The International Rice Research Institute Annual Report for 1973

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The International Rice Research Institute, Los Baños, Laguna, Philippines, 1974

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*Left during year

About this report

This is the 12th annual report of the International Rice Research Institute since it was founded in 1960. The major financial supporters of IRRI are the Ford Foundation, The Rockefeller Foundation, U.S. Agency for International Development, The Overseas Development Administration (U.K.), the International Development Research Centre (Canada), and the Japanese government. This report covers work done during the 1973 calendar year.

Data in the report are given in metric units, e.g. "t/ha" means metric tons per hectare. Unless otherwise stated, "control" means untreated control, grain yield is calculated as rough rice at 14 percent moisture, and protein content is calculated as a percentage of brown rice at 14 percent moisture. A single asterisk (*) means significant at the 5-percent level, a double asterisk (**) means significant at the 1% level, *but* if value for a control is given, a single asterisk means significantly different from the control at the 5% level and a double asterisk means significantly different from the control at the 1% level.

Because of the increasing complexity of the breeding program, the system for indicating pedigrees has been changed. Instead of the multiplication sign (×) a slant bar (/) is used. For example IR22 × IR24 is now written IR22/IR24. The sequence of crosses is indicated by the number of slant bars: (IR22 × IR24) × CR94-13 is now written IR22/IR24//CR94-13. The fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are indicated by a superscript numeral.

The report frequently mentions three fundamental types of rice culture. Upland culture means rice grown without irrigation in fields without bunds. Rainfed paddy culture means rice grown without irrigation but in fields that are bunded to impound rainfall. Irrigated or flooded culture means rice grown with irrigation in bunded fields.

The thumb index on the back cover provides quick access to any research section. To use it, bend the book in half and follow the margin index to the page with the black edge marker.

Research highlights

PRELUDE

The world food situation remains serious. Bad weather cut rice and wheat production by 10 percent in some countries in 1972. Most of the poor and over-populated countries, where two-thirds of mankind lives, were already importing food. A world-wide food shortage prompted spiralling prices; the poorest of the poor suffered the most.

The weather was generally favorable and the crops were good in 1973, relieving somewhat the food crisis. Still, food prices remain high and some Asian cities have been torn by food riots. Even more shocking, prolonged drought has scorched the earth and brought famine to sub-Sahara Africa.

The 1973 energy shortage sharply reduced the supply of chemical inputs—the fertilizers and pesticides that farmers need for high yields. Input costs are sharply rising, particularly for vital nitrogen fertilizer. The hungry nations are being hit hardest of all because they don't have the capital to compete with the more developed nations for the limited chemical inputs.

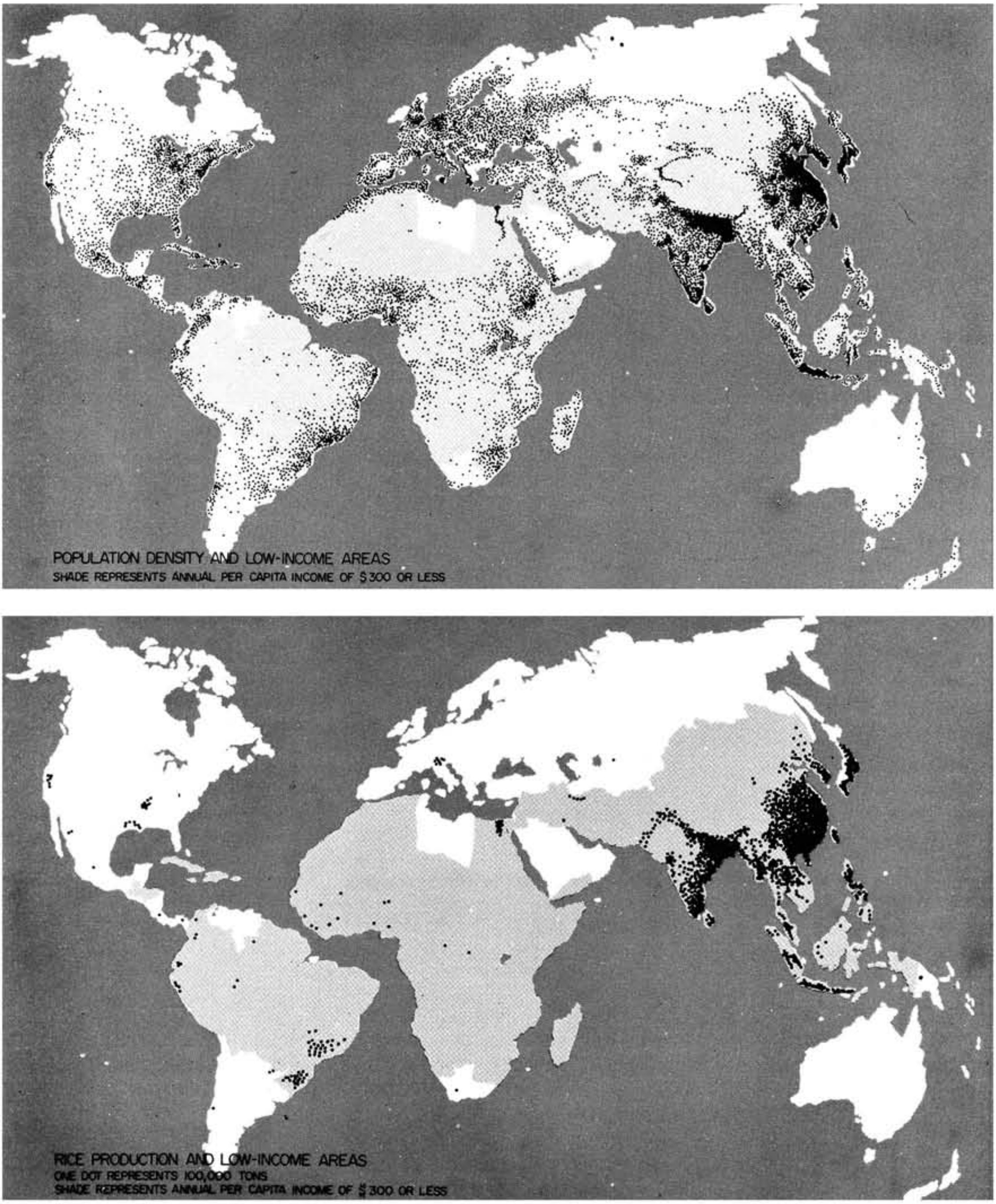
Population pressures continue to mount in these poor nations. The earth's population today is 3.8 billion, and is increasing at 2 percent per year. It will double by the year 2000. In the poor nations, population is increasing at a rate of 2.5 percent per year, and will double in about 25 years.

In the past, the developed nations had large buffer grain reserves to help feed the growing numbers in the less fortunate countries if crops failed. No such grain reserves exist today.

Some think that the grave predictions of 18th century economist Thomas Malthus are inevitable—that man's numbers will outdistance his capacity to produce food, and the world will slide into a nightmare of famine, pestilence, social decay, and wars for limited land.

We at the International Rice Research Institute are more optimistic. We are applying science to agriculture, to help raise food production in the hungry nations enough to avert famine and even to curtail widespread hunger until man learns to control his numbers. The low-income farmer who lacks the skills and resources to use modern chemical inputs will be helped by IRRI's new rices which are resistant to major insects and diseases. Fertilizer practices and pest control methods have been specially tailored for the small farmer. Techniques of packaging practices for country-wide rice production programs have been tested. Innovative multiple cropping systems to induce more food production from the limited land are being evaluated and improved. The potential for increasing production has never been greater.

If resources are available to capitalize on past successes, IRRI scientists can continue to chart the way to higher yields and more dependable food production. These achievements are essential if man is to feed himself while the earth's population growth is being brought under control.



1. Rice is the primary or secondary staple food of nine-tenths of the low-income people in the most densely populated regions of the world. (a) Population density and low-income areas. (b) Rice production and low-income areas.

RICE—FOOD OF THE LOW-INCOME MASSES

Rice truly means life itself to the world's poorest and most densely populated regions. A third of mankind—1.3 billion people—depends on rice for more than half of its food. For another 400 million people, rice is a major secondary staple, providing from 25 to 50 percent of their total food. In some countries, rice supplies more than half of the total protein consumed.

Rice is the primary or secondary staple food of nine-tenths of the low-income people of the most densely populated regions of the world (fig. 1). The average annual income of those who depend primarily on rice is only $80.

Population increases in most rice-consuming countries are among the highest in the world. Consequently, demands for rice are expected to increase by 30 percent in the next 10 years. Some countries which have traditionally exported rice are now having difficulty producing food for their own populations.

The precarious balance between supply and demand for rice is illustrated by the effect of adverse weather conditions in 1972 on the adequacy of the supply of rice and, especially, on its price (fig. 2). When rice became limited, prices doubled and even tripled within a few months in some countries. Such instability most severely affected those least able to pay the soaring prices. For example, in the Philippines, the poorest people, who were already spending 37 percent of their meager incomes on rice before the price increase, would have to spend 74 percent after the price increase if they continued to purchase the same amount of rice. Thus, abundant rice production is critical not only to the hundreds of millions of rice farmers struggling to make a living on their 1- to 2-hectare farms, but also to the landless laborers and to the low-income workers in villages and cities. Anyone seriously concerned with the welfare of the poor and the hungry must be concerned with rice.

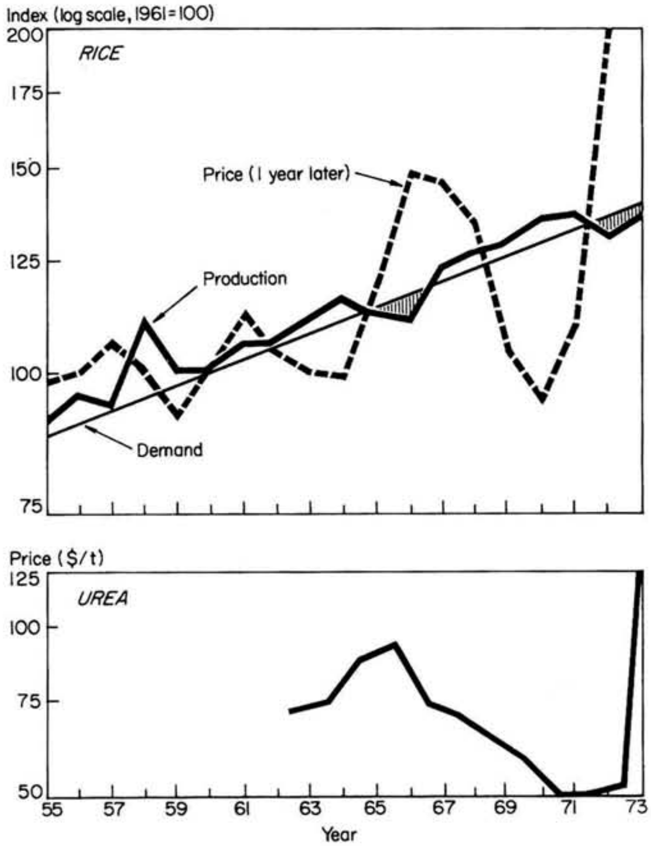
Improved weather conditions have brought relief to rice farmers and consumers alike. Abundant yields in 1973 appear to have averted widespread hunger. But the demand for rice is still high; so is its price. National storage stocks have not been built up to the 1971 levels.

The scarcity and high price of fertilizers and other agricultural chemicals add to the mounting problems of all farmers, particularly those with low incomes. With credit uncertain and costly, the small farmer can not compete for the scarce supplies of chemicals and other inputs needed to capitalize on the productive potential of new rice varieties.

In spite of the impressive technological advances of the past decade, national production figures show increases barely high enough to meet population growth. The experiences of the past few years remind us that the production revolution needed to feed rice consumers has only begun. Accomplishments such as those summarized in this report give us a glimpse of what science can do to help accelerate this revolution. They also show how IRRI's research and training programs are already helping many low-income farmers and their city or village counterparts, and how expansion of these programs can be relied on to reach many more.

Progress has been made. The problems of the small rice farmer continue to receive primary attention of IRRI scientists. Following up on the successes of IR8, IR5, IR20, and other high-tillering, fertilizer-responsive, semidwarf varieties, we have broadened our focus in recent years to include other improvements of the rice plant. These improvements will help farmers control disease and insect pests, obtain reasonable yields in spite of droughts or floods, and grow rice on poor soils.

IRRI's first rice variety, IR8, demonstrated that the productive potential of rice can be substantially raised by selective breeding. Scientists screened, crossed, and



2. World demand, production, and lagged price of rice (upper), and price of urea (lower), 1953–73.

selected until they developed a rice which had the characteristics they sought: a semidwarf plant type with a stiff straw. When fertilized, the strong stem holds the plant upright, not allowing it to topple. Extra plant nutrients, added as fertilizer, are converted to more grain.

Most modern rices which followed IR8 were of the semidwarf plant type. By 1972, semidwarf rices were grown on 16 million hectares in South and Southeast Asia, about 20 percent of the area's rice land. Of Latin America's $6\frac{1}{2}$ million hectares of rice land, about 0.6 million are now planted to stiff-strawed varieties developed to a considerable extent from IRRI genetic material. About 90 percent of the irrigated rice areas in some Latin American countries are planted to these high-yielding varieties.

Average farm yields are steadily increasing in nations where the new rices have been adopted. Still, actual rice production in the poor nations is far less than potential production. We are now identifying the major constraints to higher rice yields, and are organizing to systematically develop improved varieties and technologies that will overcome these production constraints.

IR26 and tomorrow's companions. Great strides were made during 1973 in IRRI's genetic improvement program. A new variety, IR26, was released. It has good grain

Variety	Lodging	Diseases					Insects			Soil problems			
		Blast	Bacterial blight	Bacterial leaf streak	Grassy stunt	Tungro	Green leaf-hopper	Brown plant-hopper	Stem borer	Alkali injury	Salt injury	Iron toxicity	Reduc-tion products
IR8	R	MR	S	S	S	S	R	S	MS	S	MR	S	MR
IR5	MR	S	S	MS	S	S	R	S	S	S	MR	S	MS
IR20	MR	MR	R	MR	S	R	R	S	MR	S	MR	R	MR
IR22	R	S	R	MS	S	S	S	S	S	S	S	MR	MR
IR24	R	S	S	MR	S	MR	R	S	S	MR	MR	MR	MS
IR26	MR	MR	R	MR	MR	R	R	R	MR	MR	MR	R	MR

3. Resistance ratings of IRRI varieties. R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

quality and yielding ability. But more important, it has moderate to high levels of resistance to seven major insect pests and diseases (fig. 3), including the brown planthopper which has become a major threat in the Philippines, South Vietnam, Sri Lanka, and parts of India. This variety is expected to spread rapidly into these hopper-infested areas as well as into regions where tungro virus, green leafhoppers, and blast have been problems in the past.

The development of IR26 continues the trend set by IR20, emphasizing insect and disease resistance. In IRRI's breeding pipeline are other potential varieties with welcome resistance to major insects and diseases. Two more breeding lines in advanced testing have resistance or moderate resistance to seven of the most serious disease and insect pests; six other lines have the same degree of resistance to six such pests; and four more lines have resistance to five.

Remarkable progress is being made in introducing resistance to insects and diseases. In 1973, 70 percent of the 185 entries in the annual replicated yield trials at IRRI had multiple resistance to at least five important disease and insect pests. The comparable figure in 1972 was only 5 percent. IRRI's scientists are making headway in blending insect and disease resistance into lines already known to have good grain quality and yielding ability.

Another measure of the progress at IRRI in the genetic improvement of the rice plant is the number of crosses being made. More than 2,000 such crosses were made in 1973, double that accomplished in 1972 and five times the number crossed in 1971. We consider such high-volume crossing essential because desirable genetic characters are often associated with bad ones. We must make a large number of crosses to incorporate combinations of favorable plant characters into high-yielding lines.

We expedited our hybridization (crossing) effort by constructing a simple "vacuum emasculator" to speed up the removal of unwanted anthers from the florets. This replaces the time-consuming conventional method of using forceps to manually remove the anthers. By the new suction technique, an operator can emasculate 425 florets per hour, compared with 250 using the conventional method. We are releasing the design of this inexpensive machine on request to other plant breeding teams.

Adaptation of varieties. Modern varieties developed by IRRI scientists and their cooperators are being widely grown by farmers in rainfed areas as well as those in irrigated regions. The characteristics of the new stiff-strawed semidwarfs appear to make them as adaptable to rainfed as to irrigated conditions. This illustrates the wide adaptability of our breeding materials.

Cooperation with national programs. We continued our efforts to help cooperating country programs develop and improve rice varieties suitable for their local conditions. In 1973, we sent 7,618 seed packages of breeding lines to research workers in 45 countries. Some of these lines are being used as parents in the national breeding programs. Others are being tested directly for their adaptability to local conditions. A total of 25 IRRI breeding lines so tested have been released as commercial varieties by other countries, six of them this year.

Examples of the adaptability of these lines are: "Parwanipur 1" (IR400-29-9)—an early maturing line adapted to the foothills of the Terai region in Nepal; varieties "R" (IR1052) and "S" (IR1055)—two long-grained selections, named in Guyana, with quality characteristics especially suited to that area of the world; "Thon Nong 73-1" (IR1529-680-3)—a high-yielding selection named in Vietnam with sturdy stems and excellent grain quality, and resistant to blast, bacterial blight, and green leafhoppers.

GENETIC EVALUATION AND UTILIZATION (GEU)

We further systematized IRRI's coordinated rice improvement program in 1973 by formalizing an institute-wide Genetic Evaluation and Utilization (GEU) program. Interdisciplinary and problem-oriented rice breeding is the backbone of GEU. Plant breeders are teamed up with "problem area" scientists, such as plant pathologists, entomologists, and cereal chemists. Each team member contributes his specialized knowledge to the joint effort to identify, screen, and cross diverse rices. By so doing, the best characteristics can be incorporated into nutritious rice varieties which resist or tolerate the environmental and pest enemies of the rice plant (fig. 4). Major GEU problem areas include:

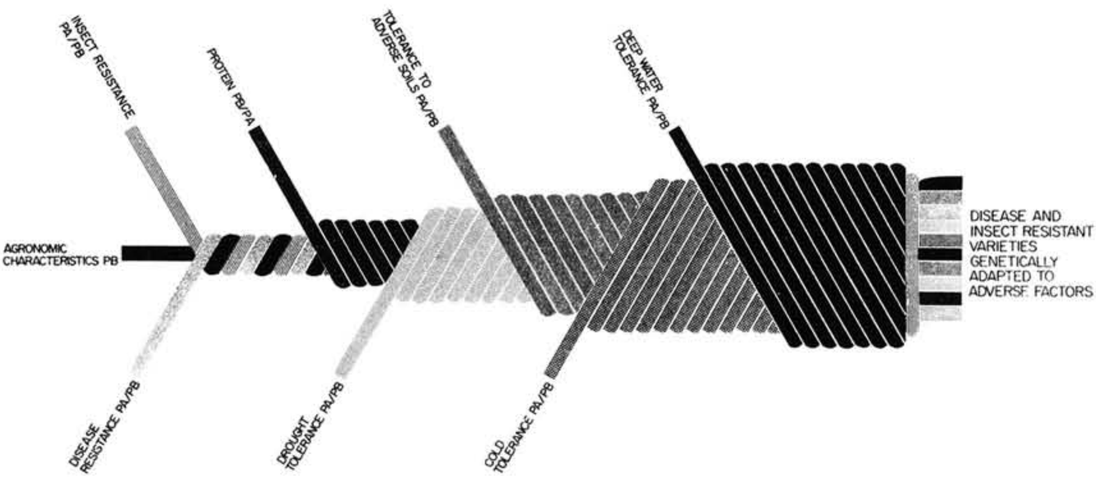
- resistance to diseases
- resistance to insects
- high protein levels
- tolerance to drought
- tolerance to toxic soils
- tolerance to deep water
- tolerance to cold

Figure 5 shows the flow of rice germ plasm or genetic material through the GEU. The 30,000-sample germ plasm bank is the primary source of genetic materials. From this bank, promising varieties from all over the world are screened to determine which have desired characteristics to use in crossing, or hybridization, programs.

Hybridization and screening of the progeny provide lines which can be tested at IRRI and shared with cooperating country programs throughout the world. The ultimate objective of GEU is to help these country programs develop and place in the hands of farmers new varieties with characteristics suited to local conditions.

The nature of the GEU screening and field evaluation demands close interdisciplinary cooperation, which has always been a strong feature of IRRI's rice improvement program. Such cooperation is responsible for the results described in the following sections.

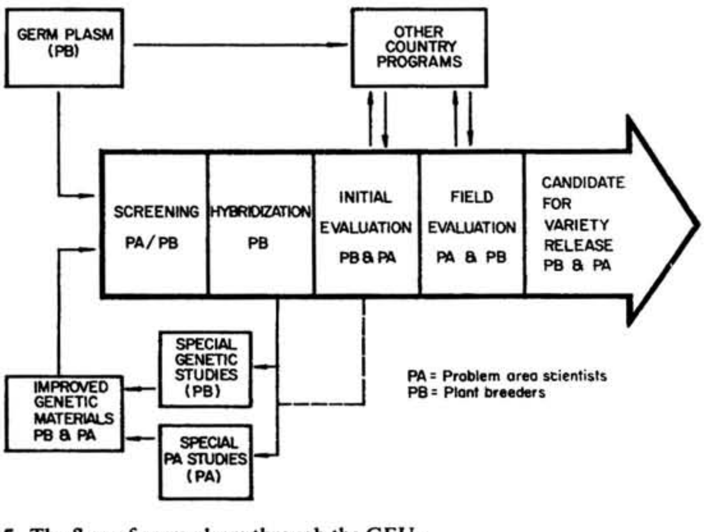
Germ plasm conservation. The hub of the GEU program is IRRI's growing germ plasm bank, which now contains more than 30,000 of the world's estimated 100,000 varieties.



4. Superior agronomic characteristics and disease and insect resistance will be incorporated into all new rice varieties developed through the Genetic Evaluation and Utilization (GEU) program. Plant breeders (PB) and problem area scientists (PA) will work together to incorporate the ability to withstand other production constraints.

Many of these varieties yield poorly but have inherent genetic characteristics, evolved or selected over centuries, that adapt them to specific environmental conditions (such as rices that grow on toxic soils or rices that are tolerant to drought).

Many of these rices face the threat of extinction. Farmers often abandon their traditional rices as they adopt high-yielding varieties. Encroaching urbanization and resource exploitation wipe out wild and primitive species. When such rice strains disappear, the invaluable genes which carry the desirable characters from one generation to the next, also vanish.



5. The flow of germ plasm through the GEU.

IRRI cooperates with rice specialists throughout the world to locate, collect, and preserve as many rice strains as possible, including those of unknown potential, before these strains disappear. During 1973, IRRI scientists helped in germ plasm collection efforts in Bangladesh, Burma, East Malaysia, Indonesia, the Khmer Republic, the Philippines, and South Vietnam. We collected many special types reported to be resistant to salinity, tolerant to acid-sulfate soils, or resistant to drought.

Almost 4,000 new accessions were saved and added to the germ plasm bank during 1973. Scientists in 38 countries draw nearly 10,000 seed samples from the bank to use in national breeding programs.

Agronomic characteristics. In some countries varieties with intermediate plant type, represented by IR5 (120 cm high), are more popular for lowland rice production than the shorter statured varieties, such as IR8 (100 cm high). Strains with intermediate heights are also favored for upland conditions. Consequently, we are introducing genes for intermediate stature into lines known to be resistant to the major insects and diseases and to have high tillering capability, erect leaves, and sturdy stems.

In response to the growing demand for short-seasoned varieties, we have developed lines which mature in about 105 days. For comparison, IR8 matures in 130 days. The short-seasoned IR2061 selections are the most promising of these new lines. Their grain qualities are good; their insect and disease resistance remarkable; and their yields are among the highest of the early maturing selections.

We continued to improve grain quality to satisfy the tastes of rice consumers in different parts of the world. We are blending the qualities of desired amylose content, aroma, and stickiness into lines with high resistance to insects and diseases.

Disease resistance. Rice is often cultivated year-round in the hot, humid tropics. These conditions encourage rapid buildups of pathogenic organisms. The breeding of resistant varieties is the most practical way to control diseases. Continuing efforts are being made to screen varieties and hybrid progenies for resistance to major diseases and to study the behaviors of the different pathogens.

We have found that races of the variable blast fungus disease (*Pyricularia oryzae*) constantly change in the field. For example, in an epidemic in the 1973 upland variety trial, we found 11 races out of 46 isolates tested from the same field. Ten of the 11 races are new to the Philippines. The 10 new races attacked CO_{25}, which was resistant to most races in previous tests, but they did not infect Khao-teh-haeng 17, which was susceptible to most of the previously identified races.

Blast resistance is generally "vertical"—a variety may be highly resistant to one race of blast, but susceptible to others. We are incorporating broad spectrum resistance into new lines so they will remain resistant in different regions and seasons. The line IR1514A-E666, for example, was resistant to most races of blast during the 1973 epidemic of upland rice. Ten new races of blast were identified at IRRI during 1973, bringing to 229 the total number of races identified.

We continued to coordinate the International Blast Nursery for the 11th year. We distributed the seed of test materials to 26 countries. Local scientists are evaluating them under their specific environmental and cultural conditions, and using the best materials in their national breeding programs.

Searching for ways to cut time and land requirements for sheath blight resistance screening, we tested three new methods: the seedling test, the detached flag leaf test, and sheath inoculation. Varieties react distinctly to all methods, but results of the three tests do not always agree. Unlike blast disease, no distinct physiological races of sheath blight pathogens have been found. This may indicate that incorporation of stable resistance to sheath blight will not be too complicated.

We initiated the International Sheath Blight Nursery this year by sending 60 varieties and lines with varying degrees of resistance to nine Asian countries. These will be tested and the results shared among scientists in the cooperating countries.

We found very little variation in the physiological properties of Asian isolates of the bacterial blight pathogen *Xanthomonas oryzae*, but virulence was found to vary greatly. This is significant to scientists who are incorporating bacterial blight resistance into new varieties.

We observed a particularly virulent strain of *X. oryzae* which breaks down the resistance of IR20 and other resistant varieties in Isabela province, Philippines. We are closely observing the new strain and have found two varieties (BJ1 and DZ192), and their dwarf progenies, to be resistant to it.

Using the efficient "clipping technique" for inoculation, we screened all of the new entries in the germ plasm bank, and all relevant breeding lines, for resistance to bacterial blight in 1973.

We coordinated the International Bacterial Blight Nursery for the second year. Material was tested at 18 locations in nine Asian countries.

A new screening technique allowed us to vastly expand our testing for resistance to tungro, one of the most devastating virus diseases. We screened 11,000 rices in 1973.

We studied the epidemiology of tungro in farmers' fields and in greenhouses. By learning more about the factors affecting the oubreak and spread of the disease, we can determine better control methods and learn how to predict epidemics.

We observed tungro incidence in farmers' fields, and collected green leafhoppers (the vector, or carrier, of tungro disease) at 26 sites in the Philippines. We caged green leafhoppers with rice plants to determine which factors contribute to tungro infection.

We found that tungro incidence is proportional to the number of insect vectors. In cage studies, increasing the number of insects from 15 to 600 per cage of 16 pots increased the infection from less than 10 to 90 percent. Increasing the number of diseased plants in the experiment increased the infected seedlings from 43 to 85 percent. Prolonging the duration of caging increased the infection from 9 to 94 percent. The nymphs spread the virus less efficiently than did the adults.

We found that an insect can infect about 10 to 12 seedlings with tungro during a 24-hour period. Although the percentage of infection rose with longer periods of inoculation, the number of seedlings inoculated by an insect per unit of time decreased with longer period of inoculation.

We developed a field screening technique for determining resistance to grassy stunt virus. Resistant lines were entered in the replicated yield trials for the first time. The proportion of our F_2 populations with at least one parent resistant to grassy stunt has risen from 10 percent in 1971 to 44 percent this year.

Insect resistance. Economic studies show that rice farmers generally use small amounts of insecticides, and then only when damage is visible. This does not help if the insect transmits a virus disease to the rice crops. And by the time a farmer observes damage, it is often too late to control the insect.

But the success of IR20 showed that farmers quickly adopt varieties which are resistant to these insect pests. Not only does insect resistance stabilize yields in farmers' fields, it also lowers production costs. The newly released variety IR26, for example, with its resistance to brown planthoppers, should help stabilize yields in parts of India and the Philippines where this pest has devastated crops.

During 1973, 2,000 rice accessions and hybrids were screened for resistance to green leafhoppers, brown planthoppers, and whitebacked planthoppers. We screened 1,500 accessions and lines for zigzag leafhoppers and found 44 to be resistant. Among the most resistant is the variety Ptb 21 from India, which is also resistant to green leafhoppers and brown planthoppers.

Up to now, 12,000 accessions and lines have been screened for resistance to the rice whorl maggot. Unfortunately, none were resistant, but a few moderately resistant varieties are being crossed to try to increase the level of resistance to this pest. We crossed varieties that are moderately resistant to striped borers and found that some of the progeny are more resistant than either of the parents. We are investigating several progenies which have the semidwarf plant type and are resistant to most of the leafhopper and planthopper species.

Protein content. Rice is an important source of protein, supplying more than 50 percent of the total protein consumed in some countries. For that reason, even a modest increase in protein levels in rice varieties would provide a significant nutritional boost, especially for children, whose protein requirements are high. IRRI's efforts to incorporate higher levels of protein into high-yielding varieties, if successful, could affect the lives of millions.

In a cooperative study of the factors that affect protein content, statisticians, agronomists, plant breeders, and chemists found that protein levels were affected more by environmental factors than by genetic differences. Thus, yield-limiting factors such as insects, diseases, or adverse soil conditions are likely to result in a high protein content. Weather conditions and cultural practices, such as rate and time of fertilizer application, water management, and weed control, also affect levels of protein. These factors complicate selective breeding for higher protein.

We know, however, that there are real differences among varieties, which can best be expressed in terms of "protein threshold," the level beyond which an increase in yield is accompanied by a decrease in protein level. The experimental line IR480-5-9 yielded well and produced grains with 2 to 3 percent higher protein content than did IR8 in farmers' fields in the Philippines. But it is susceptible to bacterial blight disease. We are crossing IR480-5-9 to lines more resistant to insects and diseases.

During the 1973 growing seasons, we evaluated 424 lines for their protein content and discarded 264 lines. Many crosses were made with lines resistant to the major insects and diseases. Several such crosses with Ptb 18 and *Oryza nivara* have reached advanced stages of testing in the disease and insect programs. The protein levels of these lines appear promising.

We studied the nitrogen balance of weaning children $1\frac{1}{2}$ to 2 years old who were fed diets of rice and fish. Substituting high protein rice in place of low protein rice in their food raised the nitrogen balance of these children. This means that the added protein was retained and used by the children.

Drought tolerance. Rice is grown in the tropics under conditions of normally high rainfall. But the time and intensity of rainfall varies markedly, so rice is often subjected to periods of severe moisture stress. A major objective of GEU is to develop rice varieties which are tolerant to drought, and which will recuperate quickly when the rains come.

Drought-tolerant varieties are most needed for upland conditions, where rice is grown in unbunded fields that are prepared and seeded under dry conditions. They depend entirely on rainfall for moisture. Upland rice farmers are among the poorest of the world's subsistence farmers. Drought tolerance is also important for rainfed lowland rice, the yields of which are often limited by unseasonal drought. Even deep-water rice must have some drought tolerance because in some countries it is direct seeded on land long before the high waters come.

We developed a mass screening technique to evaluate field tolerance to drought at different growth stages. Using this method of testing, hundreds of lines and varieties can be screened under low moisture conditions in the dry seasons. We have identified drought tolerant lines from traditional upland as well as lowland types. The semidwarfs generally have low levels of drought tolerance, although they vary markedly in this character.

Some varieties tolerant of drought in the field were found to have high proportions of long, deep, and thick roots, which reach into the subsoil for water during moisture stress.

Our agronomists have developed a technique by which a constant soil moisture tension can be maintained in pots. With this technique, they screened 14 varieties and lines for drought tolerance. The line IR1529-430-3 was most tolerant of soil moisture stress.

We also tested 75 upland varieties and lines, including rices from Asia, Africa, and Latin America, in farmers' fields in Batangas, Philippines. Rainfall was above average and was well distributed during this trial. Twenty-four rices were identified as promising. The highest yield was 6.6 t/ha from the experimental line IR3260-91-100.

In another test of upland varieties at the IRRI farm, soil moisture stress reduced the plant height, tiller number, and dry matter production of all rices except the African varieties E-425 and Moroberekan and the lowland semidwarf selections IR1661-1-170, IR1531-86-2, IR1646-623-2, and IR1721-11-6. IR1646-623-2 was most tolerant of drought. We found that late moisture stress reduced yields more than early stress. Rices are probably more vulnerable to stress during the reproductive and ripening stages.

We have crossed many diverse types to combine drought tolerance with superior agronomic characteristics. Upland rices of intermediate plant height and moderately high tillering ability might be more responsive to nitrogen than tall traditional types. Through rigorous selection of hybrid progeny under upland conditions, we have identified breeding lines that have good drought tolerance and improved tillering ability. We are testing these lines in major upland rice areas in several countries.

Resistance to the movement of water vapor through the cuticle layer of the leaves of rice is an important characteristic for drought tolerance. We measured the cuticular resistance of the leaf surfaces of 35 rice varieties and found great variability in this characteristic.

Studies of plant characters and grain yields in rainfed rice over three cropping seasons lead us to believe that varieties can be developed which are capable of adjusting their growth characteristics to fit existing land and water management systems (upland, lowland, and moderately deep water). Such adaptability would insure against total crop failure if rainfall is too low or too high for specific water and land management systems.

Tolerance to injurious soils. IRRI scientists have used genetic variability to produce lines that can tolerate insects, diseases, drought, and cold. We are now identifying genetic materials that are adapted to injurious soil conditions such as salinity, alkalinity, iron toxicity, phosphorus deficiency, and zinc deficiency. Iron deficiency is a problem in many upland soils, and manganese and aluminum toxicities are common problems in acid upland soils.

We are screening the world collection of rice germ plasm to identify varieties with natural tolerance to these soil problems. We start by screening varieties which originated in areas where the adverse soil conditions are common. Hopefully, tolerance to injurious soils can be transferred into varieties of good grain quality, high yield potential, and high insect and disease resistance.

Excess salt prevents rice from being grown on millions of hectares of low land in deltas, estuaries, and coastal areas in the tropics. It also limits rice production in some arid irrigated areas. In India alone, 7 million hectares of land are affected by salt. Since projects to reclaim saline land are very expensive, high-yielding salt-tolerant varieties are the most practical solution to the problem.

We have developed a technique to screen varieties for tolerance to salt. We raise rice varieties in solution cultures and transplant them at 2 weeks of age into solid cultures which contain 0.4 percent common salt. We are using this technique to screen the world collection of varieties.

Alkalinity retards the growth of rice on several million hectares of irrigated soils in the arid parts of India, Pakistan, Iran, and Egypt. These areas have abundant sunshine, and far fewer disease and pest problems than do the humid tropics. But the alkalinity problem must be solved, particularly if new land is to be brought into production.

Alkalinity can be corrected—at high cost—by applying gypsum and following with intensive irrigating and leaching. Developing varieties tolerant of this problem is a simpler and cheaper alternative.

