be used with a reaper attachment and with front-mounted implements for interrow weeding of dryland crops.

planter make it suitable for no-till and conventional planting. Results from tests of the model with 25-cm-in-row spacing for planting of soybean, mungbean, and maize were promising. For rice the model with a hill-to-hill distance of 15 cm gave better results in terms of weed control.

The major advantage of the whole system lies in reducing the time and energy required on a small farm to establish a dryland crop after rice, and in conserving soil water.

Low-cost 3-hp tiller

Costs of the currently available tillage machines are rapidly rising beyond the reach of small farmers. In many instances the initial cost precludes ownership by all but those with large landholdings.

To help make power farming available to small farmers we developed and tested a 3-hp tiller. The simple design gives a low-cost, lightweight tiller suitable for wetland tillage. It is easy to operate and has excellent maneuverability and mobility even on deep paddies. Two men can carry the tiller to fields not easily accessible.

Although the new tiller is intended primarily for preparation of wetland fields, it can also be used for intercrop cultivation and weeding of dryland crops Tests on irrigated fields indicated that it can perform as much tillage work as larger units but with less fuel consumption.

An important feature of the new design is that the engine is easily transferred from front to rear, which permits attachment of a reaper, grass cutter, and other front-mounted implements without adversely affecting machine balance. An extendible handle can be pivoted to its mounting bracket to adjust the height to suit the operator.

Machinery extension

In 1981 an IRRI engineer started work with the Division of Agricultural Engineering, Bureau of Plant Industry in the Philippines to help develop an Industrial Extension unit. There are now six countries in our Industrial Extension Network — Philippines, Indonesia, Thailand, Pakistan, Burma, and Egypt.

The Industrial Extension engineers assist small manufacturers in the fabrication of IRRI-designed machinery. Blueprints are provided free to manufacturers.

TRAINING AT IRRI

The strong national rice improvement programs that are emerging in Asia have somewhere within them almost 5,000 people that trained at IRRI sometime during the past decade. Our resident training program gives participants — scientists and extension workers — both academic and practical experience in rice culture and rice-based cropping systems.

Abdul Mazid, an IRRI research fellow from Bangladesh, does field work on fertilizer application methods as a part of his research in the IRRI Agronomy Department.

Table 1. Participation in IRRI's training programs, 1962-81. Number of participants for 1967 and for 1970-81 include technicians trained in 2-week rice production courses. The 1973 training included 604 Filipino technicians trained for the Philippine Government's rice extension program.

Year	Countries participating	Participants
1962	3	29
1963	8	58
1964	15	101
1965	14	85
1966	19	107
1967	19	329
1968	19	126
1969	25	133
1970	24	239
1971	29	241
1972	26	240
1973	24	801
1974	24	230
1975	28	271
1976	27	358
1977	29	330
1978	29	460
1979	33	497
1980	32	470
1981	34	546

The training program maintained its pace in 1981 with more than 500 participants in various training activities. The number of trainees has doubled since 1971 (Table 1). More than 36 countries are served by IRRI training.

Scholars at IRRI in 1981 included 38 postdoctoral fellows, 50 Ph D candidates, and 105 master's degree candidates. During the year, 16 Ph D, 27 MS, and 24 nondegree scholars completed their training.

Most of the degree students did course work at the University of the Philippines at Los Baños and their thesis research at IRRI. For that research they were assigned to departments where they worked closely with IRRI researchers. Nondegree scholars — also working with IRRI researchers — do practical training for periods ranging from 3 to 12 months.

An Integrated Pest Management course was offered for the first time. It prepares pest management technicians to implement integrated pest management projects on farms.

The popular 2-week rice production course was offered 4 times in 1981. Special courses in farm management and agricultural economics research methodology were also offered. A special course on scientific writing was offered twice in 1981 to IRRI fellows, scholars, and junior researchers. The course aimed to help fellows and scholars who use English as a second or third language to prepare better technical reports.

A trainee at IRRI uses an audiovisual teaching module. All rice production and cropping systems trainees have free access to the audiovisual room and library.

An audiovisual teaching module has 60-80 slides, a tape recording of the script, a booklet with photos and script, and a study guide. In 1981 more than 900 modules were ordered for use in national training programs. Translation into local languages has been done in some national programs.

Audiovisual teaching modules

Work on a series of audiovisual teaching units started in 1976. Of the projected 61 modules, 52 had been completed by the end of 1981. A module consists of a set of slides, a cassette tape recording, an illustrated script, and a study guide. The slide-tape units are used in our formal training courses and are also useful in national training programs.

Participants in the 1980-81 Cropping Systems Training Program and the 1981 6-month Rice Production Training Program used and evaluated the modules. The evaluators indicated that the units:

- serve as a good source of information for a lecture or field activity;
- present subject matter clearly and systematically;
- serve as an aid in reviewing and facilitate the retention of facts;
- enable trainees to control pace of studying; and
- help improve English proficiency.

INTERNATIONAL ACTIVITIES

We continued to emphasize collaborative work with rice-growing countries. In 1981 IRRI scientists and administrators discussed, and jointly prepared, collaborative work plans with their counterparts from Indonesia, China, Sri Lanka, Korea, Japan, India, Cuba, and Vietnam.

Cooperative country projects continued in Bangladesh, Burma, Indonesia, Pakistan, Philippines, and Egypt. International rice research networks coordinated by IRRI scientists were:

- the International Rice Testing Program,
- the Asian Cropping Systems Network,
- the Agricultural Machinery Network,
- the Agroeconomic Research Network on Yield Constraints in Farmers' Fields, and
- the International Network on Soil Fertility and Fertilizer Evaluation for Rice.

In addition, liaison scientists were posted to Indonesia and Malaysia, Africa, Latin America, India, and Thailand.