We developed a screening technique for alkalinity. It is similar to our salinity screening method, but we transfer the plants into a solution containing 1.3 percent sodium carbonate.

Zinc deficiency is the third most important nutritional problem of lowland rice. Zinc deficiency is found in alkali soils, in some calcareous soils, and in continuously wet soils. Varietal resistance offers the simplest solution. We have found in experiments in Agusan del Norte, Philippines, that the varieties H4, IR5, and IR20 survived on a zinc-deficient soil on which 29 other varieties died.

Iron toxicity is probably the most important single soil factor limiting rice yields on vast acid-soil areas of the tropics, especially on acid sulfate soils. It severely retards rice growth in mangrove swamps brought into production.

Lime can correct iron toxicity—but it is not economically feasible. The obvious solution is to use improved varieties that tolerate iron toxicity.

Iron deficiency limits yields on upland soils, especially those of high pH. It can be solved at prohibitive cost by submerging the soils or by applying iron compounds. We hope to incorporate tolerance to iron deficiency into improved upland varieties. CAS 209, from Senegal, and the line IR1561-228-3 are good sources of resistance to iron deficiency. We are searching for others.

Manganese and aluminum toxicities retard the growth of rice on acid upland soils. Varieties such as Monolaya, from Colombia, and M1-48, from the Philippines, tolerate excess manganese and aluminum.

Tolerance to deep water. In large areas of South and Southeast Asia, the water level during the growing season is too deep for the new high-yielding semidwarf varieties. In the so-called floating rice areas, the water depth ranges from 150 to 500 centimeters. Millions of hectares of such rice are found in Bangladesh, Thailand, Indonesia, India, Vietnam, and parts of Africa. The rice is planted before the heavy rains, in dry soil or where there is little standing water. As the monsoon rains raise the water level, the stems rapidly elongate, keeping the panicles above water. Floating rice is sometimes harvested from boats. In areas where the water recedes before harvest, a tangled mass of stems and curving shoots is left behind. Floating rices yield somewhat like traditional unimproved lowland rices.

Floating rice culture has not been thoroughly studied by scientists. Varietal improvement has been limited to selection of the better existing varieties.

We hope to increase and stabilize the grain yields of floating rice. First, we must identify the factors which limit yields. We are screening and classifying germ plasm of floating rice and selecting the most appropriate materials for crossing work.

We plan to establish an international nursery program to test promising genetic material under different cultural and environmental conditions.

In an even larger area than that occupied by floating rice, the annual flood waters commonly reach up to 150 cm in depth. The varieties used are tall indica types and not necessarily floating rices. A genetic evaluation program similar to that for floating rice is being undertaken to improve the yielding ability of these rice varieties. Improved varieties may be semidwarfs which have the ability to elongate as flood waters rise, to prevent the plants from being submerged. But in years when the water level is low, the plants will remain short, providing a better plant type.

Crops are often completely submerged by unpredictable floods in vast rice areas where water control is poor. Submergence may last from 1 to 30 days at different growth stages. We hope to develop flood-tolerant varieties which can withstand such conditions, and will yield well. Varieties screened in the GEU program for deep-water rice will provide breeding material for the flood tolerance program.

Cold tolerance. Modern rices have not been adopted in subtemperate and in many mountainous areas because of poor performance when grown under low temperatures. In some irrigated valleys, cold irrigation water from the surrounding uplands has limited the new rices.

Through our cold tolerance program, we are identifying rices that grow well under lower-than-normal temperatures. We hope to incorporate this ability into high-yielding varieties.

IRRI scientists have developed a technique to identify tolerance to cold water at the seedling stage and are determining other methods of screening at later growth stages. We will screen materials under controlled environmental conditions in the phytotron.

An international cold tolerance nursery will be established once we have identified enough promising lines.

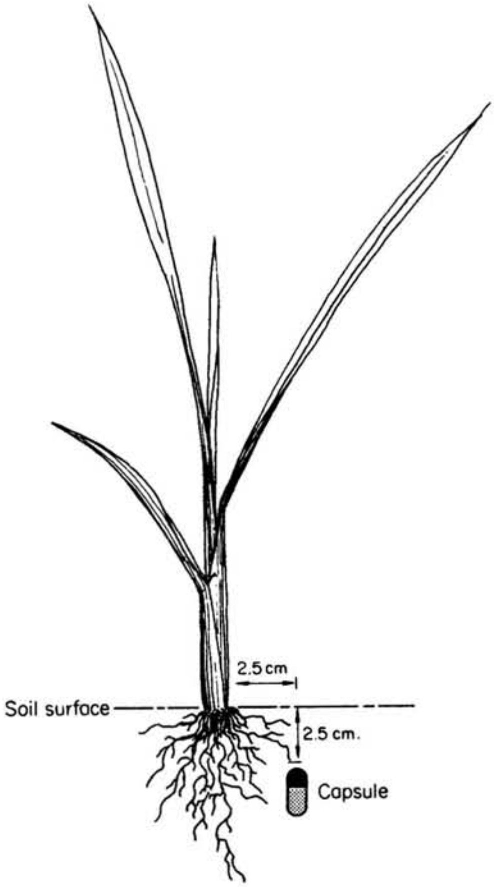
Insect control and management. While host resistance is being sought for the major insect pests, the use of pesticides will likely continue to be an important component of an integrated pest control program. Our objective in working with these chemicals is to find inexpensive and effective means of complementing control through host resistance.

We evaluated different insecticides and application methods to learn how farmers can maximize returns on insecticidal investments.

We found that insecticides, when packaged in capsules and placed in the root zones, are more readily available to the plants by systemic effect. Inserting the insecticide capsules below the soil surface protects them from heat, sunshine, volatilization, and drainage with overflowing water (fig. 6).

We analyzed plant tissues and found that 10 times more insecticide was absorbed by plants when applied to the root zones than when applied to the soil surface or incorporated into the top soil. Even at 40 days after treatment, twice as much insecticide was found in plants which received the root-zone application as in plants which received the other treatments. Root zone application is more effective and lasts longer than paddy water application.

In biological control studies, we found that a predator organism (*Cyrtorhinus lividipennis*) can kill an average of 0.6 brown planthopper nymphs per day, or 50 green



6. Packaging insecticides in capsules and placing them in the rice root zones protects the insecticides and makes them more readily available to the plants.

leafhopper nymphs per day, for at least 4 consecutive days. The predator prefers to prey on nymphs rather than on adults, and prefers green leafhoppers to brown planthoppers.

We studied "integrated pest control" or the combination of host plant resistance and insecticide treatments. Frequent applications of insecticides often increased yields, but were not usually profitable. In most cases, we found that IR20 could be grown more profitably with no insecticide treatments. In areas where insect and virus problems were minor, even susceptible IR22 could be grown profitably without insecticide application. But in areas where the brown planthopper was a serious pest, susceptible varieties yielded only moderately, even with frequent applications of insecticides.

In the laboratory and in farmers' fields, we identified insecticides that are effective against green leafhoppers, brown planthoppers, and striped borers. Thoroughly spraying the lower halves of rice plants, where brown planthoppers live, with perthane, chlordimeform, and bux provided long lasting control of the pest. For larger farms, agricultural engineers have designed a 12-meter boom spray with drop nozzles which can be attached to a power sprayer.

We are studying the economic thresholds for insect control. Insect damage by green leafhoppers and brown planthopper nymphs caged on plants was found to be significant when the plants were young, and at the booting-to-flowering stages. Plants can usually tolerate 5 to 10 nymphs per tiller for 2 weeks without yield loss. We think that certain densities of young nymphs at different plant stages may be simple economic thresholds for field control of brown planthoppers.

Weed control. We put together herbicide trials and distributed material for 142 experiments in 15 Asian countries in 1973. The experiments were conducted under transplanted, direct-seeded, flooded, and upland conditions. Herbicides for 15 more trials were sent to the West Africa Rice Development Association (WARDA).

Based on the results from these cooperative studies, several new herbicides are now being marketed in Asia, including formulations and derivatives of 2,4-D and MCPA, butachlor, and benthiocarb. Competition helps keep prices low.

With pressures on the land increasing, farmers need to prepare land in a shorter time for intensive rice or multiple crops cultivation. Zero-tillage and minimum tillage are methods of doing this.

Using herbicides for weed control, we investigated zero tillage for growing direct-seeded rice under flooded conditions. Plots treated with glyphosate followed by paraquat, and never tilled, yielded as much as those plowed once and harrowed twice.

Scirpus maritimus, a fast-growing sedge, wasn't much of a problem a few years ago. But better control of annual weeds and the introduction of irrigation water have helped to spread the perennial sedge. *Scirpus* has underground tubers that are left in the ground when a farmer kills the topgrowth. Thus, ordinary cultivation or herbicides may allow the weed population to shift until *Scirpus* predominates.

Plant physiologists are studying different aspects of the growth of *Scirpus*. When we know the growth characteristics of the plant, we can find better ways to control it. Our agronomists have identified two herbicides (bentazon and silvex) that control *Scirpus*.

We have found in experiments in farmers' fields that intermediate-statured rices may compete with weeds better than semidwarfs. This is one reason we are developing some varieties intermediate in height as well as semidwarfs.

Water management. Our program in water management focuses on water measurement and control within irrigation systems, since farmers appear to allocate water fairly well on their farms, where they have control of it. We are looking at two competing indices of water management, that of efficient water use, and that of minimal moisture stress in irrigated areas.

Field research carried out jointly with the Philippine National Irrigation Administration (NIA), the University of the Philippines at Los Baños College of Agriculture, and IRRI showed that yield loss due to stress tends to be low in fields located near the beginnings of distribution canals, but increases markedly in irrigated fields near the ends of the canals. Efficiency of water use tends to be much lower in areas near the beginning than in areas located further along the canal. This indicates a tendency for farmers near the beginnings of canals to overirrigate, and for those in the lower reaches of major canals to have insufficient water. The date of transplanting is often delayed as much as a month in the lower reaches.

In a pilot study in cooperation with the NIA, we are exploring different ways of managing a 5,000-ha system to equalize the distribution and achieve greater overall production of rice.

Nitrogen fixation and fertilizer utilization. Nitrogen is perhaps the most limiting plant nutrient for rice production. Without adequate supplies of nitrogen, high grain yields are impossible. The worldwide production of nitrogen fertilizer is far less than the demand, so prices are skyrocketing. This development is especially threatening to agricultural production in the poorest countries.

Ironically, the air around us holds an unlimited supply of nitrogen. IRRI scientists are searching for ways to make more of this atmospheric nitrogen available to plants, decreasing the farmers' dependence on costly fertilizers.

IRRI researchers have discovered that atmospheric nitrogen can be "fixed" in paddy soils in a form that rice plants can use. The equivalent of 60 kilograms per hectare of nitrogen has been fixed in some experiments. This may explain how rice has been grown continually on the same paddy fields, without fertilization, for hundreds of years.

IRRI scientists are studying the mechanism for this fixation. We know the rice plant has a mechanism for transporting atmospheric nitrogen to the root zone. Bacteria surrounding the roots derive part of their energy from organic exudates from the roots and use this energy to convert the gaseous nitrogen into combined forms which the plant can use.

We have observed only low rates of nitrogen fixation in upland soils. This indicates that the bacteria fix significant amounts of nitrogen only when oxygen concentration in the root zone is low, as in submerged soils.

We hope to find ways to increase the efficiency of nitrogen fixation, and to determine the conditions under which the plant best uses the fixed nitrogen. We are screening rice varieties to determine their relative nitrogen-fixing capacities. Perhaps in the future, rice varieties can be selected which encourage high rates of nitrogen fixation and which use fertilizer and soil nitrogen more efficiently.

In the laboratory, we have found that rice plants fix higher levels of nitrogen when phosphorus and potassium are added. Also, in one field experiment at IRRI, significant yield increases were obtained from adding either phosphorus or potassium without nitrogen. Such nutritional response to phosphorus or potassium is not common at IRRI, suggesting that the beneficial effects of adding these two nutrients may have been due to their indirect influence on nitrogen fixation.

We have also found that leaving rice straw in the field after harvest accumulates a substantial amount of nutrients. Using this practice, we produced yields of as high as 5 t/ha from Philippine lowland soils without fertilizers.

Because of the increased emphasis on upland rice, we are searching for more efficient methods of applying different forms of nitrogen under poor water management. In soils that are continually flooded at 5 cm, or that are intermittently irrigated, we found that readily soluble sources of nitrogen produced higher yields when applied as three split doses rather than when all the fertilizer was applied as basal before planting. Slowly available sulfur-coated urea gave slightly higher yields when applied as a single basal treatment. In farmers' fields in Nueva Ecija, Philippines, we also found that ammonium sulfate and ordinary urea produced higher grain yields when applied in split doses. But with sulfur-coated urea, yields were higher when the fertilizer was applied as one basal application.

Fertilizer is relatively expensive in Asia, and labor for applying it is relatively cheap. So applying ordinary fertilizers as split doses has more merit than applying slow-release fertilizers as one dose, even though the split dose requires more labor. Slow-release fertilizers may be better, however, when water control is inadequate and the soil is alternately wet and dry.

Environmental influences. The rice plant is influenced markedly by the environment in which it is grown. This environment includes factors such as solar radiation, temperature, humidity, soil moisture supply, and the supply of carbon dioxide in the atmosphere.

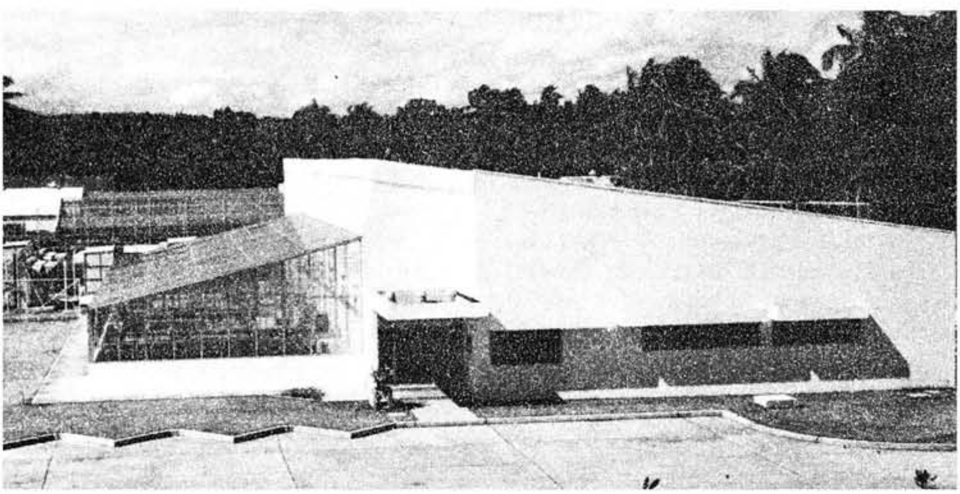
We determined the effects of climatic variables on yields and components which affect yields by planting an early maturing rice line (IR747-B2-6) every 2 weeks, a total of 26 crops in one year. The yields varied from 4.6 to 7.1 t/ha and were related to the season of the year during which the crop grew.

A combination of high solar radiation and low temperature in the period 25 days before flowering markedly increased yields, primarily through an increase in numbers of grain per square meter. This characteristic was by far the most important yield component. It accounted for 74 percent of the measured yield variation while percent of filled grains and weight per unit of grain accounted for the remainder of the measured variation. Disease and insect control was maintained by the use of pesticides in this trial.

We studied the relationship between solar radiation, leaf resistance (combined resistance of stomates and cuticle), and soil moisture stress (drought). Rice plants grown under flooded conditions had low leaf resistance, suggesting that stomates remained open even during the daytime. Plants grown under soil moisture stresses, similar to those found in upland rice conditions, had high leaf resistances, especially in the afternoons on sunny days. Increasing the light intensity actually reduced the rates of photosynthesis for plants grown under moisture stress. Such photosynthetic restriction during periods of drought suggests that strong sunlight may be wasted under water stress. Upland rice culture under partially shaded conditions (such as under coconut trees) merits further study.

New phytotron. The Australian government has constructed a simulated climate control facility (phytotron) at IRRI to strengthen research on the response of the rice plant to environmental changes (fig. 7).

The environment can be controlled and manipulated in the phytotron's growth rooms. Scientists will be able to simulate many of the climatic conditions under which rice grows in different regions, and can measure how the rice plant responds to these conditions. Temperature, daylength, and humidity can be controlled in the phytotron's six glasshouse rooms, 10 artificially lighted growth cabinets, and eight naturally lighted growth cabinets. Light intensity can also be controlled in the artificially lighted cabinets.



7. IRRI's new phytotron, a simulated climate control facility, will strengthen research on the response of the rice plant to environmental changes.

With the phytotron, scientists can measure the effects of individual climatic factors separately from those of closely related factors. Many experiments can be repeated at any time of the year. The phytotron will go into operation in 1974.

Machinery development and economics. Farm machines are usually designed for large operations in the labor-scarce developed nations; they are often technically or economically unsuited for small-scale farmers in the rice-producing countries. Simple inexpensive machinery is being developed at IRRI for these smaller farmers. The machinery is designed not to replace but to increase the productivity of labor. The designs are released free to manufacturers who want to locally produce IRRI equipment. This saves foreign exchange, creates employment, and builds local industry.

Most popular among the IRRI machines is the 5-hp to 7-hp power tiller. It is being built in small machine shops from locally available materials and sold at about half the price of a comparable imported model.

Sales of the power tiller are impressive. More than 3,000 were sold in the Philippines during 1973—about 70 percent of the total power tiller sales for the country. The machine has been tested in a dozen countries and is being produced commercially in Sri Lanka and Thailand. This year, we redesigned certain components of the tiller, and adapted several attachments to broaden its utility.

We completed field testing of the axial flow multicrop thresher in 1973. This versatile machine can thresh not only rice, but also other crops. It is being produced in the Philippines, Pakistan, Sri Lanka, and Thailand.

We modified the design of our PTO-driven thresher, and neared completion of a 6-row stripper harvester. A wooden bin has been designed to reduce initial investment costs of the 1-ton batch dryer. We are evaluating a modified Engleberg steel-huller mill. Tests indicate that recovery of both total rice and head rice (unbroken grain) can be significantly increased through minor changes in the machine.

Because chemical herbicides are becoming more expensive, we designed a machine to directly apply non-selective herbicides. It seems to perform well in row crops.

Economists are studying how the production of IRRI designs affects employment. We found that employment had increased by 96 percent at five firms when they began to manufacture IRRI machinery. Most of the firms previously had excess utilization capacity; producing the IRRI machines increased the use of their existing plants and equipment by 20 to 30 percent.

Many more jobs are created when these firms sub-contract the production of assemblies and component parts to other small industries. The five firms subcontracted work for the production of IRRI equipment to 45 other firms.

To determine how farm machinery is being used, and to determine the effects of mechanization on labor and economics, we interviewed 142 large tractor operators in Nueva Ecija, Philippines. The tractors are used 60 to 70 percent of the time for contract operations, principally land preparation. Use is seasonal. If suitable implements and accessories are made available at reasonable costs, we see considerable potential for increasing their use.

Grain handling and processing. Rice production doesn't end when the grain ripens. The crop must be harvested, dried, and milled before reaching the consumer. We are searching for ways to help farmers minimize grain losses during these phases.

We analyzed grain losses during wet and dry seasons on 50 farms in Central Luzon, Philippines. We found that about 3 percent of the grain is lost during harvest, and that these field losses are affected by time and season of harvest, variety, and the availability of irrigation water. Harvesting grain at high moisture level (above 20 percent) reduces shattering and cuts field losses to less than 1 percent.

We compared solar and mechanical drying by measuring both total rice recovered after harvest and head rice recovered after milling. We found that harvesting rice at high moisture levels and drying it mechanically decreases field losses at harvest, lowers milling losses, and gives milled rice of better quality.

Grain quality. Gel consistency indicates the rates at which cooked rice hardens. Low gel consistency is preferred over high, even for waxy rices.

We developed a rapid and simple test to measure the gel consistencies of different rices. This test is designed to complement the amylose test to help us select grain types that consumers will prefer.

Constraints to rice yields. Because yields in farmers' fields have remained far lower than those in experiment station plots, we have focused several studies on farm level constraints to high yields.

We coordinated a regional project in Pakistan, India, Malaysia, Thailand, the Philippines, and Indonesia to study the changes in production, farm income, and farm employment that have followed the modern rice varieties, and to determine why the technology has been readily accepted in some areas, but not in others.

Twenty-five social scientists in the six countries cooperated with IRRI on the study. In 30 Asian villages where modern rice varieties have been well accepted, we found that farmers grow these varieties more widely in the dry than in the wet seasons. The farmers consider pests and diseases the most serious constraints to high yields for modern varieties. In some countries, government policies have discouraged acceptance of the new technology.

Suitable modern varieties were not available for some villages, particularly those where deep flooding is common. In villages where substantial land was planted to crops other than rice, yields were significantly higher than in villages where only lowland rice was grown.

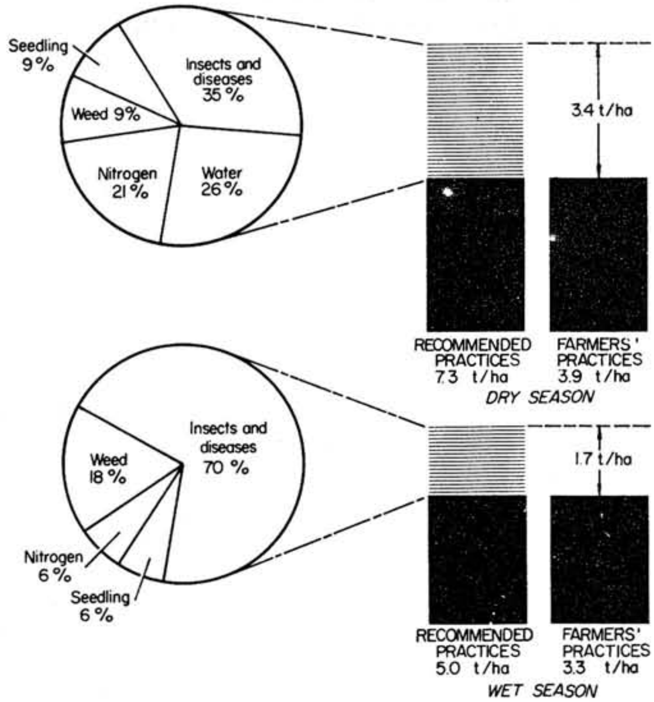
About 50 percent of the farmers reported that after adopting the new technology, they hired more labor and their own standards of living increased. About 15 percent reported decreases in hired labor and lower standards of living after the new technology was introduced.

We developed a new field plot technique to identify and quantify the constraints to yields in farmers' fields. We monitored the practices that each farmer followed and measured the rice yield on each sample farm. Actual yields are compared with the potential yields at the same location when recommended practices are applied, and with yields at various levels of intermediate technology. We applied the technique for three crop seasons in 15 farms in Laguna province, Philippines.

Pest and disease control was found to be the most crucial constraint, consistently reducing farmers' yields by about 1.2 t/ha, irrespective of crop season (fig. 8). In the dry season, water was found to be the next limiting factor, reducing yields by 0.9 t/ha; followed by nitrogen fertilization, 0.7 t/ha; weed control, 0.3 t/ha; and seedling management, 0.3 t/ha. During the wet season, weed control was relatively more important than factors other than insect control.

Using a somewhat different technique, we studied how factors both within and beyond the control of farmers affected yield levels in two irrigated villages and one rainfed village over 3 years in Nueva Ecija province, Central Luzon, Philippines.

We determined relationships among managerial factors, such as fertilizer application and cultural practices, which are within the farmer's direct control; environmental factors, such as solar radiation and soil texture, which are completely outside the farmer's control; and factors such as moisture stress, which are beyond the direct control of the farmer, but which may be potentially controllable by group action or



8. Differences between yields when farmers follow their usual practices, and when they follow IRRI recommendations. Factors which constrain yields in farmers' fields are shown in the circles (3 crop seasons, 15 farms, Laguna province, Philippines).

investment by society (for example, although an individual farmer may have no influence over moisture stress, irrigation might be extended to the affected area).

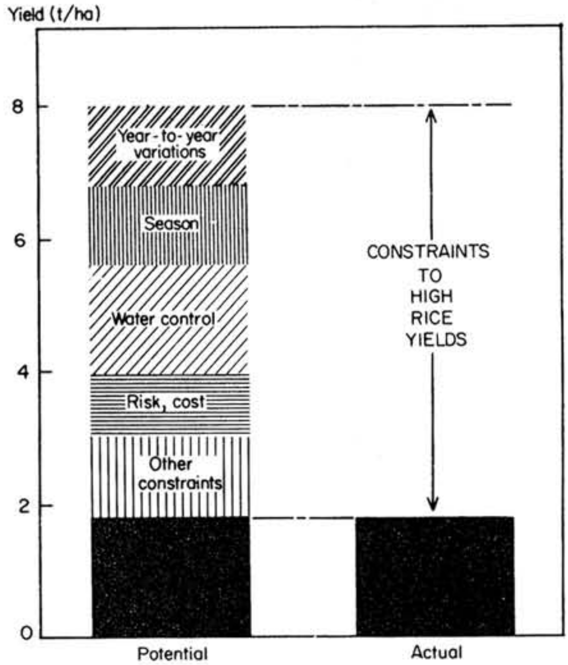
We found that, although good management practices often help explain why some farms and villages have higher yields than others, factors which are beyond the direct control of individual farmers, such as soil properties and availability of irrigation, often influenced yield differences to a much greater extent.

Among villages with similar physical resources, such as the two irrigated villages, managerial factors often accounted for most yield differences. But management factors accounted for only a third to a half of the yield differences between the irrigated and the rainfed villages.

We found that adoption of a package of management practices increased yields by at least half a ton per hectare in the irrigated villages, but did not increase yields under conditions of poor environment.

In an aggregate study of the factors which restrict yields on a national basis in the Philippines, we found that lack of water control is the single biggest yield constraint, responsible for about 25 percent of the differences between potential and actual yields (fig. 9). Seasonal factors, such as available solar radiation, account for another 20 percent of the yield differences. Economic factors, including risk, account for 15 percent of the differences. Year-to-year variability in weather conditions and in pests and disease damage account for 20 percent of the differences, and the lack of available inputs and non-adoption of new technology accounted for 15 percent.

Many of these constraints can be reduced or manipulated by appropriate financial investments, policy changes, research, and selective breeding. The construction of



9. Lack of water appears to be the single most important constraint to high yields in a preliminary aggregate study on a national basis in the Philippines.

irrigation and drainage systems, and modification of their management, can alleviate poor water control, for example. Policy measures to insure available credit and favorable prices can ease economic constraints. Fertilizer inputs might be reduced if varieties or farming systems can be developed which encourage the microbial fixation of atmospheric nitrogen in the soil. Year-to-year variability due to weather conditions can be eased by developing rices which are tolerant to drought and submergence, or which yield well under low solar radiation conditions of the monsoon seasons. Insect and disease damage can be reduced by incorporating higher levels of pest resistance into modern varieties.

Pilot extension program. We cooperated with Philippine agricultural agencies in developing an extension methodology for taking rice technology to the farm level which may be applied in other countries. The methodology was tested in the Philippine government's successful "Masagana 99" program ("Masagana" means "bountiful harvest" and "99" refers to the goal of 99 cavans, about 4.4 tons, per hectare).

The technology included the use of a package of practices: improved varieties; proper use of fertilizers, herbicides, and insecticides; supervised farm credit; fixed minimum support prices; massive promotional campaigns; farmers' field days; training, incentives, and mobility for technicians; and a trouble-shooting committee to identify and remove production constraints.

The program was very successful. Production levels appear to be near record in spite of unanticipated shortages of both fertilizers and pesticides due to the energy crisis.

The governments of Bangladesh and Thailand are considering the initiation of similar campaign programs to rapidly intensify production. Through our cooperative projects, we hope to encourage other countries to use similar methods to stimulate the rapid and widespread adoption of modern rice technology.

Rice cropping systems. IRRI scientists have demonstrated that rainfed lowland rice which is seeded directly on non-puddled soil at the beginning of the rainy season rather than transplanted during the middle of the rainy season takes advantage of early rainfall and may allow an extra crop of rice to be grown.

Although the rains begin in May in Central Luzon, Philippines, farmers seldom have enough water to plow and puddle the soils until July or August. To have seedlings of the proper age ready for transplanting, farmers must accurately forecast when sufficient water will be available and start their seedbeds 3 to 4 weeks in advance. By the time crops are transplanted, often in August, seedlings may have passed the optimum age.

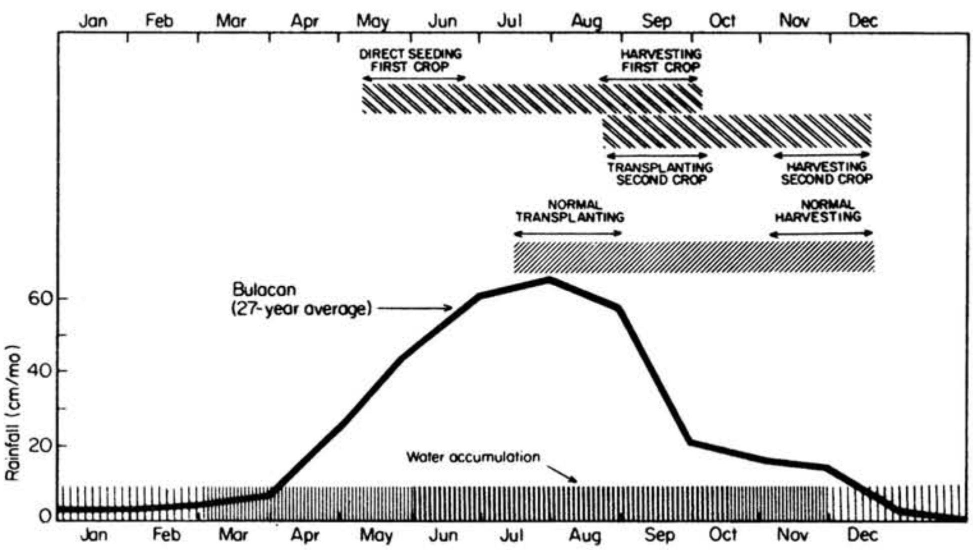
We have found that yields are similar in direct-seeded rainfed and transplanted-irrigated rice. Tests show that herbicides will control weeds in crops which are direct seeded in dry or moist soils.

Rice production specialists established experimental direct-seeded plots on farmers' fields at nine different sites in Central Luzon. The first crops of early maturing lines were sown in early May, before the heavy rains began. These crops were harvested in mid-August—before the last 40 percent of the surrounding farmers had transplanted their first crops (fig. 10). Seedbeds for the second crops had been prepared about 3 weeks earlier, and seedlings were transplanted immediately after harvest. Farmers were harvesting this second crop at the same time that local farmers using traditional crop cultures were harvesting their first (and only) crop.

We are now developing improved technology for direct seeding of rice.

Multiple cropping—growing two, four, even five crops a year on the same ground instead of only one—is another means of intensifying production.

Modern rice varieties mature a month or more earlier than traditional rices, leaving enough time and soil moisture to grow other crops. Residual fertilizer left in the ground after rice harvest can be converted into more food, rather than be wasted.



10. Early maturing rice lines were direct-seeded in farmers' fields in early May, before the heavy rains began, in Bulacan, Central Luzon, Philippines. Some of these crops were harvested before surrounding farmers, using regular cropping systems, had transplanted. Second crops were harvested at about the same time the local farmers were harvesting their first and only crops.

Alternate crops will use to the fullest advantage the long and warm growing season of the tropics.

Multiple cropping itself is not new. Farmers have grown other crops with or following rice for a thousand years. But the need to intensify cropping is far greater today than ever before.

We are studying the biological potentials of different cropping systems. We hope to develop intensive farming schemes that are slanted to the needs of small-scale farmers.

We have found that the traditional practice of "intercropping" (growing two compatible crops such as corn and upland rice simultaneously in alternate rows) is highly suited to situations of limited land and surplus labor. Intercropping increases the productivity of the land by a third—a hectare of intercropped corn and upland rice produces as much as one and a third hectares of corn and upland rice planted separately. Intercropping uses inputs more efficiently.

In fact, adding nitrogen fertilizer to an intercrop combination of corn and rice gave a much higher return on investment than did adding nitrogen to either corn alone or rice alone.

Intercropping corn and mung decreases the need for weeding and modifies weed response to fertilizer. Because the dense canopies intercept sunlight, intercropping provides a biological system of weed management. The canopies also prevent shifts in weed population to more troublesome grasses and sedges.

We are finding that certain traditional farming practices, including mixed cropping, help the small farmer control insects in his crops—even though he may not know why. We learned, for example, that intercropping peanut with corn lowers corn borer infestation apparently because the peanut crop is a natural habitat for a spider which preys on the corn borers.

Training. A hundred and twenty-six graduate students and production trainees from rice-growing countries work with IRRI scientists in the fields, greenhouses, laboratories, and classrooms.

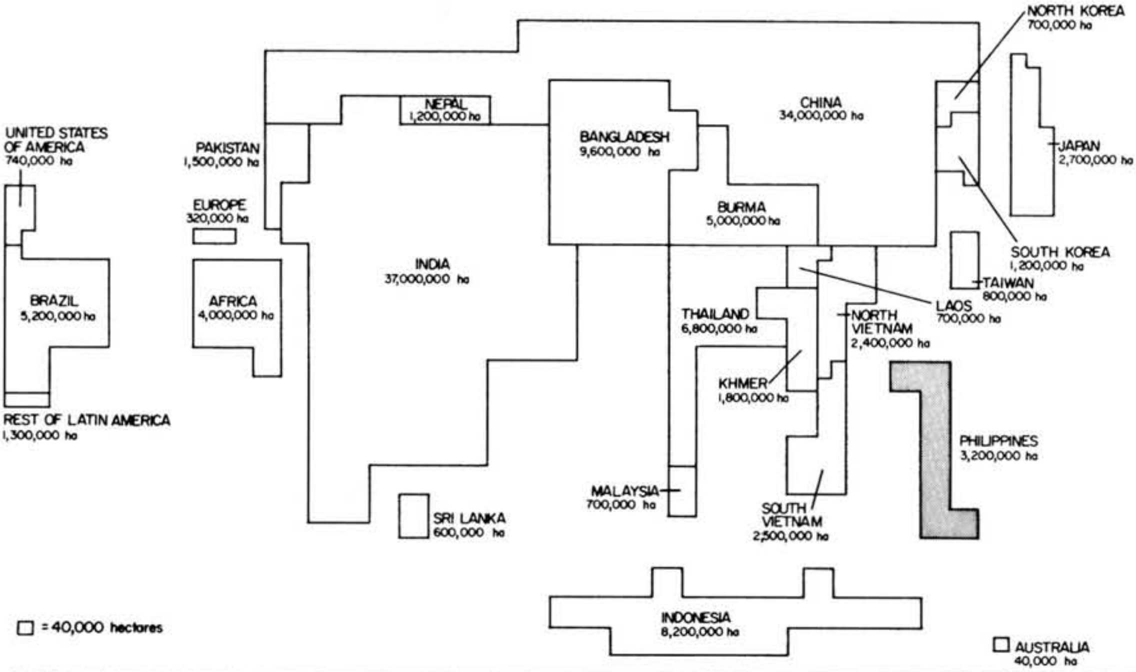
The individuals selected for training are staff members of government agencies and institutions involved in research and extension in rice-producing countries. The long-range objectives of the training program are to improve the technical proficiency of national research and extension staffs and to encourage multi-disciplinary research and production programs.

Ninety-two of the participants were in research-oriented programs. Many studied for master's degrees at the University of the Philippines at Los Baños, taking their course work at the University and conducting their thesis research at IRRI. Doctoral candidates and post-doctoral fellows conducted research in problem areas that pertained to their countries.

Thirty persons participated in rice production training programs. Most were extension and education specialists who were trained not only in crop production but also in how to run similar training courses when they return home. They studied the theories of agriculture and applied research in the classroom, but they spent half their time in the fields applying the theories and learning every step of rice production.

International programs. Because the largest areas of rice production are outside the Philippines, we continued to stress our responsibilities and opportunities to work with national rice research organizations (fig. 11). We must help strengthen national research capabilities if we are to be influential in helping rice-producing countries develop superior technologies suited to their local conditions.

IRRI coordinates several international testing programs. The types of nurseries and



11. The largest areas of the world's rice land are outside the Philippines. IRRI cooperates and works with many of these national rice research organizations to help them develop better technologies suited to their local rice-growing conditions.

the numbers of test locations increased in 1973. The nurseries now include: the International Blast Nursery; the International Sheath Blight Nursery; the International Bacterial Blight Nursery; and the International Rice Yield Nursery (fig. 12). In addition, herbicide trials were distributed to 15 Asian countries, and to the West Africa Rice Development Association (WARDA). We plan to expand our international testing systems.

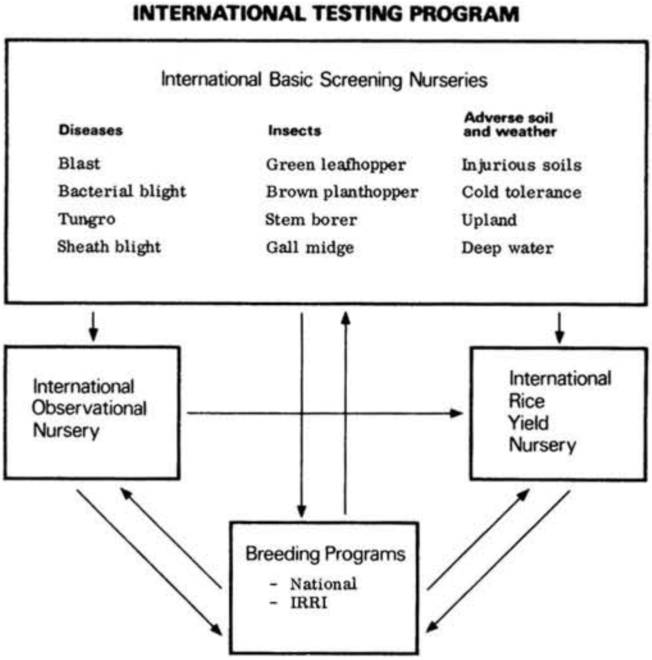
IRRI-designed machines were evaluated in India, Indonesia, Korea, Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam.

IRRI cooperates in regional rice research with the International Institute of Tropical Agriculture (IITA) and WARDA, in Africa, and with the Centro Internacional de Agricultura Tropical (CIAT) in South America.

A third of our staff is with our "outreach projects" in Bangladesh, Egypt, India, Indonesia, Philippines, Sri Lanka, and South Vietnam. We are participating, at the request of the host governments, to strengthen and accelerate the national rice research programs. The scientists live and work in the countries as members of local scientific teams. We supplied improved genetic material and helped train rice scientists. Our scientists at Los Baños serve as "back stop" subject matter specialists when needed.

In Bangladesh, we are cooperating with the new Bangladesh Rice Research Institute (BRRI), under a Ford Foundation contract.

IRRI scientists worked with Egyptian scientists to evaluate the potential of growing IRRI selections with long and slender grains in Egypt, where past production has been confined to japonica varieties with short and bold grains. This project was sponsored by Ford Foundation.



12. IRRI now coordinates international testing programs for blast, sheath blight, and bacterial blight diseases, and an international rice yield nursery. We hope to expand our international testing system to include other diseases, insects, and adverse conditions.

We cooperate with India through the All-India Coordinated Rice Improvement Project, through which India directs her resources to serve a variety of environmental and cultural conditions. The U.S. Agency for International Development (USAID) contract, which had supported IRRI scientists in India, was phased out in 1973. A Rockefeller Foundation scientist continues to be the IRRI representative in India.

The chief objective of IRRI's four projects in Indonesia is to develop a coordinated rice research program which uses limited manpower and facilities more efficiently. The projects are sponsored by the Ford Foundation, USAID, the World Bank, and the Dutch government.

An IRRI crop production specialist works with the Philippine government under a USAID contract to help incorporate research results from IRRI and other agencies into national production programs.

We have two cooperative projects in Sri Lanka: one on production aspects of rice and multiple cropping, and another on rice processing.

Two IRRI scientists work in South Vietnam under a USAID contract, helping local scientists conduct varietal yield trials, fertilizer trials, and herbicide and insecticide screening trials at four locations.

IRRI's annual rice research conference provides a forum for scientists to discuss new research findings and ideas. Seventy-five rice scientists from 20 countries attended the International Rice Research Conference in 1973. They agreed on the need for more cooperative nurseries to identify broad-spectrum resistance to diseases and insects, and for more field trials to screen promising genetic lines and to evaluate herbicides.

Seventy-eight participants met at IRRI for a conference on rice machinery in 1973, sponsored jointly by IRRI and the United Nations Industrial Development Organization (UNIDO). The participants explored ways to promote local manufacture of machinery for rice production in the developing countries.

FINANCES During 1973, the institute received cash grants amounting to $4,265,105.

The Ford Foundation gave $1,549,097. Of this amount $750,000 was toward the core operating and capital expenditures of the institute. The remainder was in support of the rice research and development programs in four countries: Sri Lanka—$162,500 as part of a 2-year grant for the rice production and multiple cropping project and another $142,000 as part of a 2-year grant for the project on rice processing and marketing; Indonesia—$90,200 which is part of a 2-year grant for an accelerated rice research program; Egypt—$38,000 which is part of a 2-year grant for the services of a project specialist with the Arid Lands Agricultural Program in the Middle East; Bangladesh—$255,600 which is part of a 2½-year grant to provide support for the Bangladesh Rice Research Institute, and another $105,000 which is part of a 2-year grant to provide support to the Bangladesh Rice Research Institute; India—$5,797 which is part of a 13-month grant for the services of a plant pathologist.

The Rockefeller Foundation contributed $672,535 during 1973. This amount included $620,000 for the core operating and capital expenditure needs of the institute, of which $500,888 was received in cash and the balance represented the value of the foundation's manpower contribution to the institute. The Rockefeller Foundation released $24,250 as part of a 3-year grant in support of the experimental program to identify and demonstrate techniques for increasing the productivity of disadvantaged Asian rice farmers, and $28,285 as part of a grant for the collection of the world's germ plasm of rice.

From various grants, the U.S. Agency for International Development released a total of $1,170,364 in 1973. The institute received $554,622 during the year for its core operating and capital expenditures and $209,094 in support of a project entitled "Research on Farm and Equipment Power Requirements for the Production of Rice and Associated Food Crops in the Far East and South Asia." Since 1967 a contract between the institute and USAID has supported a project for the acceleration of rice research and training programs in India. During the year, the institute received $104,501 for this project. Since 1971, a contract with USAID has supported a project to help the government of Vietnam to accelerate rice research for a 3-year period with a budget of $310,000 in addition to a budget of VN$12,200,000. In 1973, $54,823 was reimbursed to the institute. Since February, 1972, a contract between the institute and USAID has supported the accelerated development and utilization of improved technology in agriculture in Indonesia with a budget of $472,359 in addition to a budget of Rp. 424,582,000 which is managed by the USAID mission in Djakarta for a period of 2½ years. In 1973, $190,892 was reimbursed to the institute. Since July, 1972, a contract between the institute and USAID supported an intensified crop production and extension program in the Philippines for 2 years with a budget of $85,000 in addition to a budget of ₱92,400 which is managed by the USAID mission in Manila. In 1973, $35,096 was released to the institute. USAID contributed toward the training program of the institute by supporting scholars from various countries where USAID has active programs. The institute received $17,777 for this purpose this year. The USAID mission in Bangladesh provided $26,000 to finance the training of staff from the Bangladesh Rice Research Institute to be carried out at IRRI and at other institutions selected by IRRI. During 1973, $3,559 was released to IRRI.

The Overseas Development Administration of the United Kingdom gave $338,897 toward the support of the institute's plant breeding department.

The International Development Research Centre of Canada gave $111,085. As part of a 2-year grant to the institute for the multiple cropping research in the Philippines in cooperation with the University of the Philippines at Los Baños, IDRC released $98,275 in 1973. The centre made another grant to the institute for research on changes in rice farming in Asia and released $12,810 to the institute in 1973 for this purpose.

The Japanese government gave $228,780 in 1973 toward the training program of the institute, toward the purchase of equipment required for research activities of the institute, and toward the support of the institute's plant physiology department.

The International Development Association gave $120,000 in 1973 toward the core operating and capital expenditures of the institute.

The government of Indonesia, using a World Bank loan, released $32,631 as part of a 5-year contract toward the research facilities of the Sukamandi Branch of the Central Research Institute for Agriculture (CRIA) and toward scientific and other assistance to this new branch.

In 1967 the institute entered into a cost-reimbursement contract with the U.S. National Institutes of Health to study ways to increase the protein and essential amino acids of the rice grain through plant breeding. During 1973, $34,374 was reimbursed to the institute.

The Australian government gave $6,375 toward a short-term training program of the institute.

In 1973, the Netherlands government gave $64,700 as part of a 5-year grant for the institute's project for regional station development in Indonesia.

The names of other donors along with the areas supported and the amounts received during 1973 are given below:

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

Potash Institute of North America and International Potash Institute, long-term fertility experiments, $2,195.

Shell Chemical Co., applied variety-fertilizer trials, $5,358.

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

Bayer Philippines Inc., cooperative work with the Agricultural Productivity Commission, $8,333.

NSDB, evaluation of promising rice selections and management practices in the Philippines, $1,816.

NFAC, training of government extension technicians, $29,677.

During the year 1973, the construction of the phytotron by the Australian government was almost completed with an estimated cost of $1,000,000.

STAFF CHANGES

Mr. Thomas R. Hargrove joined the institute as associate editor, office of information services, in January.

Dr. H. Shiga joined the soil microbiology department as visiting scientist in April, to replace Dr. Tomio Yoshida, soil microbiologist, who departed in June for study leave.

Dr. Amir U. Khan, agricultural engineer, went on study leave in June. Two months later, Dr. Joseph K. Campbell joined as visiting associate agricultural engineer.

In July, Dr. Nyle C. Brady succeeded Dr. Ralph W. Cummings as director.

Dr. Randolph Barker, agricultural economist, went on study leave in July. Dr. Robert Herdt joined as visiting agricultural economist in August.

Mr. Orlando Santos, associate farm superintendent, took study leave beginning in August.

There were several changes in the institute staff in international programs.

Dr. Reed Bunker, Dr. Hiroshi Sakai, and Mr. Ernest Nunn resigned their positions with the All-India Coordinated Rice Improvement Project.

Mr. Rufus Walker resigned as rice adviser, Bangladesh Rice Research Institute, in June.

Dr. John M. Green joined the IRRI program in Indonesia in June as corn breeder and seed certification specialist.

In December, Dr. Jerry L. McIntosh joined the IRRI-Indonesia-USAID Cooperative Project in Indonesia as agronomist.

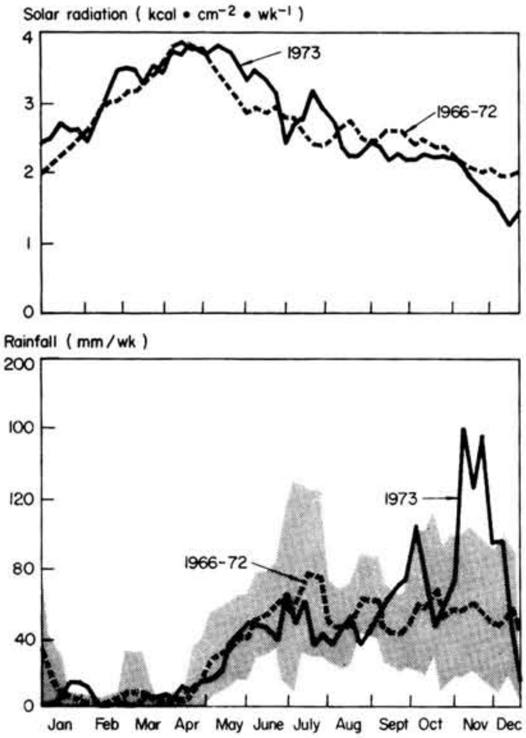
TRUSTEES Dr. Virgilio Barco of the International Bank for Reconstruction and Development, U.S.A., was appointed to the Board. Dr. Tosi Take Iida, director of the Institute for Plant Virus Research, Japan, replaced Dr. Noboru Yamada of the Ministry of Agriculture and Forestry, Japan, who had completed his term of appointment. Dr. N. C. Brady replaced Dr. R. W. Cummings, who resigned as institute director in November last year.

Crop weather

During 1973, 2,206 mm of rain fell, compared with the 7-year average of 1,981 mm. Most of the rain fell in October, November, and December while most of last year's rain fell in June, July, and August. Twice as much rain fell during October and December this year compared with the same months last year. On November 21, 236 mm of rain fell in a single day, the largest amount in 26 years. The rainfall was fairly uniform starting in August which helped both rainfed lowland and upland rice, which are entirely dependent on rain for moisture supply. There were more rainy days (0.25 mm and greater) during August and December this yea than the averages for the previous 7 years (se table). Long-duration rice varieties grown unde upland conditions at IRRI farm were helped b late rain. One late-maturing experimental lin produced 4.7 t/ha under upland rice cultur while several produced over 4 t/ha.

Table 1. Number of rainy days (0.25 mm or more). IRRI 1966-1972 (avg), 1972, and 1973.

Month	Rainy days (no.)		
	Avg 1966-72	1972	197:
January	13	14	9
February	6	4	6
March	7	7	7
April	5	9	6
May	16	18	9
June	20	18	16
July	24	31	19
August	20	21	24
September	22	22	23
October	18	15	22
November	19	24	21
December	18	11	23



Solar radiation and rainfall (three-point moving weekly average) at IRRI, 1973 and 1966-72. Shaded area shows the standard deviation of the 7-year average.

The high solar radiation in May and June thi year benefited the ripening period environmen of the dry-season crop. Because of high rainfal in September and October, solar radiation wa lower this year than last year. In December, ther was 4.0 kcal/sq cm less solar radiation than a year earlier and 2.5 kcal/sq cm less than th December average for the past 7 years. The lov sunlight in December was not harmful to most o the wet-season crop, except the very late-maturing crop.

Tropical depressions occurred on October 7, October 24, and November 19 this year. The tropical depression on October 7 caused severe damage to many wet-season crops which were maturing and to those close to harvest. Nevertheless, 1973 can be considered a year of few typhoons.

Chemistry

Nutritional studies in preschool children and with *Streptococcus zymogenes* indicated that high protein rice has better nutritional value than rice with average protein. In studies of indicators of grain protein content, nitrogen content and nitrate reductase activity of seedlings were not reliable. Plant selections from two higher lysine varieties were no higher in lysine content than the parents. ☐ A rapid, simple test, complementary to the amylose test, was developed based on consistency of a cold 4.4 percent milled-rice paste in 0.20 N KOH. Gel consistency values correlate with amylograph setback viscosity and measure the relative rate of retrogradation of the starch gel. Differences in gel consistency were found in samples of similar amylose content especially above 24 percent amylose. In a study of mutants differing in grain shape from the parent, amylose content and amylograph viscosity of the grains were similar to those of the parent. ☐ Parboiling caused a loss of thiamine and a diffusion of thiamine to the endosperm both of which depended on the severity of heat treatment. ☐ Waxy rice suitable for Philippine flattened parboiled rice and rice cake had low gelatinization temperature and lower gel consistency than poor quality waxy rices. Rice suitable for fermented nonwaxy rice cake had 24 to 26 percent amylose for adequate gas retention during fermentation and steaming, and for soft texture of the cake. ☐ Neutral oils extracted from bran-polish and milled rice with petroleum ether had similar fatty acid composition. Polar oils extracted with methanol/chloroform had higher linoleic acid content than neutral oils. ☐ Starch synthetase bound to the starch granule was solubilized with retention of activity by dispersion of amorphous starch in 75 percent dimethylsulfoxide with ultrasonic waves.

GRAIN PROTEIN

More than 21,000 rice samples from breeding and genetic studies were analyzed for Kjeldahl protein in 1973 as part of a cooperative program to raise the protein content of rice by 2 percentage points.

Protein quality. The microbiological quality of milled rice samples differing in protein content was assayed by O. Mickelsen and D. Makdani (Michigan State University, U.S.A.). The growth rate of *Streptococcus zymogenes* was used as indicator of protein quality with casein as the standard (100%). They found that microbiological quality corresponded well with chemical score based on lysine except for the high value for IR480-5-9 milled rice (Table 1). The correlation coefficient with microbiological quality was 0.86** for chemical score and −0.75* for protein content. The drop in microbiological value was only about 10 percent for an increase in protein content of over 100 percent.

Nitrogen balance studies in pre-school children were started with C. L. Intengan, Food and Nutrition Research Center, Manila. In earlier trials in which IR480-5-9 milled rice with 11.9 percent protein (N × 6.25) was used as the sole source of protein (mean intake of 314 mg N/kg body weight daily) for four children, nitrogen absorption was 75 percent of nitrogen intake and nitrogen retention was 37 percent of intake. But difficulty was encountered because some children needed more than three feedings a day to reach the required intake of nitrogen.

Table 1. Biological value of milled rices differing in protein content and chemical score of protein based on relative growth of *Streptococcus zymogenes* (O. Mickelsen and D. Makdani, Michigan State Univ., U.S.A.).

Sample	Protein (% N × 6.25)	Lysine (g/16 g N)	Chemical score[a] (%)	Micro-biological value[b] (%)
Intan	5.97	4.07	74	71.8
IR8	7.69	3.59	65	68.7
IR22	7.88	3.75	68	69.4
IR22	10.0	3.87	70	70.0
IR8	10.2	3.50	64	65.9
IR1103-15-8	11.6	3.65	66	70.0
IR480-5-9	11.8	3.34	61	68.4
BPI-76-1	15.2	3.19	58	63.4

[a]Based on 5.5 g lysine/16 g N (1973 pattern) as 100%. [b]Based on 100% for casein.

In this year's trials three milled rice samples with 7.7, 10.3, and 11.9 percent protein were used in a diet which had a constant rice-to-fish ratio of 100:17. The fish fillet (surgeon, *Acanthurus bleakeri*) had 20 percent protein and 10 percent lysine in its protein. Rice was fed at the daily rate of 10 g/kg body weight. Each diet was fed to each child for an adaptation period of 4 days, then for 6 days feces and urine were collected. Composite diets were also analyzed for amino acid composition. Each child was fed the low protein rice, and then either the high protein or the intermediate protein rice. Results so far indicate that diets with higher rice protein content had a lower chemical score (Table 2). Percentage nitrogen absorption and retention, however, were maintained so that higher protein content of rice gave a higher value for nitrogen balance. Nitrogen intake was probably inadequate in the lower protein rice diets and part of the protein was probably used for energy. The IR8 diet gave the widest range of nitrogen balance values.

High-lysine rice. We previously found that in two successive crops, the varieties ARC 10525 and Kolamba 540 had 0.5 percentage point higher lysine content of protein than IR8. In the 1973 dry season, brown rice from the best three single plant selections identified in 1972 from these varieties were screened for Kjeldahl protein and dye-binding capacity (lysine) and the best samples were analyzed for lysine by column chromatography. We found that the best samples still had lysine contents only 0.5 percentage point higher than that of IR8 and they were no higher than that of pooled sample. Because of the limited reproducibility of existing screening methods and the inherent variability in lysine content within a variety, attempts to breed high lysine varieties cannot be justified unless an increase of 1 percentage point is possible.

Milled rice protein of these two varieties also had higher lysine content than that of IR8 rice (Table 3). Extraction of milled rice protein with 5 percent sodium chloride solution and subsequent protein and lysine analysis of the fractions revealed that the cause of the higher lysine content of ARC 10525 protein was its higher level of salt-soluble protein (specifically globulin). Kolamba 540 tended to have a higher

Table 2. Mean chemical score and mean nitrogen balance of rice/fish diets (100:17 wt/wt) fed to pre-school children (C. L. Intengan, Food Nutr. Res. Center, Philippines).

Milled rice source	Rice protein (% N × 6.25)	Children[a] (no.)	Chemical score of diet[b] (%)	Daily nitrogen intake (mg/kg)	Nitrogen absorbed[c] (%)	Nitrogen retained[c] (%)	Daily nitrogen balance (mg/kg)
IR8	7.7	7	99	191	72	29	55
IR480-5-9	10.3	6	91	236	74	32	74
IR480-5-9	11.9	7	84	253	76	32	82
LSD[d] (5%)	—	—	5	17	n.s.	n.s.	21

[a]Five children partook of three diets. [b]Based on 5.5 g lysine in 1973 provisional amino acid pattern. [c]Compared with intake. [d]Based on the five children who partook of the three diets.

lysine content of salt-soluble and salt-insoluble (residual) protein than IR8. Disc electrophoresis showed no varietal differences in the protein bands of the soluble protein fractions of the three varieties.

GRAIN QUALITY

Gel consistency. A rapid, simple test, which is complementary to the test for amylose content, was developed based on the consistency of a cold 4.4 percent (dry basis) milled-rice paste in 0.20 N KOH. This test can be used to distinguish differences in the texture of cooked rice of nonwaxy varieties that have the same amylose content. To conduct the test, rice powder (100 mg at 12% moisture) is placed into 13 × 100 mm culture tubes and wetted with 0.2 ml 95 percent ethanol containing 0.025 percent thymol blue. The tube is shaken to suspend the starch, then 2 ml of 0.2 N KOH is added and the mixture is dispersed using a Vortex Genie cyclone mixer (setting of 6). The tubes are covered with glass marbles and placed for 8 minutes in a vigorously boiling water bath to reflux. The samples are removed from the water bath, set at room temperature for 5 minutes, and then cooled in an ice-water bath for 15 minutes. Consistency is measured by the length in a test tube of the cold gel held horizontally for 30 minutes or 1 hour over ruled paper graduated in millimeters (fig. 1). The coefficient of variability was 4 percent of the mean of duplicate runs. One hundred samples a day can readily be run in duplicate by one technician.

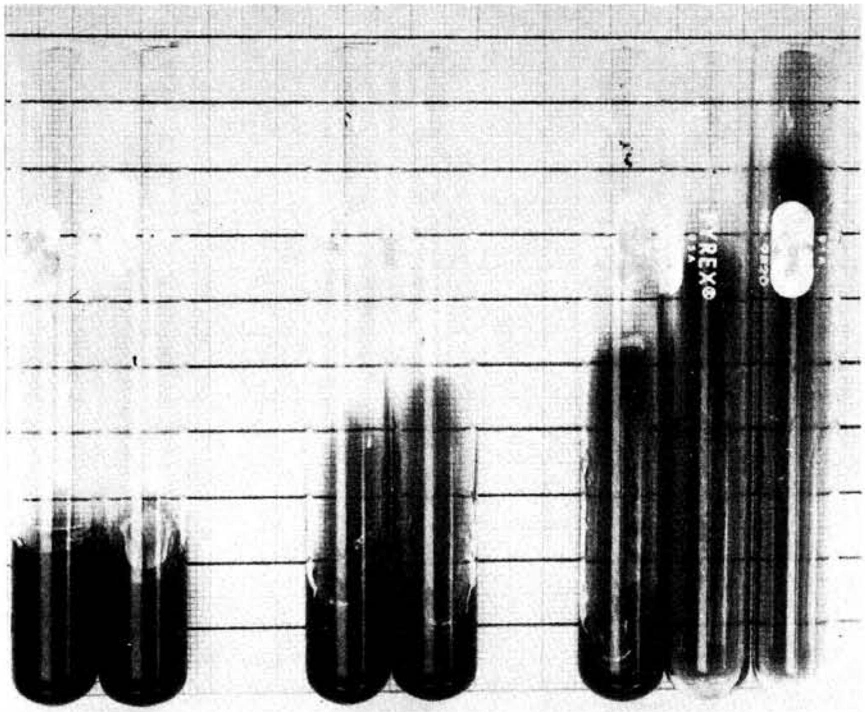
The consistency values are correlated with amylograph setback viscosity (fig. 2) and can differentiate three consistency types—high (26 to 35 mm), medium (36 to 50 mm), and low (51 to 100 mm). The test is especially useful for differentiating samples that have 24 to 30 percent amylose. For example, of 38 lines having 24 to 30 percent amylose with BPI-121-407 as parent (24 to 26% amylose and low gel consistency), nine had high consistency, 12 had medium consistency, and 17 had low consistency. Aging of raw rice has little effect on gel consistency. And, samples of the same variety differing in protein content by as much as 5 percentage points gave similar gel consistency values.

Consistent atypical gel consistency values were obtained in one out of four to six samples

Table 3. Lysine content of total protein and of two protein fractions of milled rice of two higher lysine rice varieties as compared with IR8.

Variety	Total protein		Albumin-globulin		Lysine content[a] of residual protein (g/16.8 g N)
	Of milled rice (%)	Lysine content[a] (g/16.8 g N)	Of total protein (%)	Lysine content[a] (g/16.8 g N)	
ARC 10525	9.6	3.92	13.9	4.40	3.78
Kolamba 540	8.2	4.06	11.8	4.72	3.86
IR8 (check)	7.0	3.63	10.7	4.51	3.45

[a]LSD (5%): 0.37 g/16.8 g N.



1. Typical 4.4% pastes of rice with high, medium, and low gel consistency.

of the same variety in three of the varieties tested. Samples of the same variety also differed widely in amylograph setback viscosity.

Resurvey of world rice. In the early 1960's we obtained rice samples from rice producing countries to check the amylose content of varieties. This year we resurveyed the amylose content of world rice after the introduction of the semidwarf rice varieties using the more accurate simplified assay for amylose developed in 1971. Amylose content can be classified as low (< 20%), intermediate (20 to 25%), moderately high (25 to 27%), and high (27 to 33%). Gel consistency values were also determined on these samples.

The amylose contents of the indica and japonica rices overlapped (Table 4). The highest amylose content for a japonica variety was 27 percent for Ponta Rubra from Portugal. Most japonica varieties, except those from Egypt, France, and Italy, gave low gel consistency ratings. Hence, amylose content differentiates varieties better than gel consistency for rices from Japan, South Korea, Bulgaria, Portugal, U.S.S.R., and U.S.A. Egyptian rice with poor eating quality (25% amylose) had high gel consistency. The French variety Arlesienne (24% amylose) also had high gel consistency. The Italian variety Raffaello (25% amylose) had medium gel consistency.

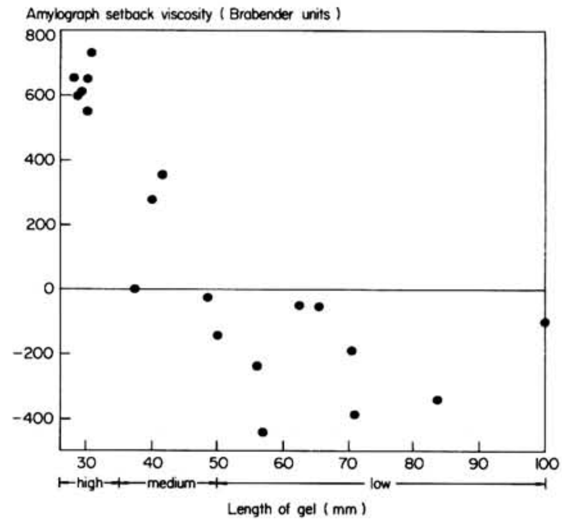
Among tropical rice varieties, low amylose rices of good eating quality such as Khao Dawk Mali 105 from Thailand and Chhuthana from Khmer had low gel consistency. Among tropical rices with an amylose content above 24 percent, most had a low gel consistency, even those with above 27 percent amylose. Four out of five market samples of fine-grain rice in Hongkong (28 to 30% amylose) had low gêl consistency and the fifth sample had high consistency. The new Indian variety IET 1991 and the premium South Vietnamese variety Tau Huong had low gel consistency. Both had high amylose content.

Among the IRRI varieties, the gel consistency of IR5 and IR24 was low; of IR26, low to medium; of IR20, medium; and of IR8 and IR22, high. The amylose content of IR24 was low; of IR20 and probably IR26, moderately high; and of IR5, IR8, and IR22, high. The dwarf varieties from Taiwan, which were the source of the dwarfing gene in IRRI varieties, all had high amylose and high gel consistency.

Among 16 Philippine rices with 26 to 32 percent amylose, consumer panels conducted by home technologists at University of the Philippines at Los Baños gave highest scores for cooked rices with low gel consistency, followed by those with medium consistency, and then those with high consistency. The check variety C4-63G (25% amylose) with a high preference score also had low gel consistency. The upland varieties Azucena, C22-51, Dinalaga, Mangarez, and Palawan were verified to have intermediate amylose content (23 to 25%). The prized aromatic variety Milagrosa had 24 percent amylose and had low gel consistency.

The results indicate the applicability of gel consistency in differentiating varieties of similar amylose contents above 24 percent amylose. In general, low gel consistency is preferred over medium or high consistency among these rices. A notable exception is Basmati-type rice which may give medium gel consistency.

Final gelatinization temperature was mainly low (<70°C) for japonica rice and either low or intermediate (70° to 74°C) for indica rice (Table 4). High gelatinization temperature (>74°C) was restricted to waxy and low amylose rices.



2. Relation of gel consistency (length of 4.4% milled-rice gel in 0.20 N KOH) to amylograph setback viscosity of 9% paste.

Mutants differing in grain shape. Workers in India have produced mutants of indica and japonica rices differing in grain shape which they reported to also vary markedly in quality and

Table 4. Ranges of amylose content, and gel consistency and gelatinization temperature types of milled rice obtained from rice-producing countries.

Country	Varieties tested (no.)	Amylose content range (% dry basis)	Gel consistency types[a]	Gelatinization temperature types[a]
		Asia		
Bangladesh	20	20-29	L > M > H	I > L
India (Hyderabad)	18	20-29	L > H > M	L > I
India (Maharashtra)	14	23-28	M > L > H	I > L
Japan	12	18-21	L	L
South Korea	10	21-24	L	L
Khmer	9	18-28	H > L	I > L
Nepal	16	23-27	L > M, H	L > I
Philippines	18	23-31	L > M, H	L > I
Thailand	12	16-28	L, M, H	L > I
South Vietnam	17	23-30	L	I
		Outside Asia		
Bulgaria	5	19-22	L	L
Egypt	9	19-25	L > H	L
France	8	20-24	L > H	L
Italy	10	19-25	L > M	L
Portugal	10	21-27	L	L
U.S.S.R.	7	19-22	L	L > H
U.S.A. short & medium	8	18-20	L	L
long	6	26-27	L	I

[a]L = low; M = medium; I = intermediate; H = high.

amylose content from the parent. These mutants were termed "indica" or "japonica" depending on the shape of their grain. Because of the poor correlation between amylose content and grain shape, we analyzed a crop of mutants of Tainan 3, TN1 (Taichung Native 1), and IR8 grown at IRRI. The three "indica" mutants of Tainan 3 had 12 to 17 percent amylose while Tainan 3 itself had 19 percent. The three "japonica" mutants of TN1 had 28 to 29 percent amylose while TN1 itself had 28 percent. Similarly IR8 had 29 percent amylose and its four fine-grain mutants had 28 to 30 percent amylose. The amylograph set-back viscosity of these mutants were similar to that of the parent sample. Hence, the amylose contents of the mutants were similar to those of the parent varieties, in spite of the change in grain shape so it is misleading to call them indica or japonica mutants.

Parboiling and nutrients of grain. Previous studies (1968) showed that parboiling causes little or no redistribution of protein in the rice grain. This year we studied whether water-soluble vitamins such as thiamine (vitamin B_1) diffuse into the endosperm during parboiling. Aside from laboratory samples, parboiled rice samples from U.S.A. and Sri Lanka were analyzed. We found that parboiling decreased the thiamine content of brown rice due to heat degradation (Table 5). The least degradation was shown by samples from hot-sand parboiling (a method developed by IRRI agricultural engineers) with a heating time of less than 0.5 minute. Parboiling for 10 minutes at 121°C caused greater loss of thiamine than parboiling for 20 minutes at 100°C.

Milled parboiled rice, however, contained more thiamine than milled raw rice at the same degree of milling (Table 5) because parboiling caused thiamine to diffuse inwardly. Both the degree of loss and the degree of diffusion depended on the severity of heat treatment. This inward diffusion was verified by thiamine assay of three successive outer milling fractions and of the residual grain of raw and parboiled IR22 rice.

The bran-polish of parboiled rice had a higher fat and protein content than bran-polish of raw rice at the same degree of milling (Table 5). The starchy endosperm of parboiled rice has a greater resistance to milling, hence the bran-polish and the germ were more completely removed. Milled parboiled rice, however, was not significantly lower in protein content than milled raw rice. The starch content of bran-polish from parboiled rice was lower than that of bran-polish from raw rice.

We verified that the degree of parboiling and percentage of parboiled grains are measured by a modified alkali test developed by Indian workers. Soaking milled rice for 1 hour in 1 percent KOH caused some disintegration in parboiled rice and no swelling in raw rice even for IR22 which has a low gelatinization temperature.

Flattened parboiled waxy rice. Five waxy rices from the 1972 wet season crop were studied for physicochemical properties and suitability for making *pinipig* (a Philippine flattened parboiled waxy rice). Storage of the *pinipig* for a few weeks amplified sample differences in stickiness of *pinipig* after hydration. The final gelatinization temperature of starch granules of Philippine waxy lines was either low (<70°C) or high (74.5°–79°C). *Pinipig* processors preferred Malagkit Sungsong because as hydrated *pinipig* it is more tacky or sticky than *pinipig* from other waxy rices even after storage (Table 6). Com-

Table 5. Effect of parboiling method on nutrient content and distribution in brown rice (at 14% moisture).

Treatment	Degree of milling (%)	Thiamine (μg/g)		Protein (%)		Bran-polish fat (%)
		Brown rice	Milled rice	Milled rice	Bran-polish	
		Laboratory method (hot soak) (IR20 and IR22)				
Raw (check)	11.6	3.80	0.58	9.0	13.4	16.6
Treated 100°C	11.1	3.60	0.95	8.7	13.6	17.4
Treated 121°C	12.0	3.17	2.94	8.6	15.0	19.8
		Heated-sand drying (IR20 and IRRI line)				
Raw (check)	10.5	3.72	0.56	8.2	13.6	16.8
Treated	10.2	3.61	1.80	7.8	13.8	18.4
LSD (5%)	0.8	0.39	0.55	0.9	0.5	2.7

pared with the four other rices it had higher alkali spreading values corresponding to a lower gelatinization temperature of starch granules. The amylopectins differed in molecular size, as indexed by sedimentation constant, and in mean chain length. Using a 9-percent neutral rice gel we found that increasing stiffness of the gel corresponded to a decrease in stickiness of hydrated *pinipig*. Malagkit Sungsong also had a higher level of hot-water soluble starch than the other samples.