The IRRI-designed manual rice transplanter was introduced in Burma during 1980. By early 1981 more than 300 transplanters had been built by Burmese manufacturers and 160 people trained in transplanter operation.

FINANCES

The Institute received $20,634,733.83 during 1981.

The United States Agency for International Development (USAID) gave $6,541,730.75 — $4,275,000 for core operations, $49,141.23 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; and $265,455.98 for industrial extension of small-scale agricultural equipment developed at IRRI.

USAID also released $1,952,133.54 for continuing contracts:

- $753,977.80 for a contract between IRRI and the Government of Sri Lanka for assistance in implementing rice and cropping systems research projects with funds provided by a USAID loan.
- $200,575.68 for a contract between the Arab Republic of Egypt and the Regents of the University of California and IRRI for a technical assistance relationship to aid in increasing production and improving the quality of rice in Egypt through the development and adoption of improved agricultural practices and rice varieties.
- $488,203.31 for supporting a 3.5-year project for accelerated development and use of improved rice technology in Indonesia.
- $116,788.09 for collaborative rice research in Pakistan.
- $230,733.66 for a project on the consequences of mechanization on small farms.
- $70,805 for applied research and training in water management.
- $91,050 to support setting up of a Nutritional Evaluation Laboratory as a regional center for research on the nutritional value of high-protein cereals and legumes and weaning foods for children.

The Japanese Government gave $3,150,000 for purchase of research and training equipment, for partial support of cropping systems research, for expenses of the Plant Physiology and Soil Microbiology Departments, and for partial support of the GEU program.

The Ministry of Overseas Development, United Kingdom, gave $1,251,500 for the core program.

The Canadian International Development Agency gave

$1,181,040 for core operations; $207,900 for cooperation between the Bangladesh Rice Research Institute and IRRI; and $310,842.67 for cooperative research on rice, rice-based cropping systems, and development of machines for small-scale farming by the Government of Burma and IRRI.

The International Development Research Centre (IDRC), Canada, gave $398,195.50. Of that $314,403 was part of a 3-year grant for cropping systems outreach in South and Southeast Asia and $83,792.50 was part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute.

The European Economic Community gave $651,598 for water management, scholarships for candidates from developing countries, and partial support of the GEU program.

The Australian Government gave $864,885.21 of which $637,759 was for core operations, including travel of Australian scientists, and $227,126.21 was for expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute.

The Federal Republic of Germany gave $584,090 for core operations and $3,883.77 for support of a visiting scientist in soil microbiology.

The International Development Association gave $480,000 for core operations and capital expenditures.

The United Nations Development Programme released $1,088,757.00, of which $1,053,375 was for international rice testing and improvement and $35,382 toward a meeting of the Nitrogen Fixation Advisory Committee and a seminar on rice policy.

The International Fund for Agricultural Development gave $1,700,000 for research on rice-based cropping systems.

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

The Government of Indonesia, using a World Bank loan, released $201,068 to IRRI 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 Government of Denmark gave $144,115.89 for the core program.

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

The Government of Sweden gave $215,897.94 for the core program.

The Swiss Federal Council, represented by the Swiss Development Corporation, gave $30,000 for an exploratory workshop on the role of anthropologists and other social scientists in interdisciplinary teams for food production research; and $9,000 to support a rural migration team.

The Ford Foundation gave $477,960 — $200,000 for core operations and capital expenditures, and $277,960 in support of rice research and development in Thailand ($18,960), Bangladesh ($100,000), India ($134,000), and the Philippines ($25,000).

The Rockefeller Foundation gave $175,000, which included $150,000 for core operations and capital needs, and $25,000 for a workshop on the role of anthropologists and other social scientists in interdisciplinary teams for food production research.

The Government of Mexico gave $100,000 for core operations.

The Government of New Zealand gave $21,400 for the core program.

The Government of Belgium gave $31,010.15 for a joint project of IRRI and the Rijksuniversiteit Gent to conduct collaborative research on the control of bacterial blight on rice in developing countries by use of low-cost bactericidal or bacteriostatic compounds.

Since July 1976, a contract between IRRI and the International Centre of Insect Physiology and Ecology has supported a joint program for ecological research on rice planthoppers using funds from the Australian Government. In 1981, $40,272.89 was released for use.

Since February 1978, a contract between IRRI and the International Fertilizer Development Center (IFDC) has supported a joint project on the fate and efficiency of nitrogen fertilizers in wetland rice. IFDC reimbursed IRRI $42,122.24.

Other donors were:

- Philippine Council for Agriculture and Resources Research, cooperative applied research on rainfed rice $45,728.63
- National Food and Agriculture Council, training government extension technicians 38,467.75
- International Board for Plant Genetic Resources:
  - Field collection of indigenous rice germplasm in South and Southeast Asia 37,442.94
  - Third meeting of the IBPGR/IRRI Rice Advisory Committee in India 18,000.00
- Imperial Chemical Industries, research grant 5,000.00
- Stauffer Chemical Company, weed

control	3,000.00
• Ciba-Geigy, agrochemical research	3,000.00
• Monsanto, herbicide research	2,500.00
• American Cyanamid Overseas Corporation, weed control and insect control	5,000.00
• UN University, research on protein requirements of young Filipino adults	12,764.50
• Office of Rural Development, Korea, seed multiplication program and cooperative research program	87,410.00
• Hoechst, AG, research work at IRRI	5,750.00
• Minister for Development Cooperation, The Hague, project on reclamation of acid sulfate soils	16,400.00
• SKW Trostberg Aktiengesellschaft, soil fertility research	2,000.00

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*Left during the year
**On study leave
***Joined and left during the year
+Part time
++Acting as of 1 June 1981