Thus waxy rice suitable for *pinipig*-making has a low gelatinization temperature and a low gel consistency (of 9% paste). The relatively low molecular weight of amylopectin in the samples with low gelatinization temperature probably contributes to the stickier texture and softness of hydrated *pinipig*.

Waxy rice cake. Thirteen waxy lines from 1973 dry-season yield trials of the University of the Philippines at Los Baños were assessed for suitability for *suman* (a Philippine waxy rice cake) by home technologists at UPLB. Three parts milled rice were cooked with five parts coconut milk, then wrapped in banana leaves and steamed. A consumer panel gave higher scores to samples that had low gelatinization temperature than to those that had high gelatinization temperature, but the scores for the two types overlapped (Table 7). Measuring stickiness using a beam balance technique gave similar results. In previous tests freshly boiled waxy rice gave similar taste panel scores regardless of gelatinization temperature. But the softness of *suman* which had been stored at 4°C for several days clearly differentiated samples that had high gelatinization temperature from those with low gelatinization temperature, with the exception of IR833-6-2. Softness was determined by an improvised penetrometer. Waxy rice with low gelatinization temperature is preferred for the preparation of waxy rice cake because it has a slower rate of retrogradation or hardening of cooked rice as compared with rices with high gelatinization temperature. Values for hot-water-soluble starch (11.3 to 13.4% glucose) overlapped among the two gelatinization-temperature classes.

The behavior of the IR833-6-2 sample was anomalous because it was one of the better lines

Table 6. Physicochemical properties of waxy rices differing in the quality of hydrated stored *pinipig*.

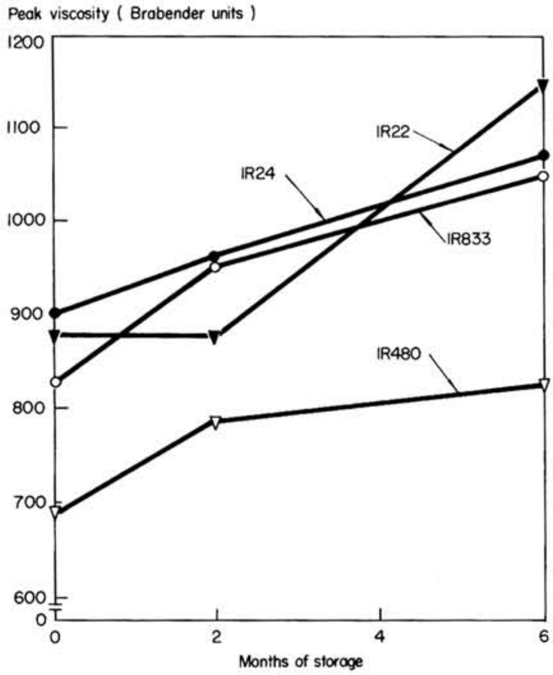
Variety or line	Stickiness of hydrated *pinipig* (g/g hydrated *pinipig*)	Milled rice: Alkali spreading value[a]	Milled rice: Gel consistency[b] (mm)	Starch: Final gel. temp. (°C)	Starch: Sedimentation constant[c], $S_{20,w}$ (S)
Malagkit Sungsong	336	6.0	68	61	82
IR833-6-2	192	5.0	54	65	66
IR833-34-1	125	5.0	56	67	58
IR253-16-1	120	5.0	45	70	58
Panpet 63	32	2.3	28	77	242
LSD (5%)	40	0.3	6	3	20

[a]Range: 1 = low, 7 = high. [b]Modified procedure using 200 mg rice powder (12% moisture) gelatinized with 1 ml 0.3 N KOH; gel is neutralized with 1 ml 0.3 N acetic acid. [c]0.5% solution in dimethylsulfoxide.

Table. 7. Properties of waxy lines differing in starch gelatinization temperature and in softness of cold rice cake.

Lines	Milled rice: Final gel. temp.	Milled rice: Alkali spreading value	Milled rice: Gel consistency[a] (mm)	Rice cake: Preference score[b]	Rice cake: Stickiness (g/cm²)	Rice cake: Softness index (mm)
Four lines	high	2.7 ± 0.20	37 ± 2.9	−2.1 ± 0.19	7.3 ± 0.16	0.6 ± 0.23
Seven lines	low	6.4 ± 0.17	64 ± 4.9	1.6 ± 0.24	5.7 ± 0.23	11.5 ± 0.47
IR833-6-2	low	6.4	60	−3.4	7.1	0.7
IR253-4 (check)	low	6.1	64	2.1	5.6	13.6
LSD[c] (5%)		0.3	9	0.6	0.3	0.7

[a]200 mg rice in 2 ml 0.15 N potassium acetate. [b]Total of 12 assessments per sample. 39 judges given four samples each with scores between 1.03 to −1.03 (Mrs. A. M. del Mundo, home technology dept., University of the Philippines at Los Baños). [c]Sample mean.



3. Effect of storage on amylograph peak viscosity of 9% starch paste of four rices differing in amylose content. IR833-6-2 milled rice is waxy, IR24 has 18% amylose, IR480-5-9 has 24% amylose, and IR22 has 29% amylose.

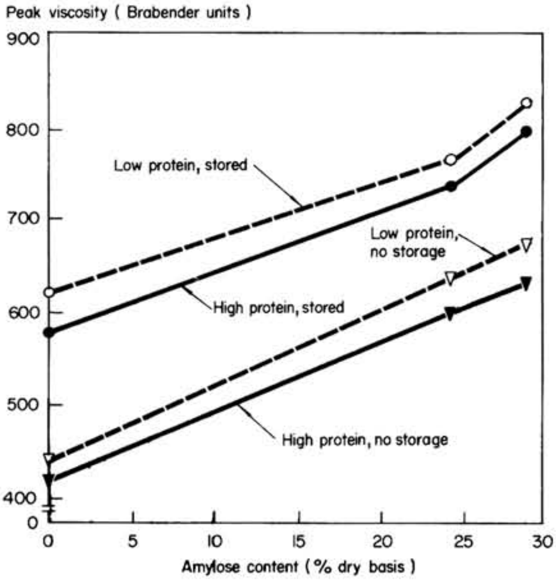
for *pinipig* preparation. But the low preference scores coincided with its poor stickiness index. With IR833-6-2 excluded ($n = 12$), the correlation coefficient with softness was 0.92** for alkali spreading and 0.92** for gel consistency. The corresponding values with IR833-6-2 included ($n = 13$) were 0.78** and 0.83**.

Fermented nonwaxy rice cake. Rice varieties suitable for making fermented nonwaxy rice cake (*puto*) produce dough which retains gas adequately during yeast fermentation and give steamed cake with good texture. C4-63G is the variety manufacturers prefer. Among 10 rices aged for a year prior to milling, gas retention during fermentation of the dough tended to decrease with increasing amylose content and was higher for waxy rice. In addition, relative viscosity of the dough using a pipette also was negatively correlated with amylose content, indicating cohesion between raw starch granules. Since rice dough, unlike wheat, has no gluten, gas retention during fermentation is probably due to cohesion of starch granules in the dough as affected by amylose content. The effect of protein content on these properties was not clear-cut.

During steaming, however, waxy and low amylose rices were not able to retain the entrapped gas (CO_2) while rice with 24 to 26 percent amylose (C4-63G, Intan, BPI-76-1) showed adequate gas retention resulting in good volume expansion. Intermediate amylose content also insured a soft texture for the steamed cake. These rices also had low gel consistency, except for IR20 which had medium gel consistency.

Mechanism of rice aging. Most studies on the changes rice undergoes during storage have been made with milled rice although rough rice and brown rice are known to undergo the same changes during storage. To obtain a general mechanism of rice aging, rough rice, milled rice, surface-defatted milled rice, and rice starch of four samples with 0, 19, 24, or 29 percent amylose from the 1972 dry season crop were stored at 4°C and 28°C for 6 months. Samples differing in protein content were also included.

In general, all samples showed similar changes regardless of the form of storage, amylose content, or protein content. Most notable was the increase in amylograph peak viscosity regardless of amylose and protein contents (fig. 3 and 4). Denaturation of the α-amylase of brown rice flour by acidification and subsequent neutralization did not result in an increase in amylograph peak viscosity of freshly harvested rice. Volume expansion and water uptake during cooking increased while dissolved solids decreased progressively, particularly in samples stored at 28°C. Hardness values (as indexed by percentage of powder coarser than 80 mesh after grinding 20 seconds in a Wig-L-Bug amalgamator) increased with aging. They were higher for the high protein sample of each rice. Free fatty acids were highest in milled rice stored at 28°C compared with defatted milled rice at 28°C and control samples at 4°C. No trend was found for *in vitro* digestibility of cooked rice with α-amylase, amylose, and protein content, and in the gelatinization temperature of starch. Stickiness measured by the beam balance technique showed no change in value for cooked waxy rice but showed significant decreases for the 19 and 24 percent amylose samples. The technique was



4. Effect of storage (for 6 months at 28°C ± 3°C) on the amylograph peak viscosity of low and high protein milled rice of three varieties.

not sensitive enough for flaky rice (29% amylose).

All the major fractions underwent changes during aging. The solubility of starch in hot water decreased. Since high protein samples and surface-defatted samples behaved similarly to milled rice, and since starch also showed similar amylograph changes to those in milled rice, the starch fraction probably contributed more to the changes during aging than protein and fat.

Composition of rice oils. Ten years ago we found that oil from milled rice has lower iodine value (is more saturated) and smaller amounts of essential fatty acids (mainly linoleic) than bran-polish oil. Since later studies elsewhere showed the opposite relationship using chloroform/methanol (2/1 vol/vol) instead of petroleum ether, we restudied, by gas chromatography, the fatty acid composition of oil extracted from bran-polish and milled rice of IR20 and IR22. Methyl esters were prepared by refluxing oil in methanolic HCl.

The fatty acid composition of oils extracted from bran-polish and milled rice with petroleum ether were similar and the ratios of oleic acid to linoleic acid were about 1.0 (Table 8). Milled rice oil extracted with methanol/chloroform, however, contained more linoleic acid and less oleic acid than oil extracted with petroleum ether. Thus, oil extracted by the polar solvent methanol/chloroform was more unsaturated than neutral oils extracted with petroleum ether.

SEED AND PLANT METABOLISM

Oxygen uptake, peroxidase, and grain dormancy. Studies last year indicated rice hulls have a high peroxidase activity and that dehulling increases germination of dormant grain. But oxygen uptake, measured by Warburg manometry, did not show a corresponding increase after dehulling. Changes in oxygen uptake, peroxidase activity, and dormancy were examined during the development of the grain (variety H4) in the 1973 wet season. Ripening grains were assayed with and without air-drying. We measured oxygen uptake by a polarographic assay with the Clark oxygen electrode on grains which had been soaked for 2 hours. Oxygen uptake of the

Table 8. Fatty acid composition of oils from bran-polish and milled rice of IR20 and IR22 extracted with petroleum ether or methanol/chloroform.

Fatty acid	Composition[a] (%)						LSD
	Bran-polish oil		Milled rice oil				
	pet. ether		pet. ether		methanol/chloroform		
	IR20	IR22	IR20	IR22	IR20	IR22	(5%)
Palmitic	0.4	0.3	0.7	0.3	1.4	0.9	0.2
Myristic	19.8	18.4	23.0	17.9	23.1	22.6	3.2
Stearic	1.6	1.4	1.7	2.1	1.4	1.6	n.s.
Oleic	38.5	40.7	37.8	38.1	27.0	28.5	2.3
Linoleic	37.4	36.5	34.6	38.3	46.1	45.2	2.1
Linolenic	2.3	2.7	2.2	3.3	1.0	1.2	n.s.

[a]Percent by weight. Trace palmitoleic acid present in bran-polish and milled rice oils; trace lauric acid found in milled rice oil only.

whole grain decreased progressively during ripening. The dehulled fresh grain (brown rice) had 4 to 29 times higher rates of oxygen uptake than the whole grain and dehulled air-dried grain had four to six times higher rates particularly during the first 2 weeks of grain development. Peak uptake for dehulled grain occurred about 10 days after flowering (623 nmol/h O_2).

Germination of dehulled air-dried developing grain was nil in the 4-day grain (i.e., 4 days after flowering), 45 percent in the 7-day grain, 67 percent in the 10-day grain, and 87 percent in the ripe grain. Fresh grain failed to germinate. Peroxidase activity was constant during the first 3 weeks of grain development (1.2 to 1.4 nmol purpurogallin $\cdot$ min^{-1} $\cdot$ $seed^{-1}$) but decreased during grain desiccation (to 0.22 nmol purpurogallin). The hull contributed from 80 to 90 percent of peroxidase activity of rough rice. The results are consistent with the reported viability and complete formation of the embryo 1 week after flowering.

A comparison of dormancy and O_2 uptake of ripe H4 seeds showed that the oxygen uptake of fresh rough rice (0% germination) was 8 nmol/h, that of air-dried rough rice (1.3% germination) was 12 nmol/h, that of fresh brown rice plus hull (78% germination) was 34 nmol/h, and that of air-dried dehulled rice plus hull (87% germination) was 53 nmol/h. Apparently the hulls of dormant grain are a barrier to oxygen uptake by the rice seed thus retarding germination. Oxygen uptake by nondormant rough or brown rice increased progressively during the first 6 hours of soaking.

Pricking brown rice at the distal end before soaking in water for 20 hours did not increase oxygen uptake (42 nmol/h), but pricking at the embryo end increased oxygen uptake to 56 nmol/h. No difference occurred in seeds soaked for 2 hours. Since pricking brown rice near the embryo results in complete germination, the aleurone layer and seedcoat, as well as the hull, reduce the oxygen uptake of the embryo. Thus the apparent dormancy of the rice grain is not seed dormancy, rather the covering structure of the nondormant embryo restricts oxygen diffusion, thus preventing germination.

Dry matter loss during grain soaking. Indian workers have reported that grains of the semi-dwarf varieties are less suitable for parboiling than grains of traditional rice varieties due to greater dry matter loss during soaking. In addition, the breakdown products act as substrate for microbial growth in the steeping water. Since the new varieties have weaker dormancy and different starch properties (particularly gelatinization temperature) than the traditional varieties, we studied the rate of release of free sugars and dry matter loss of varieties differing in gelatinization temperature, presence of white belly, and amylose content at different degrees of dormancy during soaking for 1 to 4 days in water at 30°C.

Dormancy and endosperm opacity contributed to differences in dry matter loss. Dormant samples released sugar in the soaking water more slowly. In addition because another contributing factor was their characteristic white belly, IR8 and IR5 rice gave higher free sugar formation after 1 day of soaking than a waxy rice sample. Presumably, the air spaces between starch granules in the white-belly portion of IR8 and IR5 allow faster dry matter loss than the air spaces in the starch granules of waxy rice. Nondormant IR22 grains with translucent endosperm and low gelatinization temperature had similar rates of dry matter loss to nondormant H4 with intermediate gelatinization temperature. That indicates that gelatinization temperature of starch is a minor factor in dry matter loss during soaking.

Enzyme changes during germination. We studied the endosperm enzymes, catalase and cellulase, for changes in germinating IR8 grain. Catalase levels increased progressively during germination in light and reached a maximum (15 times that of the mature grain) on the sixth day of germination. The changes followed a trend similar to those of peroxidase. Cellulase activity, measured by release of reducing sugars from carboxymethyl cellulose, showed a first peak on the third day of germination followed by a decrease during the fourth to the sixth day and an increase again in activity on the seventh day.

The sequence of production of phytase, lipase, and β-1,3-glucanase was studied in embryo-less IR8 seed halves incubated in 0.2 μM gibberellin A_3. In germinating IR8 grains, they are produced in the endosperm in the order: phytase, lipase, β-glucanase. In the embryo-less seed halves, phytase was produced first, followed by β-glucanase and lipase together. Lipase production was delayed and its activity was slower in this artificial medium. Phytase activity was lower but that of β-glucanase was higher. Delayed lipase production has been also reported in wheat seed halves. Glutamine and hydroxylamine (1 mM) which accelerated lipase production in wheat had no effect on rice lipase production. Production of β-glucanase coincided with production of α-amylase in the embryo-less seed halves in gibberellin A_3. Thus hydrolases in the rice aleurone layer were produced in sequence during germination and during incubation in gibberellin A_3.

RNase (ribonuclease) is a key enzyme of nucleic acid metabolism in developing and germinating grain. RNase I or cytoplasmic RNase is found in large amounts in developing and mature corn. In a study on RNase I in degermed IR480-5-9 grain, the highest activity was in a sample germinated 4 days in the dark ($46\ \Delta A_{260} \cdot 30\ min^{-1} \cdot grain^{-1}$), followed by developing grain at midmilky stage ($17\ \Delta A_{260} \cdot 30\ min^{-1} \cdot grain^{-1}$) and least in the mature grain ($3 \Delta A_{260} \cdot 30\ min^{-1} \cdot grain^{-1}$). Disc electrophoresis indicated the presence of one major fast-migrating, distinct, and very active RNase isozyme band in the endosperm of developing and germinating grain. The RNase isozyme was not distinct in the mature grain although a corresponding protein band was present in the extract. The major RNase band was identical in both germinating and developing grain: the band had the same width in a mixture of the two extracts. Two minor, slower migrating RNase bands were present in the developing grain but absent in the other samples.

Lipase production in bran. The foregoing results on rice seed halves incubated in gibberellin A_3 indicated a delayed production of lipase compared with the germinating seed. Since fat hydrolysis by lipase is the major reason for the poor keeping quality of rice bran, the nature of lipase production in rice bran was examined. Preliminary studies indicated that the aleurone layer produced free fatty acids at least three times faster than the germ fraction. The cells of the aleurone layer were probably more damaged during milling than those of the germ.

Starch synthetase of grain. Starch synthetase is the key enzyme involved in converting nucleotide glucose derivatives into amylose. It is present mainly in a form bound to the starch granule in nonwaxy rice, but a soluble fraction is also found in developing rice grains. Previous attempts to make the bound synthetase soluble had limited success.

In cooperation with Dr. E. J. del Rosario of University of the Philippines at Los Baños chemistry department, we isolated starch granules from developing IR8 grains at the midmilky stage and purified them by repeated washing with water, and then with 0.1 M phosphate buffer (pH 7.2) containing 0.006 M magnesium chloride. The washed starch had 2.0 percent protein. The granules were made amorphous by placing 200-mg lots in a Wig-L-Bug amalgamator for 30 seconds. The granules were dispersed using ultrasonic vibration at 20 kHz for 1 hour in 0.05 M HEPES (pH 7.5) containing 75 percent dimethylsulfoxide and 0.001 M dithiothreitol, and then centrifuged. About half of the residual protein of the starch granules was dispersed by this treatment and it had a specific activity for starch synthetase essentially the same as that of the washed granules. In the precipitate collected by trichloroacetic acid addition to the protein extract, the ratio of carbohydrate to protein was 5.5.

In a discontinuous sucrose-density-gradient centrifugation of the solubilized enzyme, two opaque bands were present between 35 and 45 percent sucrose and between 45 and 55 percent sucrose. The lighter band corresponded to peaks in protein content and starch synthetase activity in the absence of added glycogen primer. This band was also the fraction with highest amylose-iodine blue color. The heavier protein band had no synthetase activity even in the presence of primer. The results indicate that the lighter enzyme fraction is tightly complexed with amylose which functions as primer for the synthetase assay.

Disc electrophoresis of the solubilized enzyme had three bands which stained for both protein and carbohydrate. Two other faint bands were obtained. The band of slowest mobility showed the most intense staining.

Seedling test for grain protein content. In studies elsewhere on corn and wheat, the highest activity of nitrate reductase occurred in 1-week-old seedlings and correlated with grain protein content. Since our previous studies with 2.5-week-old seedlings showed no relationship between grain protein and seedling protein levels, we studied this relationship in younger seedlings grown in Hoagland's solution containing 40 ppm of either ammonium or nitrate nitrogen. Low and high protein seeds of IR8 and IR480-5-9 were used. We found greater differences and higher nitrogen levels in 1-week-old seedlings than in 2-week-old ones. The total protein of the active leaf (topmost fully expanded leaf) was higher in IR480-5-9 than in IR8 due to a heavier leaf and a somewhat higher protein level. The difference in protein level and weight of total tops was not significant. The high protein samples of the two rices tended to have lower dry matter production. Better foliage growth occurred in the ammonium medium than in nitrate, and leaf protein levels were higher. Levels of leaf nitrate reductase and root glutamate dehydrogenase were not related to grain protein content.

Repetition of the screening using 21 promising high protein lines did not reveal a trend between foliar nitrogen and grain nitrogen. Hence seedling vigor was not simply related to grain protein content and the trend found for IR8 and IR480-5-9 was due mainly to lower weight of the active leaf and tops of IR8.

We also found that 1-propanol (5%) gave higher values than two commercial surfactants as wetting agent in the *in vivo* assay for nitrate reductase in segments of rice leaf blades.

Effect of herbicides on seedlings. Two weeks after flooded soil in which 2.5-week-old IR22 seedlings were growing was treated with 0.075 ppm simetryne or 0.15 ppm benzomarc, the leaves of the plants had higher total dry matter but the same nitrogen level as leaves of the untreated control. In addition, levels of chlorophyll and free amino acids were higher in leaves of the treated plants. The glutamate dehydrogenase activity was lower in roots of treated plants due to the lower level of soluble protein since specific glutamate dehydrogenase activity was at least as high as in control plants.

Leaf proteins. A study was made of the protease and fraction I protein of rice leaf blades. Protease was extracted from active (second) leaf blades with 0.1 M phosphate buffer (pH 7) with 5 mM glutathione. Its activity was highest in the protein fraction that precipitates from solution between 60 to 80 percent saturation with ammonium sulfate. Optimum pH was 7.0. Disc electrophoresis of the fraction indicated that protease corresponds to protein bands of intermediate to high mobilities. No difference in electrophoretic pattern was noted in the protein isolated from plants at maximum tillering, panicle initiation, and booting stages.

Fraction I protein constitutes 45 to 50 percent of the soluble chloroplastic protein of vascular plants. It contains the central enzyme in photosynthetic CO_2 fixation of the rice plant—ribulose 1,5-diphosphate (RuDP) carboxylase. Workers elsewhere have been able to crystallize fraction I protein from tobacco leaves by dialysis against water. We tried such a procedure on IR20 leaf blades. Ammonium sulfate fractionation showed that the fraction precipitating between 20 to 40 percent saturation with ammonium sulfate had 56 percent higher RuDP carboxylase activity than the crude extract. Disc electrophoresis showed that fraction I protein contains two major bands. Loss of RuDP carboxylase activity of fraction I protein after freeze-drying the fresh leaf blades was associated with the loss of the slower migrating band. Storage of the crude extract for more than 4 days at −20°C also caused this slower migrating band to precipitate.

The ammonium sulfate fraction was desalted in Sephadex G-25, concentrated by treatment with polyethylene glycol, and induced to crystallize by dialysis against dilute buffer. No crystals formed from fraction I protein of rice indicating that it is albumin-like, in contrast with fraction I protein of tobacco which is globulin-like and hence becomes insoluble and crystallizes out as salt concentration decreases slowly during dialysis.

Resistance to brown planthopper. Studies with IRRI entomologists on the isolation of a chemical factor in rice plants for resistance to the brown planthopper (*Nilaparvata lugens*) were continued. Attempts to air-dry plants on large scale caused a large decrease in recovery of the factor compared with extraction from fresh tissues. Methanol (50%) extracts of Mudgo × IR8 plants continued to show higher activity on brown planthoppers than extracts of IR8. Hot extraction gave higher recoveries than cold extraction, but the difference in activity between IR8 and Mudgo × IR8 extracts was reduced.

Hopperburn. Further studies were made with IRRI entomologists on the changes in leaf blades and sheaths which occur during brown planthopper infestation, using Taichung Native 1 seedlings. In experiments using nondestructive methods, the moisture content of the active leaf blade dropped from 76 percent to 62 percent during 5 days infestation, as measured by the β-gauging method. The amount of honeydew collected daily from the feeding insects and its content of sugars and amino acids were variable. Total amino acid, particularly proline level, was higher in leaf blades of infested plants than in leave blades of control plants. Nondestructive methods—β-gauging, leaf diffusive resistance, and leaf temperature—were less sensitive than chemical measures such as proline content for indicating stress in the plants. Leaf blades of rice plants subjected to water stress by IRRI agronomists have also shown higher proline content.

Multiple cropping

The cropping systems program is using the resource utilization approach to develop more efficient and productive cropping patterns for the Southeast Asian rice farmer. Using this model, "small farm" technology has been studied to find possible clues as to how technology may be directed toward the small farmer. Traditional intercropping systems with corn using mung bean, soybeans, sweet potatoes, peanuts, or upland rice were 30 to 60 percent more productive with good management and up to 100 percent more productive as various factors became limiting. □ Studies on plant interrelationships showed that the balance of saturated systems depended on plant populations, while productivity was affected by level of management and crop arrangement. Traditional intercropping patterns have a more efficient light utilization pattern and some have a higher efficiency of utilization of applied nitrogen. This aspect may be of use in maximizing returns from fertilizer. Insect relationships in traditional patterns continued to show a high level of natural stability. This stability can be maintained in intensive patterns with careful use of insecticides, but can be lost, and the problems even aggravated if insecticides are not used at the proper times and in the right amounts. □ Weed research centered around the management of weed communities to avoid shifting toward difficult-to-control grasses and sedges with intensified cropping. The control of crop leaf area index coupled with proper management techniques has potential for this control. □ Comparisons of power sources showed that hand labor, small tractor, and carabao were similar from an economic standpoint. The biggest differences were in the speed of accomplishing the work. Hand or animal power had a lower potential for increased cropping intensity because of this time factor. Efficiency of energy production did not vary widely between sources. The energy value of cash inputs was three times that of the actual power source.

CROPPING SYSTEMS PROGRAM

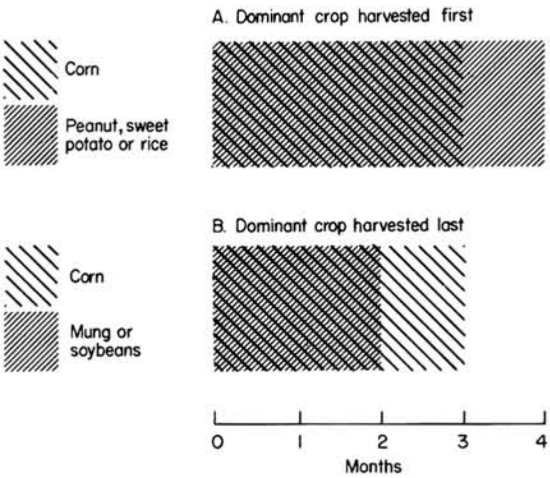
We are developing improved and intensified cropping patterns to increase the welfare of rice farmers in Southeast Asia. Cropping systems technology is being organized to use farmers' resources more efficiently in meeting this goal. Multiple cropping—growing more than one crop on the same piece of land in 1 year—is the most common method.

A small, or "disadvantaged," or "poor" farmer, typified by the average Asian rice farmer, sells only a small share of what he produces because his land holding is too small, because he lacks other production resources, or because he lacks technology, or, more often, a combination of the three may apply.

We are striving to develop technologies adapted to specific farm types, which are grouped by the degree to which a farmer participates in a market economy as well as by his physical resources.

LESSONS FROM TRADITIONAL TECHNOLOGY

In the process of developing cropping systems technology for the "small" farmer we examine his current cropping practices to see if clues can be found as to how his lot may be improved. The Javanese small farmer serves as our model. We find him using labor-intensive methods to grow several field crops in various combinations, both with natural rainfall and with irrigation, in a low cash-input situation. The widespread use of these practices by small farmers (throughout the tropics) leads us to wonder about their efficiency in meeting their needs. The often-used practice of intercropping has been chosen for study under our resource utilization model. Its biological as well as resource-use characteristics have been evaluated.



1. Common types of intercropping patterns.

Types of intercropping. We have investigated two types of annual-crop intercropping patterns. The first, which is most widely used by farmers, includes a tall-growing (dominant) crop and a shorter statured secondary crop. The dominant crop is harvested first. The second configuration also has a dominant and a secondary crop, with the secondary crop being harvested either at the same time as the dominant crop or earlier (fig. 1).

Productivity. Total productivity is a basic consideration in evaluating crop combinations. Based on yields from several replicated trials, crop combination can increase land productivity from 30 percent to 60 percent over monoculture cropping (Table 1). The land equivalent ratio (LER) is the total land required using monoculture to give total production of the same crops equal to that of 1 hectare of intercrop. It is calculated by determining the ratio of the yield of a crop in a mixture to its yield in monoculture under the same management (weeds, fertility, etc.) level. The optimum monoculture population is used for comparison. The ratios of all crops in the mixture are then added to give the land equivalent. For example in a corn-soybean intercrop (Table 2), corn yielded 5.28 t/ha and the soybeans yielded 0.85 t/ha. The monoculture yields (at optimum populations, but at the same management level) were 5.52 t/ha for corn and 2.33 t/ha for soybeans. The ratios of intercrop yields to monoculture yields were 0.96 for corn and 0.36 for soybeans. The sum is 1.32. Total productivity is thus 32 percent higher, and the land equivalent is 1.32 hectares.

These results indicate that during the dry season under irrigation, intercropping (alternate-row planting) is usually more productive than monoculture.

Wet season (rainfed) trials in a farmer's field showed similar results from corn-rice inter-

Table 1. Land equivalent ratio (LER) under good management for five crop combinations with corn (95-day maturity). IRRI, 1973 dry season.

Crop	Maturity (days)	LER
Dry soybeans[a]	90	1.3
Green soybeans[a]	65	1.6
Mung bean[b]	60	1.5
Sweet potato[b]	120	1.5
Peanut[b]	110	1.6

[a]From a single management level, four replications. [b]Avg of four levels of weed management, three nitrogen levels, and eight corn populations and row spacings.

Table 2. Effect of intercropping field corn[a] in soybeans.[b] IRRI, 1973 dry season.

Crop combination	Grain yield[c] (t/ha)		
	Corn	Soybean	LER
Soybean alone	—	2.33	—
Field corn alone	5.52	—	—
Soybean + field corn[d]	5.28	0.85	1.32

[a]Variety Thai Early Composite (87-day maturity). [b]Variety Multivar 80 (85-day maturity). [c]Means of four replications. [d]1-m spacing.

cropping (Tables 3 and 4). IRRI trials of intercropping patterns have thus shown that under Los Baños conditions, with highly productive improved varieties having approximately the same growth duration as farmer's varieties, intercropping makes better use of a farmer's land resources. A higher return on cash inputs may even be possible (Table 5).

Plant spacing and time of planting. The timing of the overlap period and the crop configuration (row spacing, population) are important to the success of these patterns. In our trials, both crops in the combinations were planted at the same time. With corn-mung, the mung reaches the flowering stage (30 to 35 days after planting) before being shaded by corn. The yield reduction in the mung (as compared with monoculture) is usually about 50 percent if nothing hinders the mung growth relative to that of corn. If mung is planted after corn it will not yield well because of its sensitivity to shading in the seedling stage. Since mung usually covers the ground rapidly it would not be effective to plant corn later because the corn is equally sensitive to shading in the seedling stage.

The total productivity of corn-mung when planted together is rather independent of the corn population. We have plotted corn and mung yields as a fraction of their monoculture checks (at the same management level) for several levels of weed control and fertility in figure 2. Points on a curve represent differences in corn populations only. As corn population increases, its yield increases and the mung yield decreases in a linear fashion (as shown by the high *r* values). The diagonal lines labeled with percentage figures show the relative increase in productivity over the monoculture check (lines of equal LER). At 270 kg/ha of nitrogen and with weed control (1.5 kg/ha a.i. of butachlor) the advantage of intercropping remained 20 to 30 percent above monoculture. Only with no weed control

Table 3. Yield and gross returns from upland rice-corn intercropping. Farmer's field, Laguna, Philippines, 1973 wet season.

Crop	Yield[a] (t/ha)	Value (P/ha)
Corn (Thai Early Composite)	4.3	4300
Rice (IR442-2-58)	3.9	3100
Corn and	4.0	
rice	2.2	5800
Corn (Penjalinan)	1.7	1710
Rice (IR442-2-58)	3.8	3055
Corn and	1.4	
rice	3.4	4134

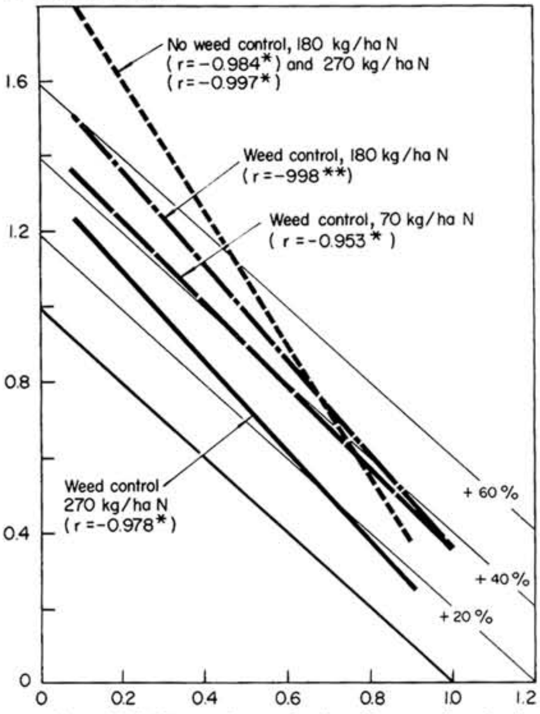
[a]At the best management level.

Table 4. Corn (Early Thai Composite, 85-day maturity) and rice (IR442-2-58, 120-day maturity) intercropped at varying levels of nitrogen. Farmer's field, Laguna, 1973 wet season (avg of four replications).

Crop	Yield (t/ha)		Total value (P/ha)[a]
	Rice	Corn	
	60 kg/ha N		
Corn	—	3.9	3900
Rice	4.2	—	3300
Rice and corn	1.5	2.9	4100
	120 kg/ha N		
Corn	—	4.0	4000
Rice	4.4	—	3500
Rice and corn	2.2	2.8	4600
	180 kg/ha N		
Corn	—	4.3	4300
Rice	3.9	—	3100
Rice and corn	2.2	4.0	5800
	240 kg/ha N		
Corn	—	4.4	4400
Rice	3.0	—	2400
Rice and corn	2.0	3.4	4900

[a]P804/t of rice, P1000/t of corn.

Corn yield in intercropping as a fraction of its monoculture check



Mung yield in intercropping as a fraction of its monoculture check

2. Relations between the yields of corn and mung in an intercrop combination as a result of different corn row spacings and populations at three levels of nitrogen and two levels of weed control. IRRI, 1973 dry season.

and high nitrogen levels was there a marked increase in productivity with increasing corn population. Although the relative advantage of intercropping is greater under low management than it is at high management (100% vs. 30 to 40%) the actual productivity may be lower (Table 6).

Table 5. Peso return per peso of added nitrogen in corn-rice intercropping. Farmer's field, Laguna, 1973 wet season (avg of four replications).

Nitrogen increment (kg/ha)	Return (P / P added nitrogen)		
	Rice alone	Corn alone	Intercrop
60–120	2.2	1.1	5.6
120–180	–4.4	3.3	13.3
180–240	–7.8	1.1	–10.0

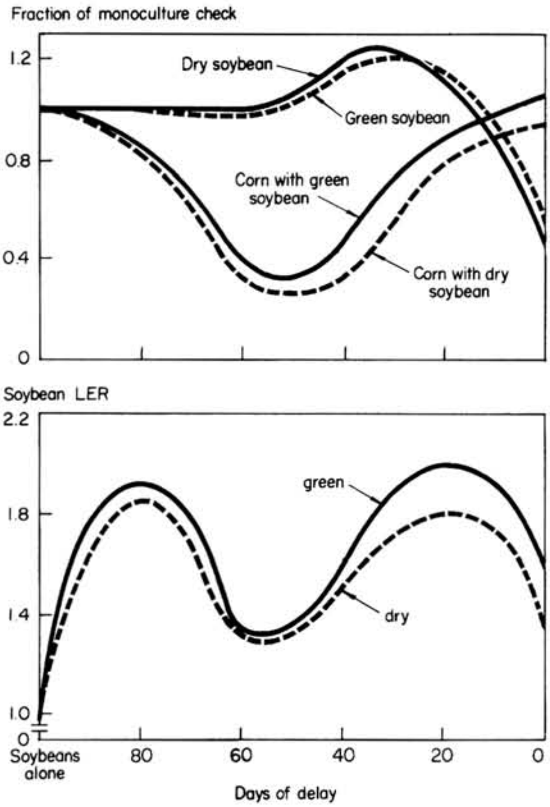
The normal crop configuration used by farmers, when mixing crops, is to plant a solid stand (as in monoculture) of the low-statured "minor" crop and then introduce the major crop at varying populations and row spacings. We have followed this practice in the intercrops of corn with mung, soybean, peanut, sweet potato, or rice. Although the time of planting should be the same for corn and mung, with corn-soybean, the soybeans start more slowly and a delay in the planting of corn seems beneficial (fig. 3). When DMR-2 corn was planted 20 days after soybeans (Shih Shih) and the soybeans were harvested as a green vegetable, the productivity of the combination was 102 percent higher than that of either crop alone and 80 percent higher when harvested dry as shown by LER values of 2.02 and 1.8 respectively (fig. 3). The 20-day delay allowed the soybeans to get a start before being shaded by the faster growing corn.

Physiology of intercropping. When the growing and reproductive stages of both crops coincide, as with combinations such as corn-mung and corn-soybeans, and when the populations of both crops are high, the relationship between the yields of the two crops is linear at a nearly constant level of productivity for a given man-

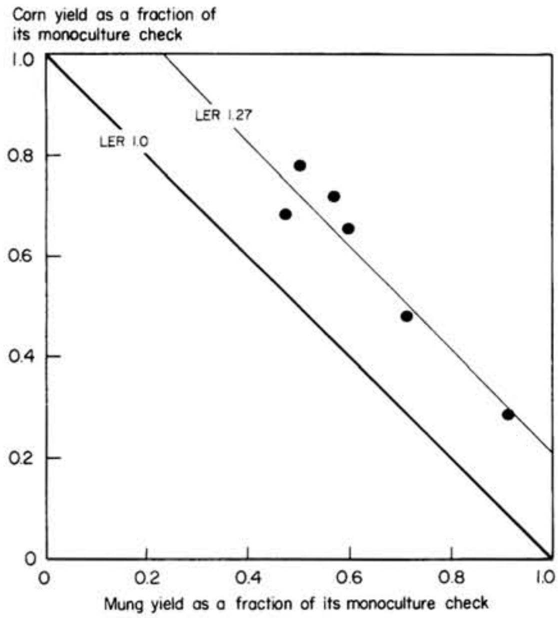
Table 6. Return per hectare for corn-mung intercropping averaged over corn-plant populations (after deducting the cost of nitrogen). IRRI, 1973 dry season.

Crop[a]	Return[b] (P/ha)					
	70 kg/ha N		180 kg/ha N		270 kg/ha N	
	No weeding	Weed control[c]	No weeding	Weed control	No weeding	Weed control
Corn alone	920	2280	1730	2130	2050	3510
Mung alone	2490	2530	1980	2590	2190	2870
Best intercrop combination	3580	3420	3490	3580	4220	4530
Mean of all intercrop combinations	2860	3280	2980	3500	3470	3930

[a]Corn variety, DMR2 (97-day maturity). Mung variety MG50-10A (65-day maturity). [b]Corn = P0.79/kg. Mung = P2.25/kg. [c]Butachlor at 1.5 kg/ha a.i.



3. Effect of time of delay of corn planting in corn-soybean intercrop. IRRI, 1973 dry season.



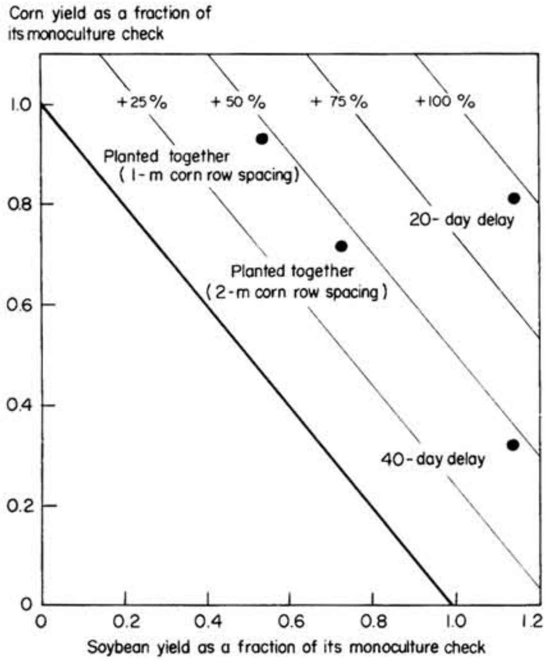
4. Relations between yields of sweet corn and mung in intercrop combinations under different corn populations (with mung population remaining constant). IRRI, 1973 dry season.

agement level. In other words, productivity is maximized at that level of light, water, nutrients, and other resources in the experiment for that given crop combination. Sweet corn-mung at high fertility with complete weed control illustrates the principle. As the corn population is changed, the relationship between corn and mung yield is linear at a productivity level 27 percent above that of the monoculture checks (fig. 4). A static and an "unsaturated" productivity are both illustrated by the corn-soybean interrelationship (fig. 5). When planted at the same time, the productivity was 40 percent above monoculture. Corn was favored at 1-meter row spacing of the corn; the balance shifted towards soybeans at the 2-meter row spacing with productivity remaining constant. A 20-day delay in corn planting resulted in a new relationship with an 80-percent increase in productivity.

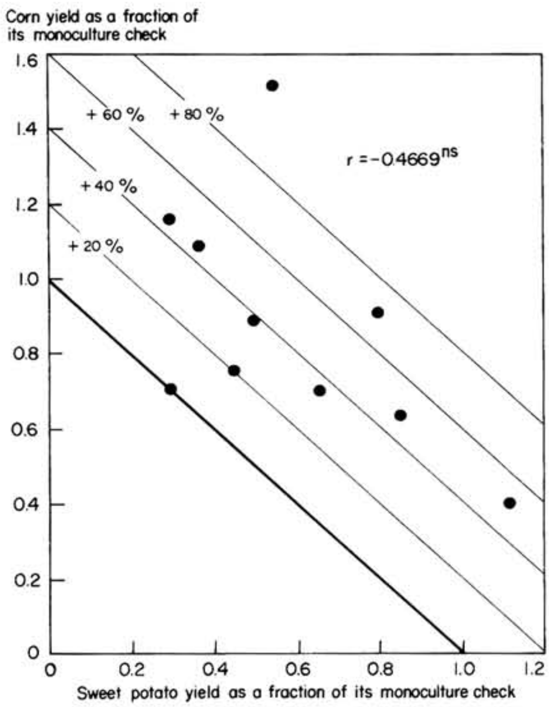
The relationships do not seem to hold as closely when the growing periods have less overlap, as with corn-sweet potato (fig. 6).

The corn-rice system is of particular interest because of its widespread use. Two experiments were conducted to study its crop-interrelationship effects. The Indonesian corn variety Penjalinan (70-day maturity to dry corn) was used with IR442-2-58 rice. These varieties fit the usual maturity pattern for this combination in farmer's fields. The two crops are planted together and the corn is mature just before the rice flowers. The rice is not appreciably shaded by the corn until about the maximum tillering stage so the period of maximum competition occurs during the time when rice is least sensitive to shading.

In the first experiment the area in rice was 43 percent, 71 percent, or 100 percent (solid planting of rice with corn added in addition) with each of three corn populations and two row spacings. At most corn populations and row spacings, a larger rice area increased total productivity without a corresponding decrease in corn yield (fig. 7). This indicated that the system was not saturated (at its maximum total productivity



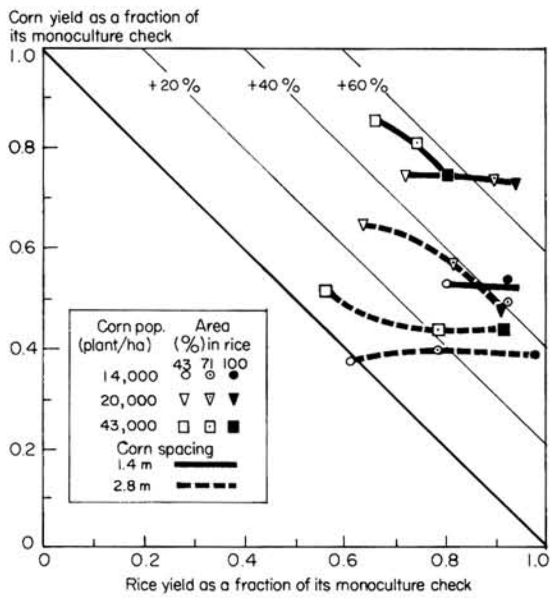
5. Effect of intercropping corn and soybeans with different length of delays in corn planting after soybeans were planted. IRRI, 1973 dry season.



6. Effect of corn population and management level on the productivity of corn-sweet potato intercrop. IRRI, 1973 dry season.

level) except at the 43,000-corn population at 1.4-m row spacing. The absolute productivity at saturation obviously depends on the productive capacity of the varieties. Table 3 shows the yield range for Penjalinan in rice as compared with that of Thai Early Composite. The total productivity of the two different combinations was about the same but was arrived at in different ways. The productivity of Penjalinan was low, but the rice compensated for it. This short-statured corn variety detracted little from the rice yield; every kilogram of corn yield was a bonus. With Thai Composite the rice yield decreased more but the corn was higher yielding.

In another experiment the area in corn and in rice was 50 percent each. This proportion was too little to approach saturation for the mixture. The planting arrangements were 15 rows of rice alternating with 3 rows of corn, 9 rows rice with 2 rows corn, 5 rows rice with 1 row corn, or 2 rows rice with 1 row corn (in this arrangement the corn was at equidistant spacing). The objective was to test the hypothesis that the advantage of intercropping (in a compatible combination) is derived from achieving maximum contact between species. In our experiment the contact between species was maximized with equidistant

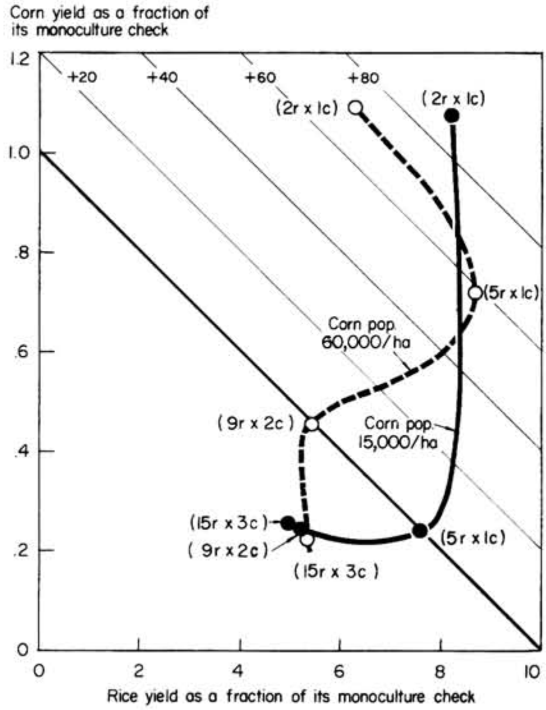


7. Effect of corn population, row spacing, and proportion of the area in rice on intercrop productivity. IRRI, 1973 wet season.

Table 7. Effect of row arrangement on the gross return from corn-rice intercropping with each crop occupying 50 percent of the area. IRRI, 1973 wet season.

Crop	Row arrangement	Return[a] (₱/ha)	
		Corn population (plants/ha)	
		15,000	60,000
Corn alone	Solid stand	710	1400
Rice alone	Solid stand	2380	2380
Corn-rice			
3 × 3[b,c]	15 rice × 3 corn	1560	1580
2 × 2[c]	9 rice × 2 corn	1540	1940
1 × 1[c]	5 rice × 1 corn	2160	3080
$\frac{1}{2} \times \frac{1}{2}$[d]	2 rice × 1 corn	3590	3160

[a]Corn at ₱1.00/kg. Rice at ₱0.80/kg. [b]Three beds of rice alternated with three beds of corn. [c]1.4-m row spacing for corn. [d]0.7-m rows for corn.



8. Effect of row arrangement on productivity of corn-rice intercrop with each crop planted to 50% of the area (r = rows of rice, c = rows of corn). IRRI, 1973 wet season.

corn spacing (two rows of rice with one row of corn) at the low corn population.

Productivity increased with increasing contact between the corn and rice (fig. 8). The 80-percent gain in productivity when half of the area was covered with rice, and corn was planted at 15,000 plants/ha (when compared with solid corn at 60,000 plants/ha and a full stand of rice) was surprising. It is evident that in corn-rice, the timing of the overlap of these varieties seems to be optimum, but we did not expect that the increasing contact between species would show such dramatic results. The gross return from these yields confirms the trend (Table 7).

Light interception. At least part of the differences in performance between monoculture and intercropping can be explained by differences in light interception. Intercropped combinations usually have a higher total light interception (Table 8) as well as a more efficient pattern over the entire season. They thus appear to make better use of light resources.

Weed response. Light interception also partially explains the differences in weed response

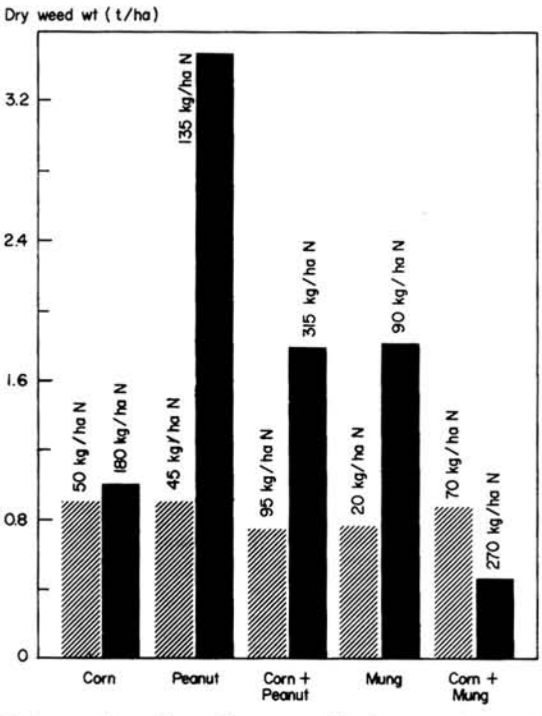
Table 8. Light transmission of various crop canopies. IRRI, 1973 dry season.

Crop	Corn population (10³ plants/ha)	Corn-row spacing (m)	Transmitted light[a] (%)				
			Above lower canopy		Ground level		
			44 DS[b]	63 DS	30 DS	44 DS	63 DS
Corn	40	1	—	—	52	32	26
Corn	20	2	—	—	77	57	45
Peanut	—	—	—	—	60	21	9
Mung	—	—	—	—	49	12	23
Sweet potato	—	—	—	—	66	45	9
Peanut-corn	40	1	32	30	35	11	4
Peanut-corn	20	2	61	45	37	8	5
Mung-corn	40	1	38	22	28	6	8
Mung-corn	20	2	60	49	36	10	15
Sweet potato-corn	40	1	40	21	34	17	18
Sweet potato-corn	20	2	53	48	36	11	5

[a]Calculated from a weighted mean of several sampling points across the rows at ground level integrated over a 24-hour period. [b]Days after seeding.

seen in intercrop plantings. Mung bean by itself is less responsive to weed control than corn alone (Table 9). The corn-mung intercrop has little response to weed control because the mung suppresses the weeds, and the total productivity is higher. The ability of mung to compete with weeds, however, depends both on the growing conditions and the type of weeds. Wet weather and low light intensities reduce early mung growth and favor growth of weeds. In the dry season with high light intensities and a predominance of annual grasses and sedges which are shade-sensitive, the effect of mung on weeds is dramatic. This plant-weed competition, however, is markedly influenced not only by the type of crops in the combination, but by fertility level.

The actual weed response interaction with crop and nitrogen level is shown in figure 9. Weed yields did not increase significantly under corn as nitrogen level increased. The increase with mung was slight, but peanut failed to suppress weeds at high fertility levels. Within crop combinations a higher population still lowers weed growth (Table 10). The interactions of crop combination with nitrogen level are also important for weed control (fig. 10). Gross returns are always higher from intercrop combinations but the returns from weed control depend both on the population of corn and the nitrogen level.



9. Interaction effects of crop combination, weed control, and fertilizer level on weed weight. IRRI, 1973 dry season.

Table 9. Gross returns for corn, mung, and corn-mung intercrop averaged over corn populations and nitrogen levels. IRRI, 1973 dry season.

Crop	Gross return (P/ha)		Increase (%)
	No weed control	Weed control[c]	
Corn[a] alone	1300	2450	88
Mung[b] alone	2480	2930	18
Corn and mung	3370	3920	16

[a] P0.79/kg. [b] P2.25/kg. [c] Butachlor at 1.5 kg/ha a.i.

Corn borer infestation normally begins with egg-laying moths which select fields by, perhaps, the sight and smell of host plants. To examine the effect of visual stimuli, we placed brown or green burlap between rows in corn plots. We found that the moths preferred corn plots with green inter-row cover less than those with brown inter-row

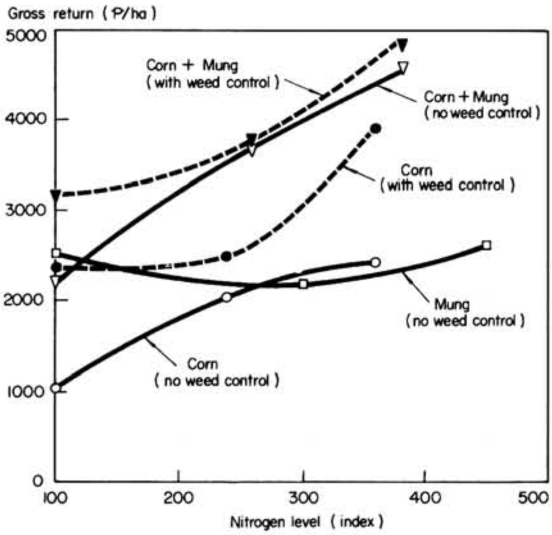
Traditional crop combinations thus have definite weed competition properties, partly resulting from their light interception patterns.

Crop combinations and insect interactions. Earlier IRRI findings that the traditional intercropping of peanut with corn decreased corn borer infestation have led to more detailed studies to determine the nature of the effect and its possible use in modern intensive systems on small farms. Three aspects of the borer's population performance were examined: adult oviposition behavior, larval feeding and establishment on corn, its principal host plant, and effects and interactions of predation by spiders (*Lycosa* spp.) and insecticidal treatments.

Table 10. The effect of corn population and spacing on weed growth for different intercrop combinations at intermediate nitrogen. IRRI, 1973 dry season.

Corn population (10^3 plants/ha)	Corn row spacing (m)	Dry weed wt (t/ha) in Mung + corn	Sweet potato[a] + corn	Peanut[b] + corn
10	1	1.3	—	1.8
60	1	0.8	0.6	0.5
10	2	0.5	1.6	1.5
20	2	0.3	0.7	1.0

[a] Sweet potato alone, 1.8 t/ha of weeds. [b] Peanut alone, 2.7 t/ha of weeds.



10. Nitrogen response of corn, mung and their intercrop at two levels of weed control (Nitrogen index: for corn, 50 kg/ha N = 100; for mung, 20 kg/ha N = 100; for corn + mung, 70 kg/ha N = 100). IRRI, 1973 dry season.

cover (Table 11). When peanuts were planted between the corn rows with and without green burlap, the corn plots with both peanuts and green burlap had lower infestations than the corn plots with only peanut, suggesting that the moths responded to olfactory cues as well as visual cues. The effects, however, diminished as the plants grew older perhaps because of the increasing spread of the corn canopy.

The survival and establishment of young, first-instar larvae which were artificially introduced on the plants were not influenced by the peanut intercrop. That is, substances from peanut in amounts toxic to feeding corn borer larvae on corn are not evidently involved.

A preliminary survey in our experimental corn fields revealed at least 19 kinds of spiders. Two species of wolf spiders (*Lycosa* spp.) were the most active and the most frequently observed preying on various insect pests, including young corn borer larvae. Trapping showed that wolf spiders from neighboring fields move more frequently towards corn plots with a peanut intercrop than to plots without the intercrop (Table 12). Within the corn field, however, the spiders moved from one plot to the other at more or less equal frequencies.

To assess the effects of spider predation and its interaction with the effects of peanut intercropping, borer infestation was compared among plots in which spider predation was minimized by a spider barrier (20-cm-high plastic wall) and parathion sprays at planting and 1 week later, or encouraged by allowing free spider movement and not treating the field with insecticides. We found that spider predation con-

Table 11. Influence of green and brown visual cues on oviposition preference of the corn borer (based on examination of 50 plant samples, avg of two replications). IRRI, June-September, 1973.

Color of inter-row burlap cover	Borer egg masses on corn (no./100 plants)		Decrease (%)
	Corn alone	Corn with peanut	
29 days after seeding			
None	13	6	54
Brown	14	5	64
Brown and green strips	11	6	45
Green	8	6	25
35 days after seeding			
None	16	2	88
Brown	46	21	54
Brown and green strips	27	22	19
Green	27	19	30
42 days after seeding			
None	58	26	55
Brown	44	38	14
Brown and green strips	49	43	12
Green	46	42	10
52 days after seeding			
None	42	42	0
Brown	38	30	21
Brown and green strips	50	51	0
Green	51	45	12

Table 12. Comparison of spider (*Lycosa spp.*) influx and preference for solid corn stand or corn-peanut intercrop. IRRI, June-September, 1973.

Spider movement	Spiders[a] (no.)	
	Corn alone	Corn with peanut
39-43 days after seeding		
From neighboring fields (influx)[b]	30	32
Within field (preference)[c]	33	32
45-51 days after seeding		
From neighboring fields (influx)[b]	35	58
Within field (preference)[c]	30	30
52-58 days after seeding		
From neighboring fields (influx)[b]	34	48
Within field (preference)[c]	28	26

[a]Avg of four plots, each 12 × 24 m. [b]Catches of 20 traps set at both ends of corn rows. [c]Catches of 20 traps set between corn alone and corn-peanut plots.

Table 13. Effects of peanut intercropping and spider predation on corn borer infestation. IRRI, 1973 wet season.

Borer stage and damage	Borer infestation[a] (no./100 plants) Without peanut intercrop	With peanut intercrop	Decrease (%)
Spider predation minimized			
Egg masses[a]	21	16	21
Larvae-pupae-pupal cases[b]	69	50	27
Pupal cases only[b]	53	36	33
Tunnels in stalk[b]	115	109	6
Spider predation encouraged			
Egg masses	10	7	23
Larvae-pupae-pupal cases	80	49	39
Pupal cases only	58	28	52
Tunnels in stalk	115	89	22

[a]Average of eight replications: egg mass data based on examination of 120 to 160 plants per replication at 28 days after seeding. [b]From dissection of portion of stalk below ear of 30 sample plants per replication at harvest (88 days after seeding).

tributed to the decreased borer infestation (Table 13). Thus the beneficial effect of the peanut intercrop was enhanced by encouraging the activities of predatory spiders. On the other hand, the regular use of the broad-spectrum insecticide, azinphosmethyl, diminished these benefits; even the use of the more selective biological insecticide, *Bacillus thuringiensis*, was detrimental but not as much as the nonselective insecticide (Table 14). Evidently, to maintain and encourage beneficial effects of intercropping on insects as management levels are increased, considerable planning and judicious insecticide treatments are required. Proper timing and placement of insecticides seem to be the more feasible approaches. Results of our studies indicate that one spray treatment with Orthene (O-S-dimethyl N-acetyl phosphoramido-thioate), a broad-spectrum insecticide, at 35 to 45 days after seeding had little or no detrimental effects, while one insecticide application at 30 days after seeding with or without additional treatments later markedly diminished, if not completely nullified, these benefits (Table 15).

Table 14. Influence of insecticide treatments and spider predation on decrease in corn borer infestation from corn-peanut intercropping. IRRI, 1973 wet season.

Treatment	Change due to peanut intercropping[a] (%) Adult oviposition[b]	Survival: Late instar[c]	Survival: Early instar[d]
Azinphosmethyl[e]	−10	− 9	−12
B. thuringiensis[f]	−42	−13	−18
No insecticide	−51	−26	−32

[a]From paired comparison of plots, 12 m × 24 m each, of corn alone and corn-peanut intercrop; corn population, 40,000/ha. [b]Egg masses counted at 28, 35, and 40 days after seeding. [c]Feeding lesions on whorl leaves counted at 28, 35, and 40 days after seeding. [d]Feeding holes on stalks counted at 48, 55, and 62 days after seeding. [e]0.05% a.i. solution. [f]Dipel applied 22, 23, and 38 days after seeding.

Economic implications. Our data on the economic returns from intercropping have come from preliminary trials on the IRRI station. Initial results indicate that the relative profitability of monoculture and intercropping depend on the management level or on the general growing conditions. With a high level of management and good growing conditions, monoculture seems to give better returns above variable costs (Table 16). Return per hectare per day is about the same, but return per unit of labor is higher with monoculture. At lower management levels, or where heavy rains or wet soil conditions restrict crop growth, intercropping appears superior for total return above variable costs, return above variable cost per hectare per day, and return per unit of cash expense. It is about the same as monoculture in return per unit of labor. The amount of labor used is higher in intercropping. It seems likely, based on very limited data, that intercropping may best fit in land-limiting, labor-surplus situations. It also may be far more productive under situations where management is less than optimum for monoculture.

Table 15. Influence of time of insecticide application (Orthene at 0.05% a.i.) on the effect of corn-peanut intercropping on corn borer infestation. IRRI, 1973 wet season.

Date of spraying: 29 DS[a]	36 DS	44 DS	50 DS	Change in larval feeding holes in stalk due to peanut intercropping[b] (%)
√	—	—	—	24
—	√	—	—	−22
—	—	√	—	−36
—	—	—	√	−17
—	√	—	√	−19
√	—	√	—	25
√	√	√	√	6
—	—	—	—	−25

[a]Days after seeding. [b]From paired comparison of plots, 5 × 6 m each, of solid corn stand and corn-peanut intercrop, mean of readings at 50, 57, and 72 days after seeding.

Table 16. Return over variable costs for monoculture and intercropping under high (H) and low (L) pest and water management levels. IRRI, 1973 dry season.

Crop	Return over variable cost (P/ha)							
	Total		Per day		Per man-day		Per peso of cash expense	
	H	L	H	L	H	L	H	L
Dry corn	3340	2340	34	24	110	82	4.40	2.40
Mung	1440	840	19	11	17	12	1.50	0.90
Peanut	3500	1000	32	9	58	21	3.20	0.90
Sweet potato	4530	3390	38	24	49	38	4.70	3.50
Avg	3200	1890	31	17	58	38	3.40	1.90
Peanut and dry corn	3510	3870	32	35	63	67	2.70	2.90
Peanut and green corn	4330	3750	36	31	39	35	5.10	4.40
Mung and green corn	370	1310	5	19	9	15	0.30	1.00
Sweet potato and green corn	4590	3340	42	30	75	56	3.40	2.50
Sweet potato and dry corn	2950	5440	25	45	28	47	3.40	6.30
Avg	3150	3530	28	32	43	38	3.00	3.40

VARIETAL TESTING OF COMPONENT CROPS

Mung bean. During the year, 476 mung lines from India and from the U.S. world collection were added to our collection, bringing the total to more than 600. The best 12 lines from two seasons of testing were compared in solid stands and also interplanted in corn (Table 17). The Philippine varieties MG50-10A and CES 55 continued to yield well in solid stands as well as when interplanted in corn. Interplanting did not change the time to flowering, but caused the plants to grow taller, to have heavier infestation of leaf disease, to have fewer pods, and to become senescent earlier (Table 18). Seed size was reduced only slightly. The interplant trials were grown with 40,000 plants/ha of Early Thai Composite corn at a high fertility level, shifting the balance in favor of corn. Data from other trials indicate that a decreased corn population would not change overall productivity but would shift the balance in favor of mung. Testing mung varieties under a corn population that would allow mung to yield 50 to 60 percent of that in a pure stand would probably show varietal differences better than the 37-percent average that was achieved for the 18 varieties we tested (Table 18).

Soybean. Of the soybean varieties previously tested, Multivar 80 continued to yield well (Table 19). Two new breeding lines from the University of the Philippines at Los Baños (UPLB) College of Agriculture, CES 16-103 and CES 16-23, were high yielding but susceptible to disease. CES 16-103 has an excellent plant type with a stiff, erect stem. Thirty vegetable soybean types were introduced from soybean breeding stations in Japan. Several were early and yielded well. The lines have high protein and low oil content and should have less viability problems in the tropics than the types with higher oil levels from temperate areas. Most of them are early maturing and short statured. Economic data show that stiff-stemmed, short-statured types can be harvested as a green vegetable by cutting the top leaves and the stem at ground level and marketing the whole stem for an extremely high

Table 17. Highest yielding mung bean varieties. IRRI, 1973.

Variety	Yield[a] (no corn) (t/ha)	Relative yield when planted in corn (%)
CES 28	1.70	28
MG50-10A	1.60	36
M 350	1.59	24
CES 55	1.58	37
M 198	1.56	33
MD 15-2	1.55	26
S-8 (yellow)	1.53	24
MG50-10A (yellow)	1.41	42
M 304	1.39	41
M 79	1.37	40
M 205	1.29	43
M 157	1.24	41

[a]Mean yields from two seasons of replicated trials.

Table 18. Response of 18 mung bean varieties to intercropping in corn. IRRI, 1973 dry season.

Character	Mung alone	With corn
Yield (t/ha)	1.5	0.6
Time to flowering (days)	31.1	31.2
Maturity (days)	63.4	55.8
Height (cm)	65.2	72.4
Pods (no./plant)	11.6	5.0
1000-seed wt (g)	53.5	49.2
Cercospora and rust[a]	3.8	4.5
Lodging[b]	2.4	2.4

[a]1 = slight, 5 = severe. [b]1 = little, 5 = heavy.

return. Protein production per day as well as per unit of labor is high.

Cowpea. Two groups of cowpea accessions were tested. Of 18 breeding lines and accessions from UPLB several appeared promising (Table 20). From 143 lines received from the Asian Vegetable Research and Development Center in Taiwan, 13 appeared to have promise. The lines were tested in an early rainy season planting when light intensity was low, tending to make the varieties viny and indeterminate. That perhaps explains why few of these lines looked good. Cowpea is the crop in our systems with the greatest need for varietal improvement. The lack of determinate growth habit and susceptibility to virus and soil-borne disease limit its usefulness in intensive systems.

Sweet potato. In trials of sweet potato varieties, BNAS 51 was consistently superior under both wet and dry conditions. In a time-of-harvest trial, BNAS 51 yielded far better than Centennial at all harvest times (fig. 11). The nitrogen level necessary for high yield seems critical. Nitrogen levels above 100 kg/ha reduced yield of tubers even with intercropping. The required fertility management of sweet potato intercrop combinations thus appears to be quite different from that of corn-rice or other combinations.

Corn. The key corn varieties we use are Thai Early Composite and DMR-2, a 97-day maturity variety from the Philippines. Thai Composite developed black layer in 85 to 87 days. Its yield potential is 6.5 to 7.0 t/ha in the dry season and 4.0 to 4.5 t/ha in the wet season under Los Baños conditions. DMR-2 is resistant to downy mildew, but is later and has a lower yield potential. Three Indonesian varieties, Pakelo, Binongko, and Penjalinan, were introduced and increased. Penjalinan appeared to be the most promising. It matures in around 70 days, producing 3 t/ha in the dry season and about 2 t/ha in the wet. Its only use appears to be in intercrop combinations, but it is questionable whether the 10-day shorter growing period compensates for the lower yield when compared with Thai Early Composite. It fits better the growth cycle of rice in intercropping than does Thai Early Composite.

Table 19. Highest yielding soybean introductions. IRRI, 1973 dry season.

Variety	Yield[a] (t/ha)	Maturity (days)	Plant ht (cm)	Pods (no./plant)	Rust rating[b]
CES 16-103	2.94	80	51	34	3.8
Kuro-daizu[c]	2.94	109	120	71	4.0
Multivar 80	2.89	84	84	28	3.0
CES 16-23	2.70	90	108	44	2.2
Higo-daizu	2.39	70	46	30	1.0
Shiro-daizu[c]	2.30	98	114	48	4.0
Hsih Hsih	2.31	73	39	30	1.0
Ao-daizu	2.22	90	36	24	3.0
Kimusume	2.20	69	48	28	1.0
Shiro-hadaka	2.19	64	46	28	1.0
Clark 63	2.14	92	103	48	2.0
Aa-2002	2.10	72	38	25	2.0
Higo-musume	2.09	69	38	29	1.0
Iyo-daizu	2.04	74	34	37	3.0
Gin-daizu	1.99	82	47	31	3.0
Ibaragi	1.95	70	34	23	1.0
Tainung 3	1.92	84	66	39	2.8
Fuji	1.90	68	42	27	1.5
Hachigatzu-daizu	1.85	80	42	23	2.5
Kailua	1.80	83	84	30	3.0
E.G. Special	1.68	78	70	29	4.0
TK5	1.58	80	66	41	3.5

[a]LSD (5%): 0.24. [b]1 = slight, 5 = severe. [c]Suitable for late planting.

CROP MANAGEMENT TECHNIQUES

Ridge-and-furrow rice growing. A final year of testing of the ridge-and-furrow method of growing rice strengthened the notion that it has little application on the heavy Maahas clay soil of the IRRI farm during the wet season. Early in the 1972 wet season, we began to prepare the soil in an upland condition with broad furrows separated by narrow ridges at 1-meter spacing. On September 7 after several aborted attempts at land preparation, weed control, seeding, and reseeding, a uniform stand of rice was finally established. During July and August, each time after the fields had been prepared and the rice

Table 20. Growth characteristics and disease rating of the top cowpea accessions. IRRI, 1973 wet season.

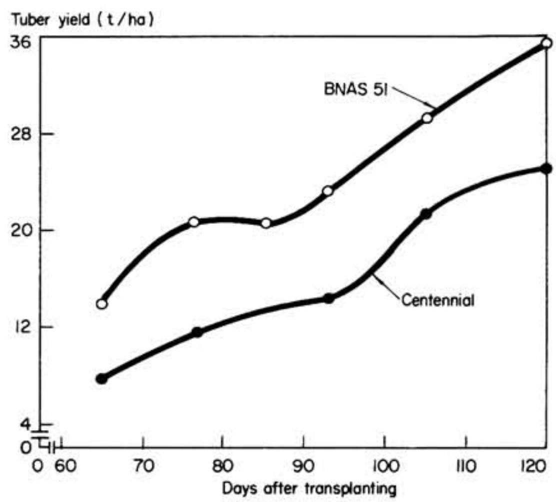
Accession	Growth character[a]	Disease rating[b]		Plant ht (cm)	Days to maturity[c]	Erect or creeper[d]
		Mosaic virus	Wilt			
Mecan pea	SD	1	1	200	75	SC
Red cowpea 6-1	D	2	1	65	71	E
Cowpea #18	D	2	2	59	68	E
Red cowpea #6-14	SD	1	2	110	66	E
Cowpea #16	D	2	2	63	65	E
Red cowpea 6-12 W	D	1	2	80	69	E
Virginia 67-3	D	2	2	70	71	E
Cowpea #15	D	1	2	60	69	E
Cowpea #23	D	1	1	62	76	E
Cowpea #21	D	2	2	51	66	E
Cowpea #14	D	1	2	63	72	E
Virginia crowder	D	2	3	59	70	E
Cowpea #33	D	2	3	60	72	E
Red cowpea	SD	3	2	136	71	SC
Cowpea #32	D	3	3	54	71	E
Red cowpea 6-12G	D	3	2	52	69	E
Cowpea #22	D	2	2	555	71	E

[a]SD = semi-determinate; D = determinate. [b]1 = no visible infection; 4 = heavily infected. [c]Days from seeding to last harvest of dry seeds. [d]E = erect; SC = semi-creeper.

sown, the dry spell was broken by a heavy rain which restricted rice emergence because of waterlogged soil and a thinly puddled surface layer. To have the precision of land preparation required in this method it should be done with irrigation before the rains start. The narrow range of soil moisture that allows good workability of Maahas clay limits the time when it can be prepared once the rains start. On a lighter, better drained soil the method may be feasible either with irrigation in the dry season or at the start of the monsoon.

In the trial, rice responded to nitrogen only up to 100 kg/ha levels. There was a response to seeding rate up to 90 kg/ha but only at nitrogen levels below 100 kg/ha. Both IR8 and IR20 showed similar responses.

In a second trial, planted at the end of the rains in November, the feasibility of using the same ridge-and-furrow system, but puddling the furrows, was tried in the hope that this might add stability to the system during rainy periods. Here, again, however, the problems of soil and water management and weed control were extensive. Weed control and management after planting were complicated by having both upland and lowland conditions in the same field. IR20 was direct-seeded in all treatments, with three different seeding methods on puddled furrows and the standard three-row planting on the "upland" type of ridge and furrow. Vegetables (cabbage and Chinese mustard) were planted on the ridges in a portion of each plot. Rice yielded better in the puddled furrows (Table 21). The higher yield with vegetables is a result of higher nitrogen levels in these treatments. Considerably more water was required to maintain standing water in the puddled treatments as compared with maintaining the upland area at close to field capacity by flushing with water every 3 to 4 days. At higher nitrogen levels, however,



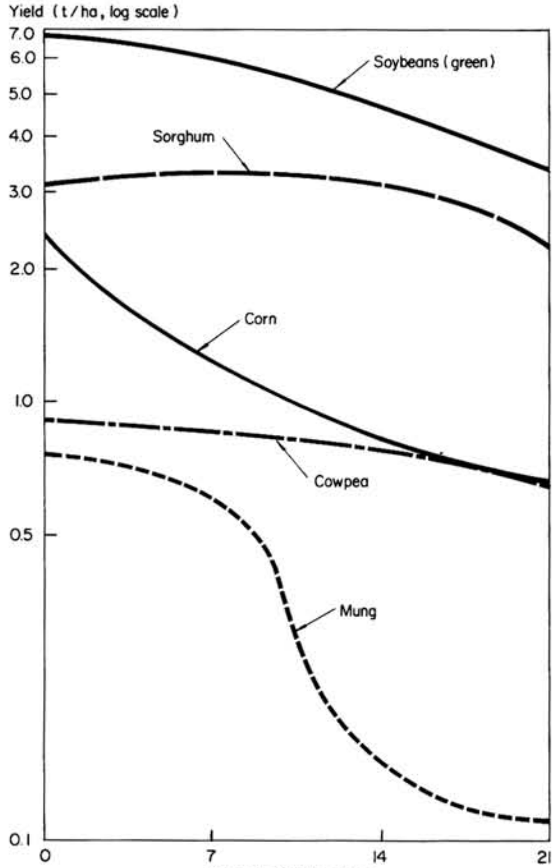
11. Growth rates for the two best yielding sweet potato varieties.

Table 21. The effect of seedbed preparation and seeding method on rice yield and water-use efficiency. IRRI, 1972-73 wet and dry seasons.

Planting method	Rice yield (t/ha)		Total water use (mm)	Water-use efficiency (mm/kg of rice)	
	Alone	With vegetables		Rice alone	Rice + vegetables
Puddled furrows, rice broadcast	4.66	6.51	1890	0.41	0.29
Puddled furrows, 3 rows rice	3.94	5.56	1890	.48	.34
Puddled furrows, 4 rows rice	4.04	5.50	1890	.47	.34
Upland ridge and furrow 3 rows rice	2.78	3.31	1020	.37	.31

water-use efficiency was greatest in the puddled treatments. On heavy, low-lying, poorly drained soil, management difficulties and high risk preclude the use of complex management systems. The more simple and straightforward the method the greater the long-term payoff.

Relay cropping after rice. In intensive cultivation systems in Taiwan, relay planting of upland crops with rice at the end of the rice-growing season is common. We tested crops relayed into IR8 rice at different times before harvest to compare their relative tolerance to shading during early growth stages. Mung bean had little tolerance to shading past the first week (fig. 12). Soybeans and cowpea showed more gradual reduction in yield with increasing time of overlap. Corn was especially sensitive to shading but sorghum was relatively tolerant for 14 days. Sweet potato showed little effect of overlapping. Rice yields were not affected. The rice canopy was completely closed over the narrow ridges (of the ridge-and-furrow system). This together with the low light intensities of the late rainy season heightened the competitive effect of overlap on the crops that followed rice.



12. Quadratic relationships between yields of different crops and number of days of overlap with rice. IRRI, 1972 wet season.

Effect of puddling on crops after rice. To test the Taiwan method of building "Poa" ridges in puddled rice for following crops, we compared this method following puddled rice with crops grown on nonpuddled soil following upland rice. The building of ridges in puddled soil before rice harvest required 450 to 512 man-hours/ha depending on the method used. These ridges had to be cultivated after the rice was harvested. The nonpuddled plots required 13 h/ha of hand-tractor use to prepare the seedbed. It was fortunate that a dry period in early October permitted this land preparation. Yields of corn, sorghum, soybeans, and mung were not statistically different between puddled and nonpuddled soils (Table 22).

AGRONOMIC AND ECONOMIC FACTORS

Crop residue problems. To reduce the cash outlay for nitrogen in intensive cropping systems as well as to conserve a commodity which will become increasingly scarce and more costly in the future, we are attempting to use grain legumes more frequently.

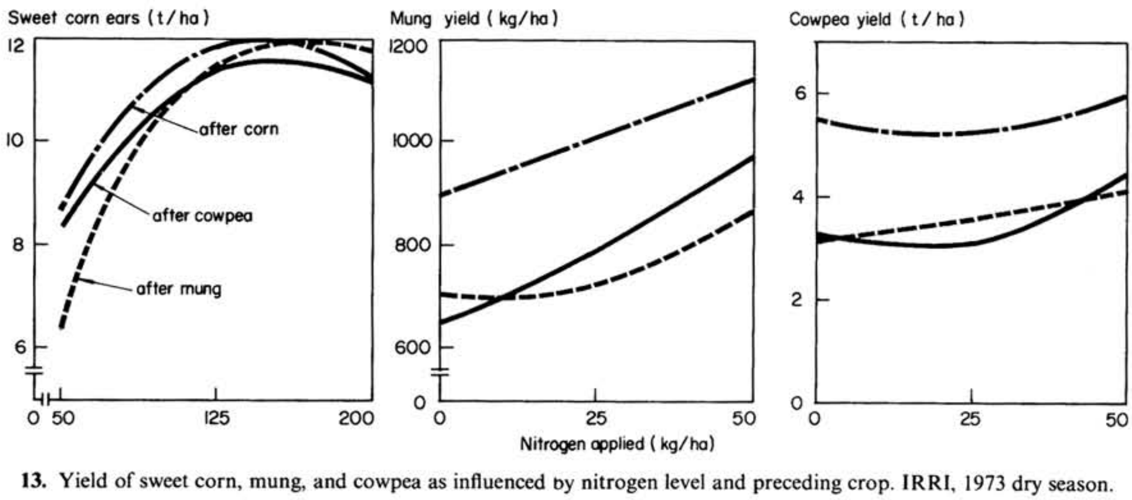
One problem we encounter with grain legumes is that yields drop when they are grown more frequently than once a year. When cowpeas were used, soil-borne disease built up rapidly, but this did not seem to happen with mung and soybean. Nematode build-up was likewise ruled out. To study the effect, we planted mung, cowpea, and corn for one season in a split-plot design. Then after harvest the same three crops were planted again in each of the plots at three levels of nitrogen. The yields of mung and cowpea were much lower after mung or cowpea than after corn (fig. 13). Corn yields were not affected by the previous crop. There was no significant interaction between the effect of previous crop and nitrogen level, indicating that the difference was not due to nitrogen. Otherwise, corn would have shown an even greater differential than did the legumes, since it is generally more nitrogen responsive. Rice grown in the third season after these combinations showed no effect at all from previous crop combinations. The effect seems especially prevalent on heavy soil that has moderately poor drainage. Corrective studies indicate that the response may be different depending on the crops causing the effect. Mung following certain combinations of crops responds to ferrous sulfate in addition to complete fertilizer. There seem to be no interactions in sensitivity between mung varieties and the residual effect.

Table 22. Yield of crops following rice on puddled and unpuddled soil. IRRI, 1972 wet season.

Nitrogen applied (kg/ha)	Yield (t/ha)			
	Corn	Sorghum	Green soybeans	Mung
		Puddled		
60	2.6	2.8	4.8	0.6
100	2.4	3.5	5.7	.4
150	3.0	3.1	5.5	.5
		Unpuddled		
60	2.6	3.1	4.2	.5
100	2.2	2.7	4.1	.5
150	3.2	3.1	4.8	.7

Weed management. On experiment stations, standard cropping with high levels of chemicals, intensive tillage, and relatively low leaf area indices nearly always results in a shift of weed species to predominantly grasses and sedges. With high rainfall during the monsoon on a heavy soil these species are extremely difficult to control. In farmer's fields, where field crops make full use of the seasonal moisture supply, this type of weed climax is seldom found, even if several crops a year are grown in intensive patterns. Instead weed communities are composed of a very few species, usually broadleaved weeds. In many areas traditional cropping patterns apparently have this built-in weed balance. Our goal is to learn how to manage this shift while giving economic control in each crop.

In a continuing year-round experiment at IRRI, we have imposed four levels of weed management on two cropping patterns. We have



13. Yield of sweet corn, mung, and cowpea as influenced by nitrogen level and preceding crop. IRRI, 1973 dry season.

Table 23. The effect of density of leaf canopy on individual weed species. IRRI, 1973.

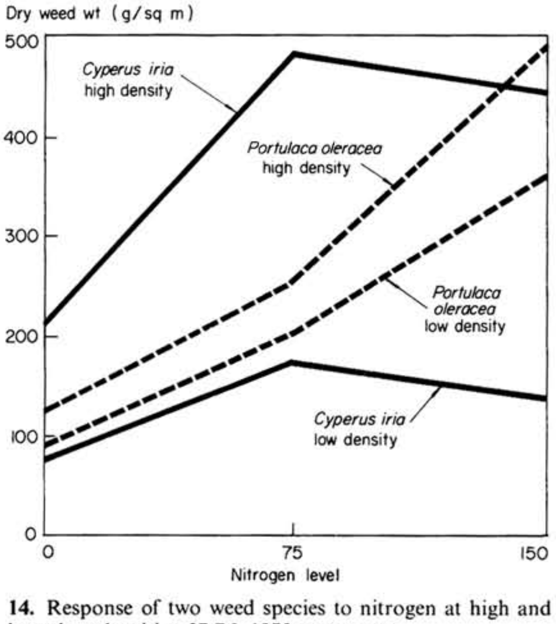
Weed species	Weeds under low density crop canopy (no./sq m)		Ratio[a]	
	1st season	2nd season	1st season	2nd season
Digitaria sanguinalis	1325	79	0.80	0.40
Echinochloa colonum	181	48	0.60	.69
Eleusine indica	39	40	1.22	.69
Portulaca oleracea	126	153	1.06	.65
Amaranthus viridis	17	23	0.19	.29
Cyperus rotundus	59	138	0.93	.22

[a]Of weeds at high crop density compared with weeds at low crop density.

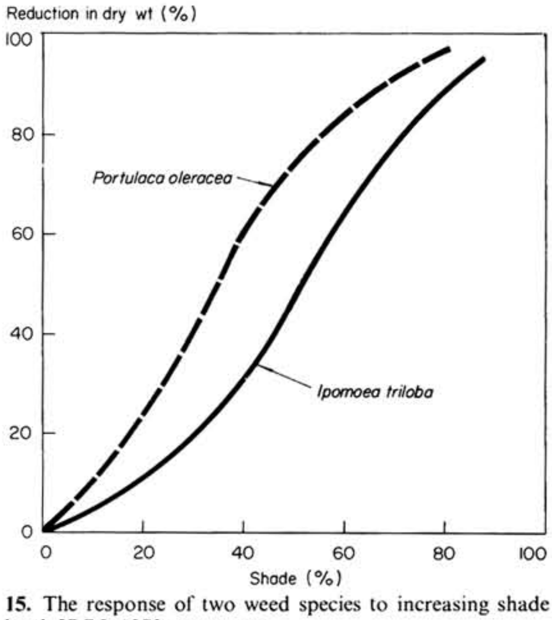
high and medium levels of management using chemicals and mechanical tillage under crop patterns of high and low leaf area index. The combination of control method and leaf area index after two seasons has already caused a marked shift in weed species (Table 23). Several shade-sensitive grass species and sedges, especially *Cyperus rotundus*, have decreased markedly under the high leaf area index. It may be possible to shift the year-round, seasonally changing weed pattern toward species which are more easily controlled during the early growth stages of each crop. In patterns where the soil is puddled for one crop or even flooded for several weeks during the rice season, the effect on the weed community and on subsequent control requirements is dramatic.

To learn how to manipulate the shift of weeds under different cultural practices we are studying several species which are predominant in fields having "experiment station" technology and also some from farmer's fields. Weeds vary in response to population and to shading. *Portulaca oleracea* shows little increase in dry weight as plant population increases above a low level but its response to nitrogen is nearly linear up to 150 kg/ha (fig. 14). It is quite sensitive to shade (fig. 15). That helps explain why it becomes predominant in intensive systems under high fertility and low leaf area index, for example, where vegetables are grown intensively. *Cyperus iria* has a much greater population response but it responds to nitrogen only up to 75 kg/ha in the wet season. *Ipomoea triloba* shows a shade-tolerance pattern. Shade may have an even greater effect through reduction of seed yield and subsequently on population shift than through reduction of dry matter.

Management of arthropods in crop litter. In intensive cropping patterns, the handling of crop stubble becomes a problem, especially where



14. Response of two weed species to nitrogen at high and low plant densities. IRRI, 1973 wet season.



15. The response of two weed species to increasing shade level. IRRI, 1973 wet season.

power is limited. Burning is seldom used in intensive systems except in lowland rice. One reason is that during wet weather the intensive schedule does not permit drying. Another is that following burning, nutrient loss by leaching is much higher. It appears that on small farms cutting the crop and allowing the stubble to decay between the rows of the succeeding crop will continue to be a common practice.

In intensively cultivated soils, organic litter turn-over rate decreases, which may affect natural buffering capacities of soils and beneficial biotic relationships in cultivated fields. For this reason the role of arthropods in hastening organic decay is important.

A survey of arthropods associated with decomposing corn, mung, and peanut litter revealed that stratiomyid flies, oribatid mites, and collembolans are the dominant agents of litter breakdown. Careful counts revealed representatives of 11 orders of macroarthropods and two orders of microarthropods. There were four suborders of Acarina represented by 27 genera. Predatory arthropods like spiders, dermapterans, and macrochelid mites were also abundant. As expected, the population of these arthropods varied with the type of litter; they also responded differently to a treatment of the litter with molasses as a food energy source (1 : 3 mixture of molasses and water) which was applied as a drench to boost initial microbial activity. Stratiomyid larvae, for instance, increased more rapidly on peanut litter than on corn.

Nitrogen utilization. Some intercrop combinations like corn-rice not only have a higher total productivity but also make more efficient use of nitrogen. In the corn-rice trial, the total nitrogen uptake was considerably higher with intercropping (Table 24). This cannot be explained solely by greater total light interception, since the combination did not have a much higher level than rice alone except during the early weeks of growth. Probably, light interception was not only slightly higher but also more efficient. The rice crop in the trial was affected by an early infection of blast at nitrogen levels above 60 kg/ha. Fungicidal sprays kept incidence low enough to give later recovery at higher nitrogen levels. The incidence of blast was greater with corn interplanting, so the response may have been biased in favor of monoculture. The greater efficiency of uptake in the intercrop was reflected in a higher gross return (Table 5).

Table 24. Total nitrogen content of above-ground plant parts in corn-rice intercropping at maturity. IRRI, 1973 wet season.

Crop	Nitrogen content (kg/ha)		
	Corn	Rice	Corn + rice
	60 kg/ha N		
Corn	104	—	—
Rice	—	95	—
Corn + rice	52	61	113
	120 kg/ha N		
Corn	81	—	—
Rice	—	62	—
Corn + rice	58	54	112
	180 kg/ha N		
Corn	95	—	—
Rice	—	68	—
Corn + rice	85	56	141
	240 kg/ha N		
Corn	99	—	—
Rice	—	91	—
Corn + rice	73	67	140

Power source interactions. The farmer's power source plays a critical role in intensive systems. In a replicated trial with large plots, six crops were grown under irrigation during a 1-year period. Rice was started in June and relay planted with sweet potato. This was followed in February with corn interplanted with cowpea and in May by corn interplanted with mung. We compared three power sources—hand labor, hand labor plus carabao, and hand labor plus hand tractor.

The three sources showed little difference in total costs and returns (Table 25). Since the methods were about the same in net return, the choice of power source can be made on other criteria. The cash flow of the systems, assuming that a farmer hired the labor, carabao, and tractor, was slightly in favor of hand labor. Less money would be required to pay for the early land preparation and thus a smaller cash outlay would be required early in the season. Return on labor was of course greater with the machines than with carabao or hand labor (Table 26). Return per unit of cash expense was higher with hand labor than with other methods (Table 27). Different power sources thus fit different resource patterns.

Table 25. Costs and returns from three power sources in a cropping pattern of rice, sweet potato, cowpea and corn, and mung and corn. IRRI, 1972-73.

Crop	Hand labor[a]			Hand labor + carabao[b]			Hand labor + hand tractor[c]		
	Total return (P/ha)	Variable costs (P/ha)	Difference (P/ha)	Total return (P/ha)	Variable costs (P/ha)	Difference (P/ha)	Total return (P/ha)	Variable costs (P/ha)	Difference (P/ha)
Rice	1000	1000	0	1100	900	200	1100	900	200
Sweet potato	4700	1200	3500	4700	1000	3700	4100	900	3200
Cowpea and corn	3100	1600	1500	3000	1300	1700	2700	1100	1600
Mung and corn	3800	1800	2000	3800	2200	1600	4300	2300	2000
Net return for pattern	—	—	7000	—	—	7200	—	—	7000

[a]At P0.75/h. [b]At P1.75/h. [c]At P7.50/h.

Consideration of timing of operations, however, gives a quite different picture. If a farmer has 1 hectare of land and three man-units of labor in addition to one carabao or one hand tractor, the advantage weighs heavily in favor of the mechanized operation. With one tractor the cropping pattern would have been roughly as accomplished at IRRI with the land being unplanted 7 percent of the time. With a carabao and three men, 1 additional month would have been required, with the land idle 16 percent of the time. With hand labor only, 2 more months would have been required, with the land idle 22 percent of the time. If weather conditions were not favorable for field operations all of the time, the hand labor system would take still longer since field preparation could not be carried out during the expected brief periods when weather conditions were favorable. With hand labor only, and a limitation on labor, two crops per year is a more reasonable pattern.

The total energy balance of the three methods is surprisingly similar (Table 28). Hand labor has a slight advantage in efficiency over other power sources but not as great as some reports indicate. The energy equivalent of the cash input was, surprisingly, three times higher than that of labor and power inputs, indicating an unrealistically high proportion of energy, for Southeast Asia, from modern chemical inputs. These relationships have important implications on a national scale.

Economic comparisons of modern intensive production. In evaluating economic returns from cropping patterns it is best to take data from farmers' fields which are in routine production. With new patterns, however, the farmer must be induced to grow them or the researcher must do it himself. We are currently using both methods, with the more complex irrigated patterns being tested at IRRI.

The managed plots at IRRI are set up in four replications. The first replication is 25 × 25 m and is used for yield and for labor-use studies. The remaining three replications are 7 × 25 m. The 25-m-row length permits hand tractor or carabao operations so that management simulates that of a farmer's field. During 1972–73, five 1-year patterns were set up to compare productivity and returns (fig. 16). The level of management was patterned after what a good farmer might use. The patterns included combinations of rice and legumes; rice, legumes, and

Table 26. Return over variable cost per hour of labor.

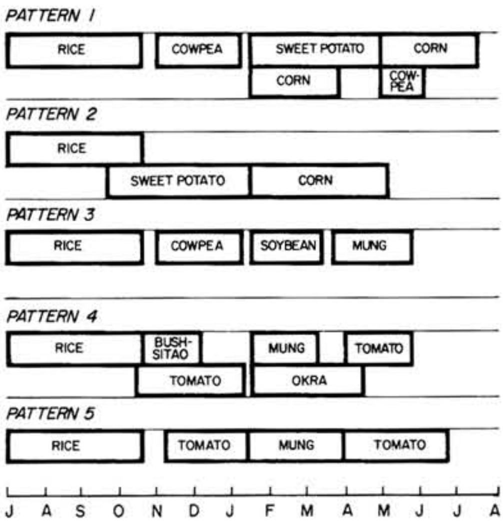
Crop	Return ($P \cdot ha^{-1} \cdot h^{-1}$)		
	Hand labor	Hand labor + carabao	Hand labor + hand tractor
Rice	0.80	1.20	1.70
Sweet potato	4.30	6.40	9.00
Cowpea and corn	2.10	3.30	4.40
Mung and corn	1.70	1.50	2.20
Total pattern	2.20	2.60	3.70

Table 27. Return over variable cost per peso of cash expense.

Crop	Return (P/P cash expense)		
	Hand labor	Hand labor + carabao	Hand labor + hand tractor
Rice	0.00	0.30	0.30
Sweet potato	7.50	5.10	5.10
Cowpea and corn	2.00	1.90	2.00
Mung and corn	7.50	1.50	1.50
Total pattern	3.50	2.80	2.00

vegetables; and rice, a root crop, and a feedgrain. Cash and labor inputs were expected to vary widely between patterns.

Yields and returns were affected not only by the season and amount of rainfall, but also by the market price at the time of harvest (Table 29). Labor requirements and returns varied from 36 man-hours at P3/man-day to 275 man-hours at P25/man-day. Rice yields and returns were low because of a severe outbreak of grassy stunt virus. The highest return was P104/man-day on 112 hours for corn-sweet potato. With many legume crops like mung, the cash return and protein production were considerably higher when intercropped. Otherwise mung is profitable only with little management. The soybeans were low yielding presumably due to the residual effect of the preceding cowpea crop. Normal protein production of green soybeans should be



16. Crop sequence and timing of five irrigated cropping patterns.

Table 28. Relative energy balance for three power sources in an intensive year-round cropping pattern.[a]

Power	Energy balance (Mcal/ha)				
	Power source	Other variable inputs	Total energy used	Marketable energy	
				Total	Per Mcal used
Hand labor	845	6,035	6,880	56,395	8.20
Hand labor + carabao	2,783	6,035	8,815	55,089	6.25
Hand labor + hand tractor	2,012	6,035	8,047	50,290	6.25

[a]Assumed energy equivalents: Human labor—0.175 Mcal/h; animal power—2.4 Mcal/h; fuel—8.45 Mcal/liter; heat of combustion of dry matter—3,700 Mcal/kg; value of goods and services—2.59 Mcal/P.

Table 29. Yield and returns for individual crops in irrigated rotations.

Crop	Yield (t/ha)	Labor (man-day/ha)	Return above variable cost (P/ha)		Marketable digestible		
					Protein		Nutrients (kg/ha)
			Total	Per man-day	Total	Per day	
Tomato	24	133	3,320	25	67	0.8	70
Tomato and bush sitao	20 0	275	6,880	25	138	1.6	140
Okra and mung	21 0.5	271	5,420	20	407	4.1	1760
Sweet potato	17	104	2,700	26	0	0	2080
Rice	2	36	110	3	126	1.0	1570
Corn	4	44	440	10	286	2.8	3150
Corn and sweet potato	7 25	112	11,670	104	224	1.9	9180
Corn and cowpea	5 0	64	1,540	24	96	1.4	1060
Cowpea	2	61	1,590	26	366	5.2	1280
Mung	0.8	95	570	6	190	2.8	670
Soybean (green)	2	75	380	5	75	1.2	450

Table 30. Labor requirements, productivity and returns from five irrigated cropping patterns.

Cropping pattern	Labor (man-days/ha)	Marketable digestible		Total return (P/ha)	Return above variable cost (P)		
		Protein (kg/ha)	Nutrients (kg/ha)		Per hectare	Per hour of labor	Per peso cash expense
1	355	710	13,135	21,105	15,340	6.16	4.22
2	164	410	6,970	6,190	3,380	3.34	1.85
3	215	860	4,085	6,615	2,180	2.02	0.69
4	542	542	4,336	19,475	10,905	2.75	2.44
5	388	388	3,104	18,490	11,625	4.50	2.56

4 to 5 kg $\cdot$ ha^{-1} $\cdot$ day^{-1}. Sweet potato, corn, and the combination are extremely high in production of total digestible nutrients.

Various measures of returns for the overall cropping pattern showed similar trends (Table 30). Rice followed by legumes (pattern 3) gave the lowest return on labor and cash expense as well as lowest total nutrient production. Total return and return on investment are not closely related to nutrient production, especially when high-return vegetables are included. If a vegetable market were not available, and especially if labor supply was limited, pattern 2 seems far more attractive than the other patterns. If labor is more plentiful, pattern 1 offers increased employment with a high return.

It thus appears that protein and total nutrient productivity can be made profitable, but not with legumes alone. Careful mixtures of legumes, grain crops, and root crops have exciting potential, not only for high levels of nutrient production, but also for total productivity.

Using the resource-utilization approach, it seems evident that for many farmers novel types of technology may be quite relevant. It is also clear that huge gaps exist in our knowledge of cropping systems for the Asian rice farmer. The effect of soil tillage properties on cropping pattern potential has not been studied. To reach our long-range goal of eventual modeling of cropping systems, we must fill in several of these gaps before our model can hope to be useful. For the present, however, there seem to be several ways in which simple changes can be made to improve production efficiency for the Southeast Asian rice farmer.

Statistics

We evaluated an experimental approach to the identification and quantification of yield constraints in farmers' fields. Instead of simply characterizing the farmers' practices, as is done in conventional farm surveys, the new approach uses field plot technique to assess, at each sample farm, the possible yield increase due to improved management. We used a factorial combination of several cultural practices each at two levels: the farmer's level and the recommended level. □ While both genetic and non-genetic variances of protein content are smaller than those of grain yield, the ratio of these variance components is much more favorable for grain yield than for protein. Moreover, the negative association between grain yield and protein content is primarily due to the environment rather than to the genotype. These results seem to indicate that the major difficulty in improving protein content of rice is not the negative correlation with grain yield nor the interference of large environmental variance, but rather the small genetic variance for protein. □ The yield response of rice to nitrogen fertilization was found to be adequately described by quadratic response functions in 1,047 out of 1,304 response curves examined.

FACTORS LIMITING FARMERS' YIELDS

Despite the rapid adoption of the improved rice varieties, farmers achieve only a small fraction of the varieties' yield potential. The usual way to study the causes of low farm productivity is a survey in which information on yield and cultural practices are obtained from sample farms, usually through interviews. But yield variation among farms can not be totally explained by cultural practices alone—climatic and soil differences are at least as important. To remedy this, some studies include the monitoring of the physical environment throughout the growing season. The major disadvantages of that approach are that monitoring climatic conditions is laborious and time consuming, and that data on physical environment can be highly useful only if its relation to yield and other cultural practices is known beforehand.

Since the limiting factors that are of major interest to rice researchers and farmers are those that are within human control—management and cultural practices—we have evaluated a procedure for removing the complications emanating from large climatic and soil differences from one sample farm to another. The procedure consists of obtaining sample farms as is normally done in surveys and conducting field plot experiments on the farms to obtain information from actual measurements instead of from the farmer.

A factorial experiment involving (i) insect control, (ii) water management, (iii) weed control, (iv) fertilizer, and (v) seed source and seedling management, each at two levels, was conducted at several farms in the 1972 dry and wet seasons. In the 1973 wet season, only four factors were tested (water management was excluded). The sample farms were purposely selected based upon reported yield levels. The two levels of each factor tested were (i) the farmer's practice, that which the farmer of the sample farm actually used (thus it varied from one sample farm to another), and (ii) the "improved" practice, the standard practice used in IRRI field experiments. The improved practice consists of 120 kg/ha N in the dry season and 90 kg/ha N in the wet season, 3 to 5 cm of standing water maintained up to 2 weeks before harvest, as close to weed-free condition as possible, maximum protection against insects and diseases through application of insecticides, and use of dapog seedlings, 10 to 13 days old, grown from breeder's seed from IRRI or from the University of the Philippines at Los Baños.

Aside from yield, data on weeds, off-type plants, rat damage, and insect and disease incidence were collected. A complete record of all management and cultural inputs from seedling preparation to harvest was kept for both the farmer's practices and the improved practices.

Relative contribution of inputs to yield increase. In the dry season, improved practices greatly increased yields in farmers' fields compared with farmers' practices (Table 1). On one farm improved practices gave a yield of 9.6 t/ha. The absolute yield increase ranged from 2.4 t/ha to 4.4 t/ha (about 50 to 300%). Each input gave some yield increase but insect control, fertilizer,

Table 1. Contribution of five management inputs toward improving rice yields in farmers' fields. Laguna, Philippines, 1972.

Farm no.	Variety planted	Grain yield (t/ha)			Contribution (t/ha)				
		Farmer's inputs	Recommended inputs	Difference	Insect control	Water management	Nitrogen fertilization	Weed control	Seedling management
				Dry season					
1	C4-63G	3.7	7.4	3.7	0.8	1.3	0.9	0.5	0.2
2	C4-63G	3.8	6.2	2.4	0.9	1.0	0.2	0.0	0.3
3	C4-63G	1.4	5.8	4.4	1.9	1.3	0.9	0.1	0.2
4	IR8	6.6	9.6	3.0	1.1	0.1	0.8	0.4	0.6
Avg		3.9	7.3	3.4	1.2	0.9	0.7	0.3	0.3
				Wet season					
1	IR22	4.3	4.8	0.5	0.7	−0.1	−0.1	0.2	−0.2
2	C4-137	4.6	5.2	0.6	0.0	0.1	0.0	0.5	0.0
3	IR579-48-1	4.2	5.0	0.8	1.5	−0.3	−0.2	0.3	−0.5
Avg		4.4	5.0	0.6	0.7	−0.1	−0.1	0.3	−0.2

Table 2. Contribution of four management inputs toward the improvement of rice yields in farmers' fields. Laguna, Philippines, 1973 wet season.

Farm no.	Variety planted	Grain yield (t/ha)			Contribution (t/ha)			
		Farmer's inputs	Recommended inputs	Difference	Insect control	Nitrogen fertilization	Weed control	Seedling management
1	IR20	3.4	6.0	2.6	2.0	0.1	0.3	0.2
2	IR20	5.0	6.5	1.5	1.1	0.0	0.0	0.4
3	IR20	1.5	3.3	1.8	1.3	0.1	0.4	[a]
4	IR22	4.1	5.9	1.8	1.3	0.2	0.0	0.3
5	IR22	1.9	4.5	2.6	2.0	0.2	0.4	0.0
6	IR1561-228-3	4.5	6.0	1.5	1.1	0.0	0.3	0.1
7	IR1561-228-3	3.4	4.8	1.4	0.9	0.3	0.1	0.1
8	C4-63G	1.7	4.8	3.1	1.6	0.6	0.4	0.5
9	C4-63G	2.2	3.9	1.7	1.1	0.0	0.4	0.2
10	C4-63G	2.3	4.2	1.9	1.8	−0.5	0.6	0.0
11	C4-63G	3.3	4.1	0.8	0.5	−0.2	0.5	0.0
12	C4-63G	2.2	4.3	2.1	1.3	0.1	0.7	[a]
Avg		3.0	4.9	1.9	1.3	0.1	0.3	0.2

[a]Data not available.

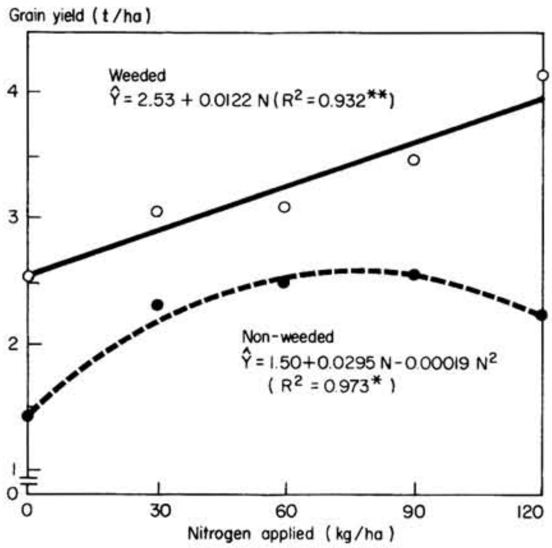
and water managemenι, were the most crucial in raising rice yields in these farms. They contributed an average of 83 percent to the total yield increase. Their effects, not unexpectedly, varied greatly from farm to farm, since the level of farmers' management varied greatly among farms.

In the wet season, the level of yield increase due to improved practices was generally low, averaging only 0.6 t/ha or 14 percent. Of the five factors tested, insect control and weed control caused the entire yield increase, although the increase was not large. As expected, water management was not as big a problem in the wet season as in the dry season. Moreover, while in the dry season, some improvement in the farmers' nitrogen fertilization practices (avg: 87 kg/ha N) was possible, it was not so in the wet season (when farmers used an average of 65 kg/ha N).

The 1973 wet season trial confirmed these results (Table 2). Again, insect control ranked as the most crucial factor in improving rice yields in the farms, giving an average yield increase of 1.3 t/ha, which is 68 percent of the total yield increase. Weed control was the second most important factor with an average yield increase of only 0.3 t/ha.

The greatest yield constraint in farmers' fields in the study area seems to be control of pests and diseases. When pest and disease problems were minimized, yields on these farms were raised 1 t/ha, irrespective of season. In the dry season, improvement in water management could raise yields 0.9 t/ha and the use of higher nitrogen rates could raise yields 0.7 t/ha. Improvement in weed control management as well as in seed source and seedling management compared with the farmers' practices did not seem to give appreciable effects.

Evaluation of techniques. An important aspect of the proposed procedure is the experimental design or the choice of treatments to be tested. If interactions among the various inputs examined are appreciable, then factorial treatments, whether complete or incomplete, may be more desirable than the discrete management packages. The use of complete factorial treatments, of course, may enlarge the size of the experiment which is undesirable, especially for trials in farmers' fields. During 1973 wet season we experimentally evaluated some of the possible interactions among the management inputs with the average farmers' level as control. We found that weed-control level gave a large differential effect on the nitrogen response of rice (fig. 1), indicating that an optimum nitrogen rate derived from fertilizer trials conducted at experiment stations under high management levels may not necessarily be appropriate under farm conditions having lower levels of other management inputs. Virus incidence (grassy stunt) was observed to



1. Nitrogen response of rice (IR20 and IR1561-228-3) grown under intermittent irrigation, as affected by weed control levels. IRRI, 1973 wet season.

be higher under continual flood irrigation condition than with intermittent irrigation, and slightly higher in weeded plots than in nonweeded plots (Table 3). These results seem to indicate a great dependence of the benefit of one input on the levels of other inputs, and the danger of extrapolating results obtained under experimental conditions to farmers' fields where the level of input use is generally lower. Because of the apparent importance of interaction effects, factorial treatments should be used in this type of experiment.

The validity of the proposed approach depends greatly on the success of the simulation of farmer's practices, which can be measured by the agreement between grain yield of farmer's paddy and that from experimental plots receiving the farmer's level in all the factors tested. Results of 1973 wet season indicated no bias in the simulation technique (Table 4). In most farms, the agreement was good; only three farms had large differences (0.8 to 1.0 t/ha). Of the four factors tested in the 1973 wet season trial, insecticide application was the most difficult to simulate. Application made 1 or 2 days later than the farmer could make a great difference since the effectiveness of insecticides depends on weather conditions, particularly rainfall.

Placing plots with low insect control level (farmer's practice) adjacent to those with high insect control level (improved practice) tended to give a slight overestimation in yield (Table 5). Moreover, because of the difficulties encountered in simulating farmer's insecticide practices it may be more practical to have the insecticides applied by the farmer himself even on the experimental plots. These findings suggest that the two sets of plots according to the insect control level should be separated to avoid a possible bias in yield as well as to facilitate the farmer's insect-control operation.

For conducting this type of experiments in farmers' fields, a plot size that gives a net harvest area (after exclusion of border rows) of 6 to 8 sq m per plot seemed sufficient (fig. 2).

In two seasons of tests in 1972, the experimental procedure was not satisfactory for assessing the contribution of water management to farmers' yields. We had great difficulty in maintaining the desired water level for "improved" plots because water was not avail-

Table 3. Degree of virus[a] incidence on IR1561-228-3 and IR20 as affected by water management and weed control levels, at varying nitrogen levels. IRRI, 1973 wet season (Data are averages of four replications).

Weed control level	Water management	Virus incidence (%)					
		0 kg/ha N	30 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N	Avg[b]
			IR1561-228-3				
Non-weeded	Continuous flooding	3.9	2.7	5.2	4.8	5.7	4.5 c
	Intermittent irrigation	0.6	0.8	0.8	1.0	0.6	0.8 d
Weeded	Continuous flooding	8.1	8.6	6.4	5.1	6.6	7.0 b
	Intermittent irrigation	1.8	1.4	2.0	1.2	0.7	1.4 d
			IR20				
Non-weeded	Continuous flooding	13.0	4.4	7.1	7.4	7.4	7.9 b
Weeded	Continuous flooding	17.0	22.6	11.2	18.0	14.8	16.7 a
	Intermittent irrigation	6.6	4.8	5.9	7.2	4.5	5.8 bc

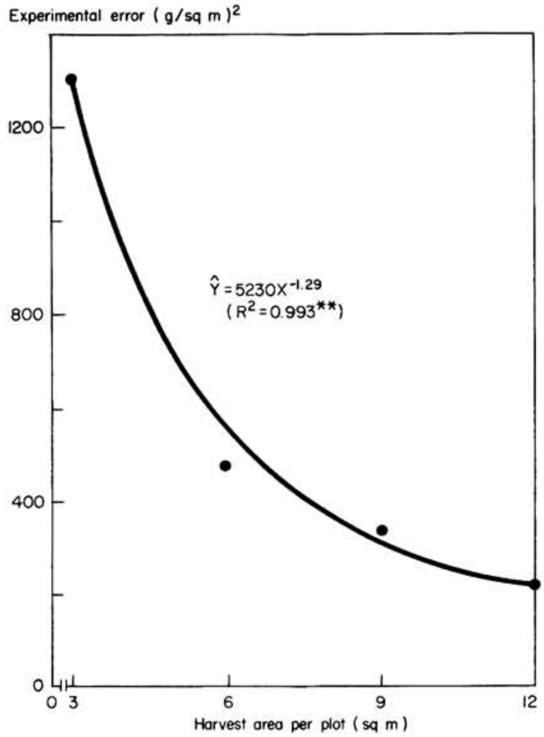
[a]Mostly grassy stunt. [b]Means followed by a common letter are not significantly different.

able at all times. Other procedures should be evaluated, such as sampling from farms that have been stratified into various categories of water availability.

VARIABILITY IN PROTEIN CONTENT OF RICE

Two problems widely believed to hinder the improvement of grain protein in rice are that protein content is highly influenced by environmental factors, and that protein content and grain yield seem to be negatively correlated. We examined the effects of environment on protein content of rice, attempted to identify the test condition that minimizes experimental error in protein trials, and investigated relationships between protein content and grain yield.

Phenotypic variance within varieties. Experimental data on protein content and grain yield of IR8 and IR480-5-9 from experiments conducted by the agronomy and varietal improvement departments were analyzed. We found that the variability due to environment constituted a substantial portion of the total variability in both protein content and grain yield. In 964 experimental plots of IR8, brown rice protein ranged from 4.8 to 12.1 percent, grain yield from 1.0 to 9.8 t/ha, and protein yield from 69 to 686 kg/ha (fig. 3). Protein content varied greatly among locations (Table 6) and among cropping seasons (Table 7). In addition to plant density, nitrogen fertilization, and method of nitrogen application previously shown by IRRI agronomists to affect grain yield and protein content, we found that improved water management and weed control increased both (Tables 8 and 9) too. On the other hand, improved pest and disease control increased grain yield without affecting significantly protein content (Table 10).



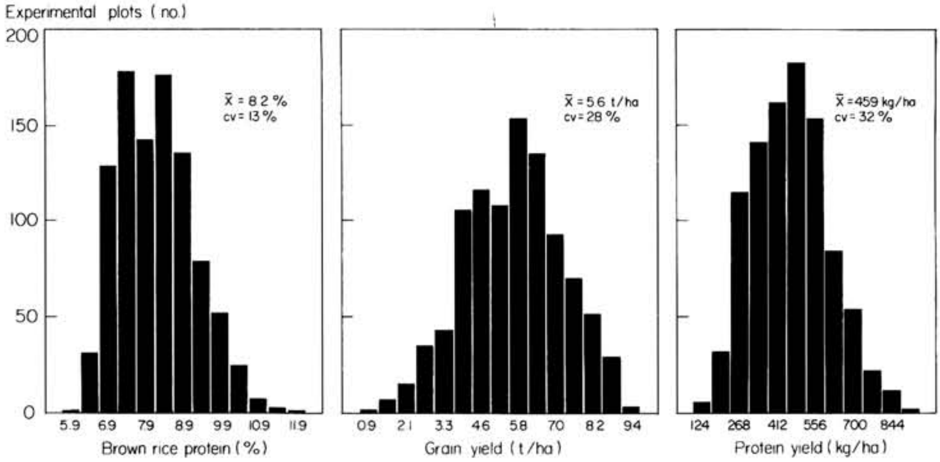
2. Relation between experimental error and net plot size for rice experiments in farmers' fields. Bay, Laguna, 1972 dry season.

Table 4. Grain yields obtained in farmer's paddy and from simulation of farmer's practices in experimental plots, under varying farm conditions. Laguna, Philippines, 1973 wet season.

Variety planted	Yield (t/ha)		
	Simulated farmer's plots	Farmer's paddy	Difference
IR20	5.0	4.2	0.8
IR20	1.5	1.3	0.2
IR22	4.1	3.9	0.2
IR22	1.9	1.7	0.2
IR1561-228-3	4.5	5.5	−1.0
IR1561-228-3	3.4	3.5	−0.1
C4-63G	1.7	1.2	0.5
C4-63G	2.2	2.4	−0.2
C4-63G	2.3	3.1	−0.8
C4-63G	2.2	1.8	0.4
Avg	2.9	2.9	0.0

Table 5. Yields of plots in farmers' fields receiving low levels of insect control adjacent to or separated from plots receiving maximum insect control. Laguna, Philippines, 1973 wet season.

Variety planted	Grain yield (t/ha)		
	Adjacent	Separated	Difference
IR20	5.3	4.9	0.4
IR20	2.2	1.5	0.7
IR22	4.9	4.1	0.8
IR22	2.2	2.1	0.1
IR22	2.5	2.2	0.3
C4-63G	2.9	1.7	1.2
C4-63G	2.0	2.1	−0.1
C4-63G	2.9	2.7	0.2
C4-63G	3.0	3.3	−0.3
C4-63G	2.7	2.2	0.5
Avg	3.1	2.7	0.4



3. Frequency distribution of brown rice protein content, grain yield, and protein yield of IR8 samples from 964 experimental plots in 31 trials. IRRI, 1968-1972.

The experimental error of protein content not only was generally lower than that of grain yield (Table 11), its magnitude was also less influenced by the cultural practices employed. While the experimental error of grain yield was greatly reduced with nitrogen fertilization (Table 12), that of protein content was not appreciably affected. On the other hand, method of nitrogen application significantly influenced experimental errors of both grain yield and protein content with the lowest errors obtained when nitrogen was applied in split dose—basal and at panicle initiation (Table 13). Thus the test condition that minimizes experimental error for grain yield is also appropriate for protein.

Table 6. Brown rice protein and grain yield of IR8 (unfertilized) grown in agronomy trials at four locations in the Philippines. 1969 wet season (Data are averages of three replications).

Location	Protein (%)	Yield (t/ha)
IRRI	7.5 ± 0.2	4.7 ± 0.1
Bicol	7.1 ± 0.3	4.6 ± 0.5
Maligaya	6.7 ± 0.1	5.2 ± 0.1
Visayas	5.5 ± 0.4	4.0 ± 0.2

Table 7. Brown rice protein and grain yield of six rice varieties as affected by crop season. IRRI, 1971-1972 (Data are averages over two trials each with three replications).

Variety	Dry season		Wet season	
	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)
IR8	7.1	5.02	7.8	3.62
IR22	7.6	4.03	8.6	3.52
IR24	7.4	4.67	9.0	4.00
IR20	7.6	4.69	9.1	3.64
C4-63G	7.4	4.70	8.8	3.49
RD-3	7.8	4.05	8.8	3.37
Avg	7.5	4.53	8.7	3.61

Data from 964 experimental plots of IR8 and 538 plots of IR480-5-9 grown under varying environmental conditions at IRRI farm revealed quadratic relationships between grain yield and percentage protein content (fig. 4). Grain yield and protein content increased simultaneously only up to a point beyond which an increase in protein content resulted in a decrease in grain yield. This suggests that there is a protein threshold representing each variety's grain protein potential. For IR8, this protein threshold was estimated at about 8.5 percent, with a corresponding average grain yield of 6.6 t/ha in the dry season and 5.1 t/ha in the wet season. For IR480-5-9, a promising high-protein line, the protein threshold was about 10.3 percent with average grain yield of 6.5 t/ha for the dry season and 4.3 t/ha for the wet season.

Phenotypic variance among varieties. A series of experiments were conducted in cooperation with the agronomy and chemistry departments at the IRRI farm for four consecutive seasons in 1971 and 1972 to examine the different components of variance and covariance in both protein content and grain yield. In each experi-

Table 8. Brown rice protein and grain yield of C4-137 grown in a farmer's field under different nitrogen rates and different levels of water management and weed control. Laguna, Philippines, 1973 dry season (Data are averages of four replications).

Weed control level	Protein (%)			Yield (t/ha)		
	60 kg/ha N	120 kg/ha N	Avg[a]	60 kg/ha N	120 kg/ha N	Avg[a]
			Intermittent irrigation			
Low	6.7	7.5	7.1 a	4.4	5.5	5.0 a
High	6.9	7.7	7.3 b	5.5	6.2	5.8 b
			Continuous flooding			
Low	7.2	8.2	7.7 c	5.4	6.6	6.0 b
High	7.9	8.2	8.0 d	6.3	7.0	6.6 c

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

Table 9. Brown rice protein and grain yield (fertilized and unfertilized) as affected by water management and weed control levels. IRRI, 1973 dry season (Data are averages of IR20 and IR22).

Weed control level	Protein (%)			Yield (t/ha)		
	Unfertilized	Fertilized[a]	Avg[b]	Unfertilized	Fertilized[a]	Avg[b]
			Intermittent irrigation			
Non-weeded	7.2	7.5	7.4 c	2.89	4.25	3.98 c
Weeded	7.6	7.7	7.7 b	3.54	4.91	4.63 b
			Continuous flooding			
Non-weeded	7.6	8.0	7.9 b	3.66	4.86	4.62 b
Weeded	7.9	8.2	8.1 a	3.88	5.56	5.22 a

[a]Average of four levels of nitrogen, each with four replications. [b]Means followed by a common letter are not significantly different at the 5% level.

ment, 16 varieties were tested under four test conditions in three replications. Eleven varieties were common throughout the four trials while the rest varied from one trial to another. To ensure a wide range of phenotypic variability, the varieties were chosen primarily for their large differences in both protein and grain yield. Moreover, varying levels of nitrogen and plant spacing, the major cultural practices affecting both characters, were included. Protein content ranged from 6.1 to 15.9 percent and grain yield from 0.51 to 7.17 t/ha (Table 14).

This series of experiments confirmed previous findings that environmental variance of grain yield is larger than that of protein content (Table 15). It was clear, however, that the genetic variance of grain yield is also much larger than that of protein. In fact, the difference between genetic variances of grain yield and protein content was more pronounced than that between environmental variances. As a result, the ratio of genetic to environmental variances was more favorable for grain yield (1.0 : 2.8) than it was for protein (1.0 : 5.2). Thus, the difficulty in the improvement of protein content of rice is not as much due to the large environmental variance as it is to the small genetic variability.

As expected, the total phenotypic covariance between grain yield and protein content was large and negative. The separation of this covariance into its genetic and environmental components (including genetic × environment interaction) indicated that all of the negative association between grain yield and protein content was due to the latter component—the genetic covariance was small and positive. Except for nitrogen

Table 10. Brown rice protein and grain yield of three rice varieties grown in farmers' fields under different levels of pest and disease control. Laguna, Philippines, 1973 dry and wet seasons (Data are averages of 8 to 16 replications).

Variety	Crop season	Protein (%)		Yield (t/ha)	
		Low insect control	High insect control	Low insect control	High insect control
C4-137	Dry	7.6	7.4	5.5	6.2
IR20	Wet	8.3	8.2	4.8	6.0
IR1561-228-3	Wet	8.9	9.0	4.4	5.6
IR20	Wet	9.3	9.3	1.5	5.8
Avg		8.5	8.5	4.0	5.9

Table 11. Experimental error of protein content and grain yield estimated from seven series of rice field experiments. IRRI, 1971-1972.

Experiment no.	Year	Degrees of freedom	Coefficient of variation (%)			
			Protein		Yield	
			Dry season	Wet season	Dry season	Wet season
1	1971	110	6.3	5.9	8.9	12.4
2	1971	130	5.4	5.9	7.7	9.1
3	1971	120	8.3	7.5	13.6	15.4
4	1972	110	6.6	5.7	8.5	9.4
5	1972	130	7.9	6.5	10.2	9.4
6	1972	120	5.4	7.7	11.6	14.9
7	1972	326	7.3	6.9	9.3	8.4
Combined		1046	6.9	6.6	9.8	10.7

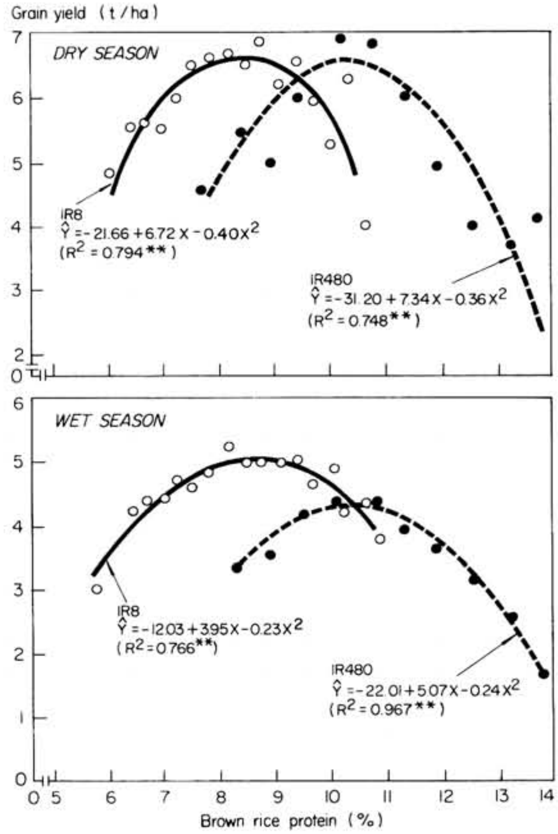
Table 12. Experimental error[a] of grain yield and brown rice protein estimated from agronomy trials, as affected by the rate of nitrogen application. IRRI, 1971-1973.

Nitrogen applied (kg/ha)	Yield		Protein	
	Mean (t/ha)	cv (%)	Mean (%)	cv (%)
	Dry season			
0	4.54	14.7	7.8	7.4
60	5.77	10.8	8.4	5.7
90	6.35	10.0	8.8	7.5
120	6.63	8.7	9.2	6.2
150	6.55	8.3	9.5	7.4
	Wet season			
0	3.52	13.7	7.6	5.9
30	3.86	8.8	8.1	5.9
60	4.10	9.0	8.2	5.5
90	4.29	9.5	8.4	6.9
120	4.29	8.8	8.7	6.8

[a]Data are averages over six trials for grain yield and four trials for brown rice protein, each trial consisting of 14 varieties tested with four replications.

Table 13. Experimental error (based on 90 degrees of freedom) of grain yield and brown rice protein estimated from agronomy trials, as affected by the time of nitrogen applications. IRRI, 1969-1970.

Time of application	Yield		Protein	
	Mean (t/ha)	cv (%)	Mean (%)	cv (%)
	1969 wet season (60 kg/ha N)			
Basal	4.37	14.0	9.4	9.0
Basal + panicle initiation	4.54	10.7	9.5	6.5
Basal + heading	4.72	10.5	9.7	6.5
	1970 dry season (150 kg/ha N)			
Basal	6.00	8.6	8.6	7.1
Basal + panicle initiation	6.24	6.9	9.0	6.5
Basal + heading	5.75	10.2	9.6	6.9



4. Relations between protein content and mean grain yield of IR8 (from 964 observations) and IR480-5-9 (from 538 observations), by crop seasons. IRRI.

fertilization, which increased both characters simultaneously, all other environmental factors, especially cropping seasons which favored grain yield, depressed protein content and vice versa.

Because of the important implications of these findings to the improvement of protein content through breeding, it is necessary that these results be confirmed in further studies with the inclusion of more genotypes and environments.

YIELD RESPONSE TO NITROGEN

We examined nitrogen response curves taken from 154 fertilizer trials conducted by the agronomy department from 1966 to 1972, involving different varieties and selections grown under widely different management and environmental conditions. In all trials, at least four nitrogen levels were tested. We found that the yield response to nitrogen in rice is described appropriately by the quadratic functions: $Y = a + bN + cN^2$, where Y is grain yield, N is nitrogen rate, and a, b, c are the regression parameters. In 1,047 of the 1,304 response curves examined, quadratic response functions accounted for more than 80 percent of the yield variability. The curves that had coefficients of determination (R^2 values) from quadratic fits of less than 80 percent came mostly from trials which involved traditional varieties or which were made in the wet season. For improved varieties or selections grown in the dry season quadratic functions can be expected to give satisfactory fits about 90 percent of the time; under other conditions, satisfactory fits can be expected in only 65 to 75 percent of the time.

Several types of nitrogen response curves were observed (fig. 5): A) Grain yield increased with nitrogen level, although the yield increment became less and less as higher nitrogen rates were used, and finally reached a point where further increase in nitrogen brought about a reduction in yield. This type of curve, which was the most common, is necessary for estimating economically optimum nitrogen rates. B) The response was still in the linear phase, that is, grain yield increased at the same rate throughout the range of nitrogen levels used. Optimum nitrogen rate can not be derived from this type of curve since maximum yield has not been reached. To avoid getting type B curves, the maximum nitrogen rate tested in the trial should be sufficiently high. C) Yield was reduced as nitrogen rates increased. This type of curve occurred mostly with traditional varieties grown in the wet season.

To find one or more measures for comparing and describing a large number of nitrogen responses, several parameters were examined. N_{max} (the nitrogen rate that maximizes yield), Y_{max} (the maximum yield), and Y_I (increment of yield increase based on N_{max} rate) were satisfactory. The use of these parameters in distinguishing nitrogen responses in the dry and wet seasons under various conditions is illustrated in figure 6. The dry season crops required a higher nitrogen rate to attain the maximum yield (N_{max} of 112 kg/ha N for dry season and 75 kg/ha N for wet season), while the maximum yield, as well as the returns in terms of kilograms of grain per kilogram of nitrogen, was also higher (Y_{max} of 6.6 t/ha in dry season and 4.8 t/ha in wet season; and Y_I of 18.2 kg grain/kg N in the dry season and 13.6 kg grain/kg N in the wet season). This indicates clearly that yield response to nitrogen application in the dry season is better than in the wet season. Of the various factors examined, the two major ones affecting nitrogen response are crop season and varietal type. The differences are illustrated in figure 7 for crop season and figure 8 for varietal type.

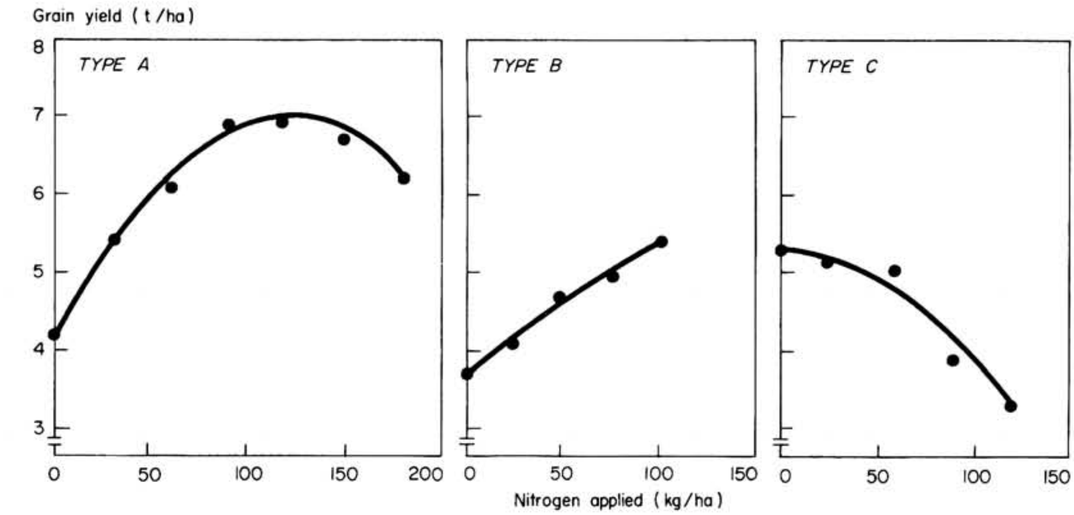
Table 14. Range and mean of grain yield and brown rice protein of 11 rice varieties and lines tested under varying environments. IRRI, 1971 and 1972 dry and wet seasons.

Designation	Yield (t/ha)		Protein (%)	
	Range[a]	Mean	Range[a]	Mean
IR8	2.56–6.73	4.41	7.0–11.1	8.5
IR22	3.13–6.46	4.27	7.6–10.6	9.0
IR24	3.20–6.73	4.56	7.1–10.7	8.6
IR20	2.53–7.17	4.39	7.6–11.5	9.1
C4-63G	1.88–5.76	3.89	7.4–12.6	8.9
BPI-76-1	1.84–5.25	3.41	7.8–15.9	10.3
RD-3	1.74–6.56	3.98	7.6–11.4	9.0
Intan	0.51–3.67	1.68	6.1–10.9	8.5
IR480-5-9	3.00–6.31	4.00	8.2–13.1	10.5
IR667-98-1	2.47–6.36	3.98	7.7–12.5	9.6
IR160-27-3	3.00–6.72	4.28	8.3–12.4	9.9

[a]Over 16 environments composed of four test conditions and four cropping seasons, each replicated three times.

Table 15. Components of variance and covariance of grain yield and protein content of rice.

Component	Degrees of freedom	Brown rice protein			Grain yield			Grain yield × protein	
		Variance	cv (%)	Contribution (%)	Variance	cv (%)	Contribution (%)	Covariance	Contribution (%)
Variety	10	0.42418	7.0	16.1	0.56219	19.3	26.4	0.08757	−14.5
Environment	15	1.82589	14.6	69.4	1.20345	28.2	56.5	− .48394	80.0
Variety × environment	150	0.37812	6.6	14.5	0.36227	15.5	17.1	− .20932	34.5



5. Three major types of nitrogen response curves of rice.

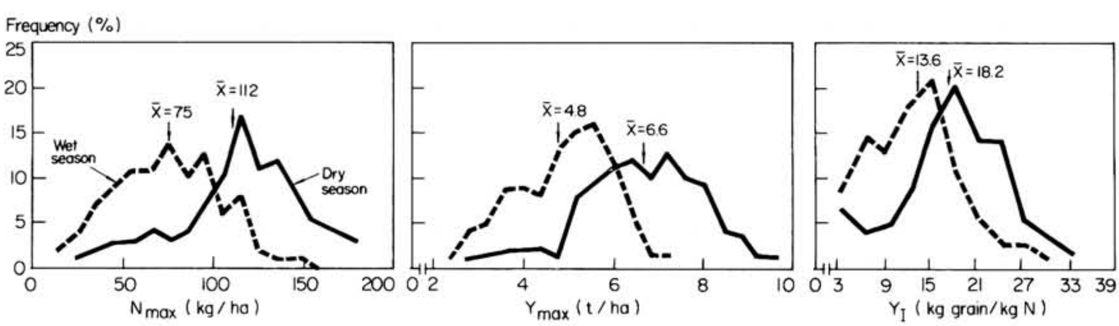
SOIL HETEROGENEITY

Planting an area to varieties differing in growth duration by more than 10 days increases soil heterogeneity in the following season (1972 Annual Report). This year, we evaluated the effect of growing varieties differing in both growth duration and tillering ability under different plant spacings.

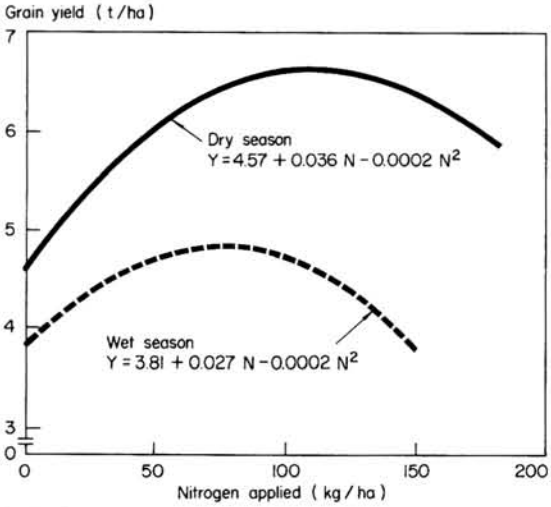
In the 1972 wet season, IR8, C4-63G, IR478-68-2, IR127-80-1, IR1561-228-3, and IR747B2-6-3, were grown under three plant spacings, 10 × 10 cm, 20 × 20 cm, and 30 × 30 cm, in three replications. In 1973 dry season, IR127-80-1, IR841-5-1, Ratna, and IR1561-228-3, were grown at 10 × 10 cm, 20 × 20 cm, and 30 × 30 cm in 11 replications. In the season following each of these plantings, IR1514A-E597 was grown throughout each area.

The dry season data indicated some differences in grain yields from plots planted to the six varieties in the previous wet season (Table 16). Yields of IR1514A-E597 from plots in which IR747B2-6-3 (having the shortest growth duration) had been grown previously were the highest, even though IR747B2-6-3 had the largest tiller number. Difference in tillering ability did not seem to give appreciable residual effect relative to growth duration.

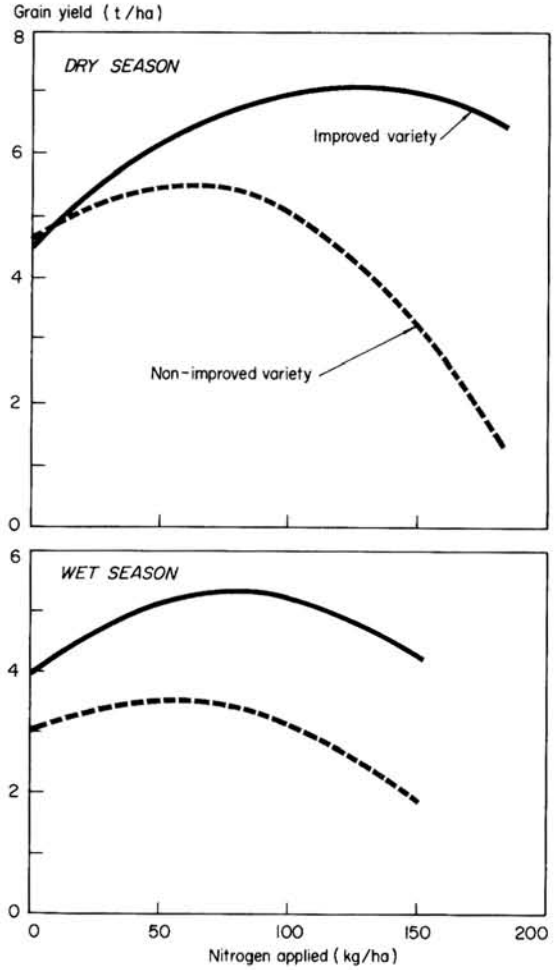
On the other hand, in the wet season trial where the four varieties tested not only had a longer growth duration but also a smaller range of growth duration than the six varieties in the 1972 dry season trial, there was no significant



6. Frequency distribution of three nitrogen response parameters, based on 564 response curves of different varieties grown under varying conditions, by crop season. 1966-1972.



7. Estimated nitrogen response of rice for dry and wet season crops, based on data from 564 response curves of different varieties grown under varying conditions. 1966-1972.



8. Average nitrogen responses for improved and non-improved varieties based on 195 response curves, by crop season. 1966-1972.

difference among yields from areas planted to different varieties in the previous season. Grain yields from areas having different plant densities in the previous crops were significantly different, however, 10 × 10 cm giving the lowest yield although average yield reduction was only about 0.2 t/ha. On the other hand, there was no significant difference between 20 × 20 cm and 30 × 30 cm spacings.

EXPERIMENTAL DESIGNS FOR MULTIPLE CROPPING

Most statistical procedures developed for agricultural research are primarily meant for experiments involving single crops. Multiple cropping technology, however, requires the simultaneous testing and evaluation of several crops following a prescribed combination or sequence of planting. Thus, instead of being concerned only with environmental factors surrounding a single crop, multiple cropping research demands a technique by which many types of crops and crop sequences can be tested under varying environments. Three major difficulties are encountered in multiple cropping experiments. First, since crop combinations and crop sequences usually have large interactions among themselves as well as with environmental factors, multi-factor experiments involving a large number of treatments are generally undertaken. Second, large experimental error can be expected when several crops which differ in plot techniques and cultural requirements are tested together. Third, since economic data are much more important in the evaluation of multiple cropping systems than in single-crop experiments, the experimental procedure must conveniently permit measurement of economic data.

To cope with the large number of multi-factor treatments involved in a multiple cropping trial, we developed a modification of the standard fractional factorial design for a test which was conducted by the multiple cropping department in 1973 dry season. The test involved 63 inter-

Table 16. Grain yield of IR1514A-E597 (unfertilized) grown in areas previously planted to varieties differing in growth duration and tiller number under three plant spacings. IRRI, 1973.

Variety planted in previous crop			Yield (t/ha) of IR1514A-E597		
			Spacing in previous crop (cm)		
Designation	Tillers (no./hill)	Growth duration (DT[a])	10 × 10	20 × 20	30 × 30
		Dry season[b]			
IR747B2-6-3	15	88	3.63	3.79	3.60
IR1561-228-3	15	96	3.52	3.48	3.64
IR127-80-1	9	109	3.15	3.19	3.79
IR478-68-2	9	112	3.41	3.41	3.31
C4-63G	10	115	3.39	3.44	3.28
IR8	11	115	3.39	3.49	3.61
Avg[c]	—	—	3.41 a	3.47 a	3.54 a
		Wet season[d]			
IR1561-228-3	15	94	3.14	3.30	3.35
Ratna	13	90	3.18	3.32	3.48
IR127-80-1	9	109	3.14	3.22	3.23
IR841-5-1	11	111	3.16	3.45	3.42
Avg[c]	—	—	3.15 b	3.32 ab	3.37 a

[a]Days after transplanting. [b]Three replications. [c]Means followed by a common letter are not significantly different at the 5% level. [d]11 replications.

cropping systems (composed of three crops—mung, sweet potato, and peanut—grown singly or intercropped at different durations of overlap and under seven planting arrangements of corn) tested under three fertilizer levels and four weed control levels. Over 750 treatment combinations were possible, but our suggested design consisted of only 256 treatments, half of which were replicated while the rest had no replication. The evaluation of the design showed its potential for reducing the number of treatments to a manageable size without losing information on some important interactions.

Although the measurement of economic data may require plot sizes larger than that of agronomic data, replication may not be necessary for achieving the required precision in the former. Thus more than one plot size should be used in a trial—larger plots (without replication) for the collection of economic and agronomic data, and smaller plots (with replications) for agronomic data.

Plant physiology

The grain yield of an early maturing line, IR747B2, planted year-round at Los Baños was highly positively correlated with solar radiation and negatively correlated with daily mean temperature during the 25-day period before flowering. The derived formula of climatic productivity index predicts that a combination of high solar radiation and low daily mean temperature will give high yields. ☐ Under moisture stress conditions, stomates of rice leaves are closed on sunny days, photosynthetic activity reaches a low plateau at low sunlight intensity, hence a considerable portion of the strong sunlight is wasted. Large varietal differences were found in cuticular resistance, which could be used as one of the criteria for drought-resistant varieties. Increasing the tiller number or leaf area for greater yield potential will make upland varieties more susceptible to drought unless the increase is accompanied by other factors which will increase drought resistance. ☐ Further studies on varietal difference in net assimilation rate indicate that large difference exists only under strong sunlight. ☐ A survey of the flood damage in the Philippines confirmed our earlier laboratory findings—the longer the duration of submergence and the younger the plants, the lower is the relative survival and the greater the damage. ☐ Studies on the biology of *S. Maritimus* showed that flowering can be induced by cutting the 140-day-old plants, coinciding with the rice harvest. This weed grows at a faster rate than rice. The growth is very sensitive to light intensity.

CLIMATIC INFLUENCE ON YIELD

In past studies, great emphasis was placed on effect of solar radiation on ripening and hence rice yield. In our analysis of grain yield of IR8, however, grain number per square meter was highly correlated with yield, and there was not much variation in filled-grain percentage or 1,000-grain weight (1968 Annual Report). Since grain number is determined before flowering, it is logical to examine climatic influences on grain number as well as on grain filling.

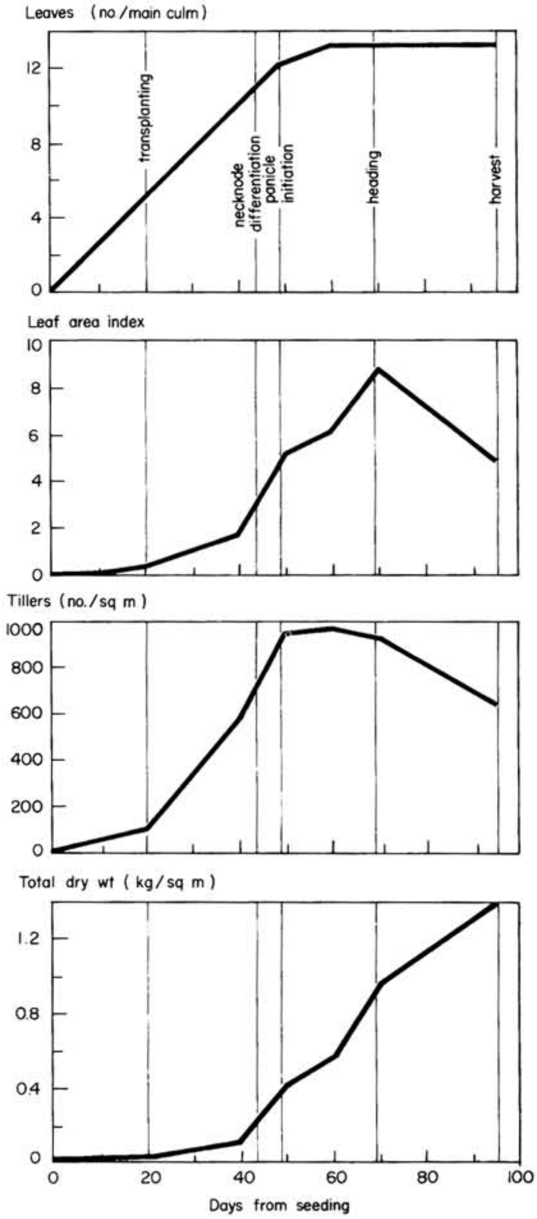
In the past, the effect of temperature on grain number has been totally neglected. Controlled environment studies, however, have shown that temperature during panicle development affects grain number (1972 Annual Report).

To examine climatic influence on yield components and yield, an early maturing line, IR747B2-6, was planted in the field every 2 weeks, giving 26 crops in 1 year from July 1972. Seven crops were excluded from the analysis because of severe lodging and damage by diseases and insects.

Growth characteristics of IR747B2-6. IR747B2-6 matures in 96 days from sowing to harvest at Los Baños throughout the year. It develops 13 leaves on the main culm (fig. 1). Panicle initiation occurs about 20 days before flowering. The estimated date for necknode differentiation stage is 25 days before flowering, about 7 to 8 days later than that for medium-maturing varieties. At 10 × 10 cm spacing and with 100 kg/ha N, it develops sufficient leaf area index and enough tillers for maximum yield (1970 Annual Report).

Yield and yield components. Grain yields of 19 crops (fig. 2) ranged from 4.6 to 7.1 t/ha. Plantings from December through March gave high yields. Grain yields were highly correlated with total dry weight ($r = 0.856^{**}$), indicating that high photosynthetic production was simply related to high grain yield. Grain yield of rice can be expressed: $Y = NFW \times 10^{-5}$, where Y is grain yield (t/ha), N is grain number per square meter, F is filled grain percentage, and W is 1,000-grain weight. Under normal weather conditions, grain number is determined before flowering, 1,000-grain weight is determined partially before and partially after flowering, and filled grain percentage is determined at and after flowering. Among the yield components measured, grain number per square meter was most variable, 1,000-grain weight was somewhat variable, and filled-grain percentage was fairly constant.

Multiple regression analysis indicated that 81.4 percent of the total variation in yield could



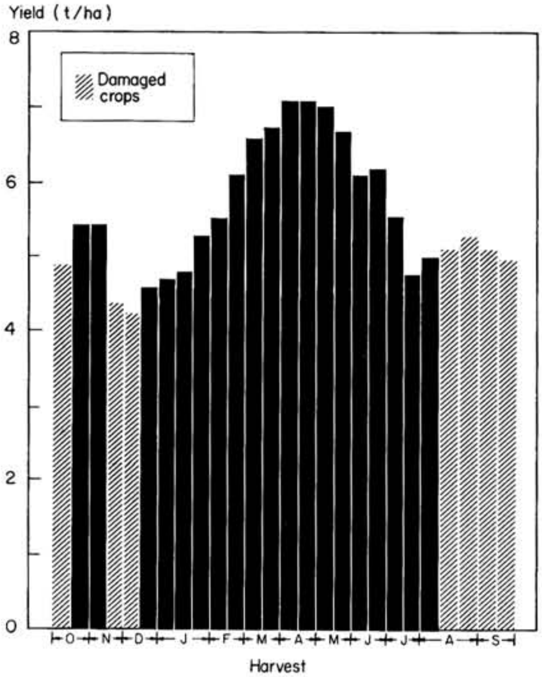
1. Growth process of IR747B2-6 planted at 10 × 10 cm spacing with 100 kg/ha N at IRRI.

be explained by N, F, and W. The relative importance of the three variables, as evaluated from standard partial regression coefficients, was 0.614 for N, 0.212 for F, and 0.345 for W. Thus, grain number per square meter is almost twice as important as grain weight and approximately three times as important as filled-grain percentage in estimating yield.

By means of correlation coefficients as well as multiple regression analysis, we computed the percentage contribution of yield components, individually or in combination, to yield. N alone explained 60% of yield variation (Table 1) while the combination of all the yield components accounted for 81% of yield variation: F and W together accounted for only 21%. If the contribution of all the yield components is taken as 100, which would be true if there were no error in measurement, the contribution of N becomes 74 percent. Thus grain number clearly was the most important yield component limiting yield in this experiment.

Climatic influence on yield. To examine effects of solar radiation and temperature on yield and yield components, the growth of the IR747 line was divided into three 25-day periods: 1) transplanting to necknode differentiation, 2) necknode differentiation to flowering, 3) flowering to maturity.

We found a high correlation between grain number per square meter (N) and solar radiation during period 2 (S_2) and temperature during period 2 (T_2) (fig. 3). This relationship can be written $N/S_2 = f(T) = 278–7.07\ T_2$. This equation implies that grain number per square meter is positively correlated with solar radiation during period 2, that is, 25 days before flowering, and negatively with daily mean temperature during the same period. The negative correlation between grain number and temperature agrees well with the results of controlled environment studies (1972 Annual Report). The above equation is rewritten $N = f(S, T) = S_2\ (278–7.07\ T_2)$. This implies that grain number of the IR747 line can be estimated in terms of solar radiation and temperature. Since grain number determines potential grain yield, the proposed function, $f(S, T)$, is called potential climatic productivity index. The correlation coefficient between measured grain number and potential



2. Grain yields of IR747B2-6 planted every 2 weeks. Shaded crops were damaged by lodging, insects, and diseases. IRRI, 1972 to 1973.

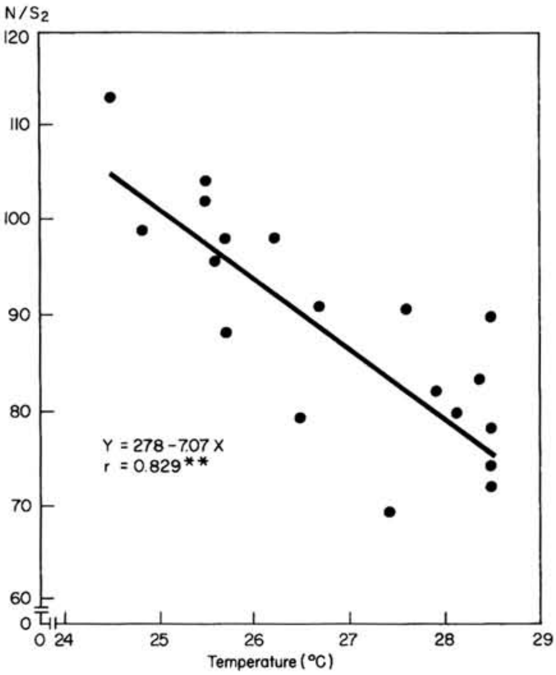
climatic productivity index was 0.888**.

Using 18.1 g for 1,000-grain weight and 86 percent filled grains (the mean values of the 19 crops in this experiment), we can estimate grain yield of the IR747 line: $Y = S_2\ (278–7.07\ T_2) \cdot 0.86 \cdot 18.1 \cdot 10^{-5}$. Since the computed yield is expressed in terms of solar radiation and temperature, it is called climatic productivity index. This index is highly correlated with actually measured yield (fig. 4) which implies that yield of the IR747 line at Los Baños is positively correlated with daily solar radiation and negatively with daily mean temperature during the 25-day

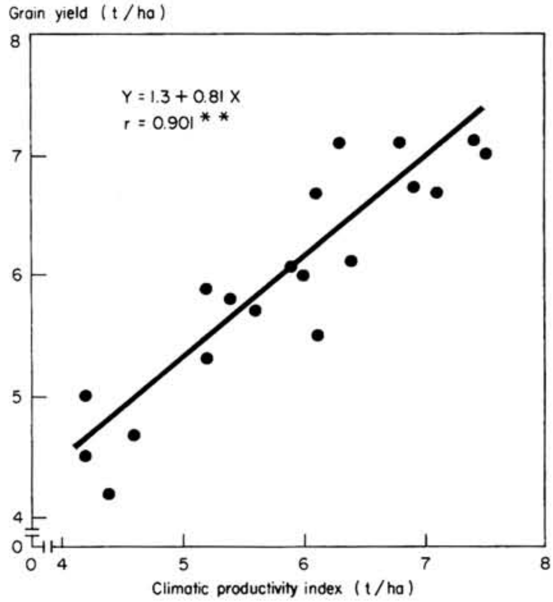
Table 1. Contribution of each yield component to grain yield.

Variables[a]	Contribution to total variation in yield (%)
N	60.2
F	21.2
N and F	75.7
N and W	78.5
N and F and W	81.4

[a]N = grain number per square meter; F = filled grain percentage; W = 1,000 grain weight.



3. Grain number per square meter (N) and solar radiation (S_2) in relation to daily mean temperature during the period of 25 days before flowering.



4. Grain yield in relation to climatic productivity index.

period before flowering. We also obtained a high correlation between grain yield and solar radiation during the ripening period (r = 0.834**). Although many workers have reached the same result, we found that solar radiation during the ripening period is highly correlated also with potential climatic productivity index in our experiment at Los Baños (r = 0.831**). Thus the high correlation between yield and solar radiation during ripening period may be only superficial.

To examine direct effect of solar radiation on yield, the correlation coefficient was computed for ripening grade and solar radiation during ripening period. Ripening grade is the product of filled grain percentage and 1,000-grain weight, and is considered a good indication of degree of ripening. Ripening grade, however, was loosely correlated with solar radiation during ripening period (fig. 5).

The evidence seems to indicate that grain number is the most important factor limiting grain yield, and it is highly correlated with solar radiation and temperature during the 25-day period before flowering, that is, from necknode differentiation to flowering. Solar radiation during the ripening period has a slight effect on ripening, but less than previously believed. This conclusion seems to be valid when daily solar radiation is more than 300 $cal \cdot cm^{-2} \cdot day^{-1}$.

In our experiment, the size of sink (grain number) was most limiting to grain yield, and hence solar radiation and temperature during the period when the sink size is determined are the strongest influences on grain yield at Los Baños.

A combination of high solar radiation and low temperature gives high grain yields (fig. 6). The concept of climatic productivity index provides a way to assess relative rice productivity for different localities under different climatic environments.

PHYSIOLOGY OF DROUGHT RESISTANCE

Leaf resistance and moisture stress. Under most conditions the major path of water loss by the plant is stomatal transpiration. Stomatal transpiration is controlled by stomatal aperture which is in turn regulated by light and moisture supply. To study relationships between leaf resistance (combined resistance of stomates and cuticle), moisture stress, and solar radiation, IR5 plants

Table 2. Effect of moisture stress on dry weight of different plant parts, number of tillers, plant height, and leaf area[a]

Field moisture capacity during treatment (%)	Dry wt (g/pot) Leaf	Culm	Root	Total	Tillers (no.)	Plant ht (cm)	Leaf area (sq cm)
Flooded	21.1	29.9	18.2	69.2	69	84	6200
70	14.7	22.4	8.4	45.5	53	72	4200
50	10.6	16.6	5.0	32.2	49	66	2700
35	6.3	8.6	2.5	17.4	37	60	1700

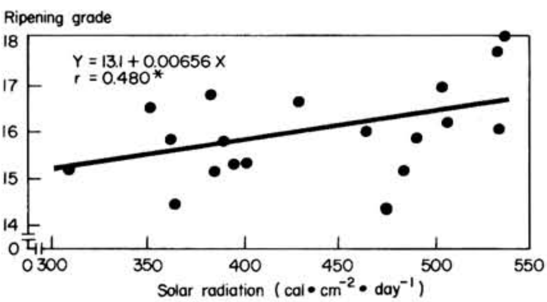
[a]Plants under upland conditions were grown at near-field capacity for the first 35 days and then subjected to the specified soil moisture stress for 3 weeks.

were grown in pots under flooded and upland conditions at near-field capacity for 35 days. The plants grown under upland conditions were then subjected to one of three water regimes—70 percent, 50 percent, or 35 percent of field moisture capacity—for 3 weeks. Plants under flooded conditions were allowed to continue to grow normally for the same period.

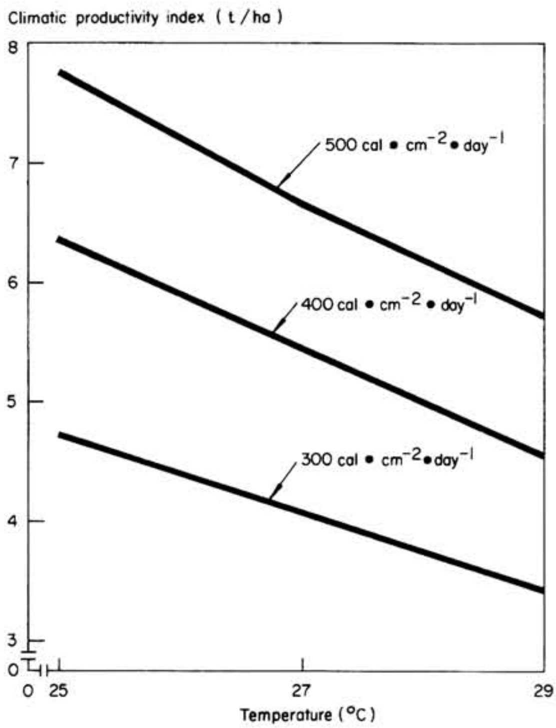
The 3-week moisture stress greatly affected leaf area and dry weight (Table 2). Plant height and tiller number were less affected.

On cloudy days, visible symptoms of moisture stress occurred only on plants grown at 35 percent of field moisture capacity while on sunny days all the plants grown under any moisture stress level showed some visible signs early or late in the day. Diurnal changes in leaf resistance of the second fully developed leaf on the main shoot were measured with a diffusive porometer on cloudy and sunny days during the stress period.

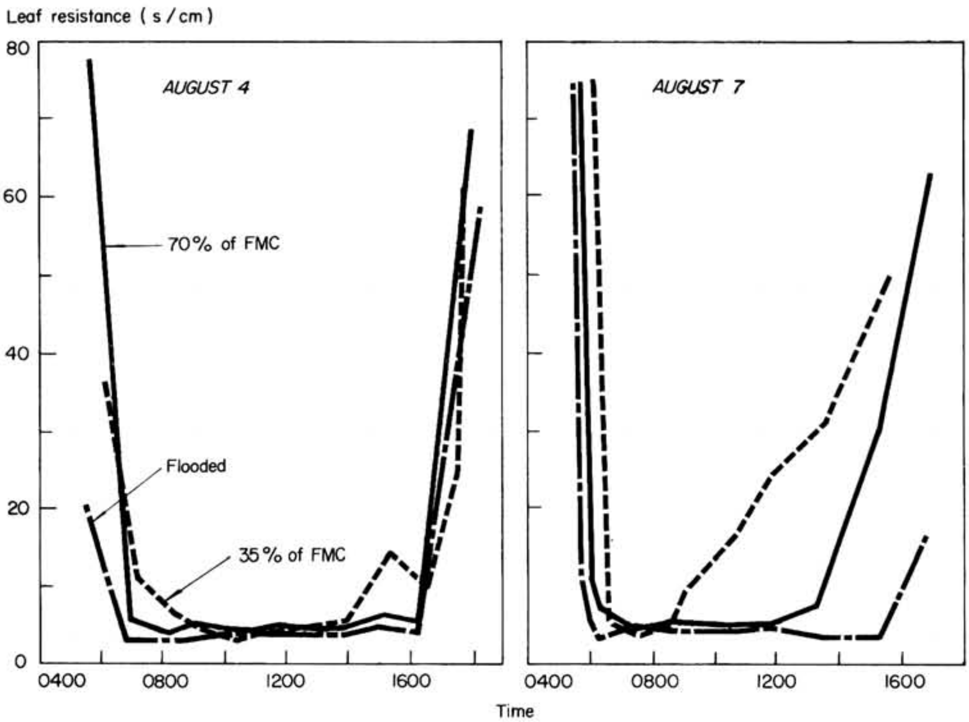
The diurnal changes in leaf resistance of the plant grown in flooded soils had a similar pattern regardless of weather conditions (fig. 7). The leaf resistance values were high early in the morning and late in the afternoon. During the daytime, the leaf resistance values remained low, around 2.5 to 5.0 s/cm. This implies that the rice plants grown in the flooded soil had little or no moisture stress, and hence the stomates were open during the daytime. Under such conditions, the plants may use solar radiation for photosynthesis at maximum efficiency. The plants grown under upland water regimes showed similar diurnal changes in leaf resistance on very cloudy days. On sunny days, however, leaf resistance values of those plants started rising rapidly in the afternoon or even in the morning depending on weather conditions. These measurements show that even under the same soil water regime,



5. Ripening grade in relation to solar radiation during ripening period. Ripening grade is the product of filled-grain percentage and 1,000-grain weight.



6. Climatic productivity index in relation to solar radiation and daily mean temperature during the period of 25 days before flowering.



7. Diurnal changes in leaf resistance (IR5) on August 4, 1973 (cloudy) and August 7 (sunny) in plants subjected to different levels of field moisture capacity (FMC).

plants are subjected to more severe moisture stress on sunny days than on cloudy days. Thus, under conditions of moisture stress, a high level of solar radiation will induce stomatal closure during the daytime, and hence radiation will not be used by the plant for photosynthesis. Therefore, relationship between solar radiation and plant growth in flooded conditions should be quite different from the relationship under moisture stress. Under flooded conditions, increasing amounts of incident solar radiation will increase plant growth. Under moisture stress, however, high solar radiation will not have a favorable effect on plant growth. Based on theoretical consideration of the light-photosynthesis curve, it is more likely that moderate incident solar radiation is more favorable for plant growth than high solar radiation. Thus, upland rice culture in partial shade such as under coconut trees merits more attention.

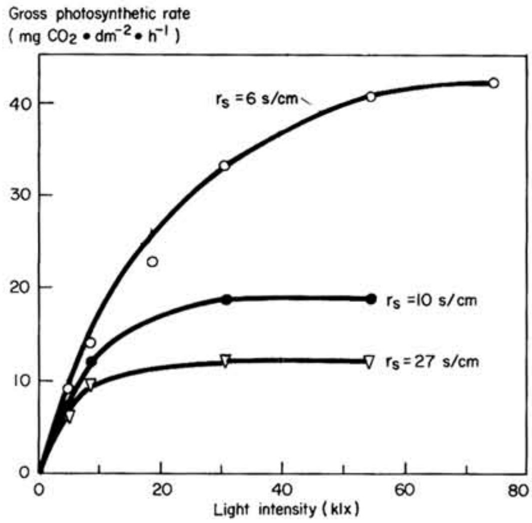
Photosynthesis under moisture stress. Since leaf resistance increases under moisture stress, photosynthesis, or intake of CO_2 which occurs through stomates on leaves, and transpiration should be affected by increased leaf resistance under moisture stress. To study how internal moisture stress affects photosynthesis of rice leaves, we grew IR5 plants in pots for 34 days with sufficient water and then induced moisture stress by withholding water from the pots. Leaf resistance was taken as an indication of internal moisture stress and measured with a diffusive porometer. The measured resistance values were multiplied by 1.71 to obtain the resistance to carbon dioxide.

Both the maximum photosynthetic rate and the saturation light intensity varied with varying leaf resistance (fig. 8) with increased leaf resistance, the photosynthetic rates reached maximums at low light intensities and the maximums were lower than those with less leaf resistance. This implies that high solar radiation is not fully used for photosynthesis under moisture stress. In other words, a large proportion of strong sunlight is wasted under moisture stress. Strong sunlight may even have adverse effects on rice growth by raising leaf temperature and by inducing stomatal closure early in the day.

Leaf rolling and moisture stress. A rice leaf rolls under soil moisture stress. Hence, leaf rolling indicates internal moisture stress for a variety. But under the same soil moisture stress one variety may roll its leaves while another does not. To examine leaf rolling of different varieties under the same soil moisture stress, two varieties were grown in the same pot. Water was withheld from the pots to induce internal moisture stress. Degree of leaf rolling was recorded along with measurement of leaf resistance (Table 3). Leaves of 81B25 were rolled without moisture stress. This was confirmed by measurement of leaf resistance. Under severe moisture stress, as indicated by high leaf resistance, degree of leaf rolling varied: 81B25 rolled more than IR20, M1-48 rolled more than IR5.

If different degrees of leaf rolling occurs at a similar leaf resistance as we observed in this experiment, leaf rolling could be regarded as a desirable character for drought-resistant varieties. Leaf rolling should decrease transpiration loss, thus conserving moisture in the soil.

Plant changes induced by moisture stress. A series of physiological events occurs when the rice plant is subjected to moisture stress (Table 4). Except for sterility, all characters are highly dynamic and hence reversible. Once moisture stress is relieved, most characters return to normal conditions. Therefore, moisture stress



8. Photosynthetic rates of rice leaves under moisture stress at different light intensities (r_s = resistance).

around flowering time, which induces high sterility, is the most critical for rice yield.

SCREENING FOR DROUGHT RESISTANCE

Field assessment. To determine varietal differences in drought resistance under the field conditions, we grew 20 varieties at the IRRI farm under three water regimes. The degree of moisture stress was varied by changing frequency of irrigation. Plant height under moisture stress relative to that under no moisture stress was

Table 3. Leaf rolling and leaf resistance of four varieties grown in pots.

Variety	Water withheld (days)	Leaf resistance (s/cm)	Leaf rolling
		Pot A	
IR20	1	2.5	None
	2	2.8	None
	3	61.0	Half
81B25	1	2.8	Slight
	2	3.9	Slight
	3	80.0	Complete
		Pot B	
IR5	1	3.4	None
	2	3.9	None
	3	75.0	Slight
M1-48	1	5.1	None
	2	6.9	None
	3	79.0	Complete

Table 4. Physiological and morphological changes induced by moisture stress.

Feature	Without moisture stress	With moisture stress
	Visible features	
Plant height	Normal	Reduced
Tiller	Normal	Reduced
Leaf area	Normal	Reduced
Leaf rolling	No	Yes
Sterility	Low	High
	Non-visible features	
Stomates	Open	Closed
Major path of water loss	Stomatal transpiration	Cuticular transpiration
Leaf water potential	High	Low
Leaf temperature	Low	High
Heat tolerance	Low	High
Photosynthesis	High	Low
Proline content	Low	High

Table 5. Drought resistance of 20 varieties as assessed by plant height reduction under moisture stress in field, IRRI, 1973 dry season.

Designation	Plant ht (cm)[a]	Relative plant ht[b]		
	No stress	Moderate stress	Severe stress	Mean
E425	75	79	77	78
Miltex	86	77	68	73
M1-48	107	72	69	71
Jappeni Tungkungo	92	68	73	71
OS4	89	68	67	68
Palawan	97	69	66	68
Dular	96	70	61	66
Rikuto Norin 21	85	74	57	66
PI215936	55	74	58	66
Azucena	105	67	61	64
Azmil	88	73	54	64
IR5	62	70	56	63
IR127-80-1	84	69	52	61
81B25	88	65	54	60
IR442-2-58	66	60	57	59
NARB	96	61	52	57
IR8	62	61	47	54
IR1529-680-3	65	60	47	54
IR841-67-1	62	57	48	53
IR20	64	57	44	51

[a]Measured 41 days after sowing. [b]Taking plant height at no moisture stress as 100.

taken as a measure of drought resistance. Plant height is one of the plant characters most sensitive to moisture stress.

Most upland varieties seemed to be more resistant to drought than lowland varieties (Table 5). Among lowland varieties, IR5 can be regarded as relatively resistant and IR20, as very susceptible. These results seem to agree well with those obtained by the varietal improvement department. Some physiological characters, such as heat tolerance and quick closure of stomates in response to moisture stress, confirm that E425, M1-48, OS4, and Palawan are resistant and IR20 is susceptible (1972 Annual Report).

Cuticular resistance. High cuticular resistance of the leaf surface is a desirable characteristic for drought resistance because when stomates are closed under moisture stress, cuticular transpiration becomes the major path of water loss by the plant. Significant differences exist in cuticular resistance among plant species. In general, aquatic species which live in water have small resistance values while xerophytic species that are adapted to dry climates have high values of resistance. The cuticular resistance values of mesophytes, to which most crop species belong, come in between the above two. Little attention has been paid to varietal difference in cuticular resistance for a given species. Since rice grows under diverse water regimes from upland to flooded conditions, a large variation in cuticular resistance may exist among varieties and this difference might be related in part to drought resistance of rice varieties.

Measuring cuticular resistance of rice leaves is difficult because the rice plant has stomates on both sides of its leaves. We measured cuticular resistance with a diffusive porometer in the dark and when the plant was fully turgid.

The cuticular resistance values of 35 rice varieties varied from 30 to 68 s/cm (Table 6). Some varieties that perform well under upland conditions showed high cuticular resistance values. These were Azmil, Rikuto Norin 21, several RP-79 lines, Azucena, M1-48, IR442-2-58, Bala, and IR5. On the other hand, some upland varieties such as Palawan, E425, Miltex, and OS4 had a low cuticular resistance. Among these varieties, Palawan and OS4 are known to have longer and more branched roots. It is not surprising that more than two mechanisms confer drought resistance.

Sorghum and corn are known to be much more resistant to drought than rice. Indeed, sorghum and corn have higher cuticular resistance values (Table 6). Their cuticular transpiration is only one-half to one-fourth that of rice varieties.

The measurements of the cuticular resistance of rice varieties indicate that there is a considerable variation in cuticular resistance of rice leaves among varieties, and high cuticular resistance accounts in part for the resistance of rice varieties to drought. It should be desirable to combine cuticular resistance with long and well-branched roots in one variety.

Proline assay. The proline content of plant tissues increases when plants are subjected to moisture stress. Therefore, increase in proline content can be an indication of physiological dryness. In barley, increase in proline content in leaf tissues is positively correlated with drought resistance.

In a preliminary study to see if proline assay can be used for screening drought-resistant rice

Table 6. Cuticular resistance of 35 rice varieties, and sorghum and corn.

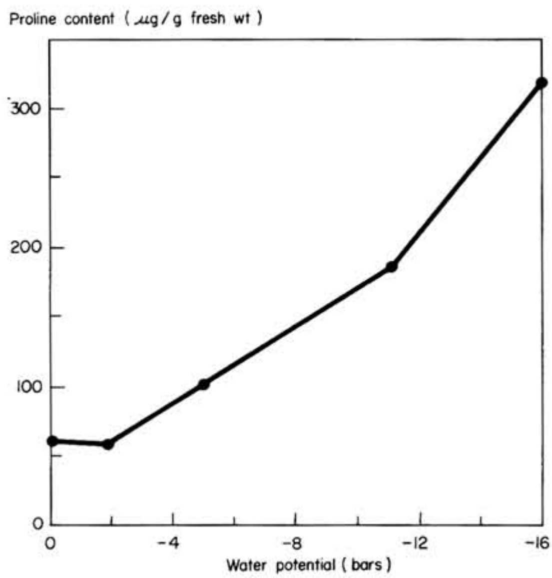
Variety	Cuticular resistance (s/cm)
Sorghum (Cosor 3)	116
Corn (Early Thai composite)	112
Azmil	68
Rikuto Norin 21	66
RP-79-19	66
RP-79-14	63
RP-79-13	60
RP-79-16	60
Azucena	60
NARB	58
RP-79-23	57
M1-48	56
IR442-2-58	54
Bala	51
Sigadis	49
Taichung Native 1	49
IR5	48
N-22	47
RP-8-8	47
IR841-67-1	47
RP-7-2	44
IR1529-680-3	43
IR1561-228-3	43
Jappeni Tungkungo	42
IR26	41
IR8	37
81B25	37
IR1541-76-3	36
IR24	35
PI-215936	35
Palawan	33
IR127-80-1	33
E425	33
IR20	32
Dular	30
Miltex	30
OS4	30

varieties, we examined increase in proline content in rice leaves in response to moisture stress. We found that proline content in leaves of intact plants (IR747B2-6) increased from 50 $\mu g/g$ fresh weight without moisture stress to about 7,000 $\mu g/g$ under severe moisture stress.

Technically, it is difficult to subject many intact plants to the same degree of moisture stress at one time. To simplify the technique of stress induction we examined use of leaf segments. Rice leaves were cut into 1-cm segments and 0.5 g of the leaf segments was placed in a petri dish containing nutrient solution plus polyethylene glycol for about 24 hours. The amount of polyethylene glycol added to nutrient solution specifies the water potential of the system, a measure of moisture stress. Proline content in leaf segments did not increase down to −2 bars but below that proline content increased sharply with decreasing water potential (fig. 9).

PHOTOSYNTHESIS

Varietal difference in net assimilation rate. Varietal differences in the net assimilation rate of 12 varieties selected from 313 varieties (1972 Annual Report) were further tested under high and low solar radiation (Table 7). Varietal differences were clearer under high solar radiation than under low solar radiation. CP231 and Molaga Samba G18 showed consistently high net assimilation rates under both high and low solar radiation. BJ1 grew very vigorously and still had a high net assimilation rate. High net assimilation rates were closely correlated with nitrogen content per unit leaf area. The effect of solar radiation on specific leaf weight was also very clear. Specific leaf weight became much smaller under a low solar radiation than under a high solar radiation. In other words, the leaves became much thinner which, in turn, was correlated with lower net assimilation rate under a low solar radiation.



9. Accumulation of proline in rice leaf segments when floating in polyethylene glycol solutions of different water potentials.

Table 7. Net assimilation rate (NAR), nitrogen content per unit leaf area (N), and specific leaf weight (SLW) of 12 selected varieties under high and low solar radiation.

Variety	At high solar radiation[a]			At low solar radiation[b]		
	NAR ($mg \cdot cm^{-2} \cdot day^{-1}$)	N (mg/dm^2)	SLW (mg/cm^2)	NAR ($mg \cdot cm^{-2} \cdot day^{-1}$)	N (mg/dm^2)	SLW (mg/cm^2)
CP231	2.00	24	4.6	0.94	16	3.1
Molaga Samba G18	1.96	20	3.7	.97	13	2.7
BJ1	1.76	20	3.9	.76	14	2.6
Siam	1.74	20	3.7	.80	14	2.8
IR747B2	1.55	19	3.4	.79	12	2.6
MTV7	1.50	17	3.2	.78	14	2.7
Gend Jah Banten	1.44	19	3.6	.86	14	2.9
Zenith	1.44	19	3.3	.87	14	2.6
IR5	1.42	18	3.1	.84	13	2.4
Sigadis	1.40	16	3.0	.77	12	2.4
O. glaberrima[a] (Acc. 100932)	1.38	16	3.2	.82	12	2.4
O. glaberrima[a] (Acc. 100989)	1.30	14	2.9	.71	10	2.2

[a]475 $cal \cdot cm^{-2} \cdot day^{-1}$. [b]284 $cal \cdot cm^{-2} \cdot day^{-1}$.

Nitrogen nutrition and stomatal resistance. Nitrogen application affects photosynthesis by increasing leaf area and maintaining high photosynthetic rate per unit leaf area. To study the second function of nitrogen, we grew IR8 in culture solution at a low and a high nitrogen concentration. We measured photosynthetic rate, specific leaf weight, nitrogen content per unit leaf area, and leaf area. We also measured changes in stomatal resistance as affected by nitrogen nutrition. Specific leaf weight of fully developed leaves was not affected by nitrogen supply (Table 8). Nitrogen supply changed nitrogen content per unit leaf area, which in turn was closely correlated with photosynthetic rate.

Using the second leaf, we found that stomatal resistance of the leaf was not affected by nitrogen supply. This suggests that photosynthetic rate of young rice leaves is simply related to nitrogen content per unit leaf area, and not to either specific leaf weight or stomatal control. With the fourth leaf, however, low nitrogen supply decreased nitrogen content per leaf area, but increased stomatal resistance. High nitrogen supply had reverse effects. Stomatal behavior in rice leaves apparently is partly controlled by nitrogen nutrition. Thus, in rice, nitrogen content per unit leaf area, is the most useful parameter relating to photosynthetic rate. This experiment demonstrated that nitrogen nutrition has a pronounced effect on photosynthetic rate of a rice leaf even after it has been fully developed.

Soil carbon dioxide flux and rice photosynthesis. In field photosynthesis, the atmosphere and the soil are the source of CO_2. We estimated the contribution of soil CO_2 to the photosynthesis of rice when the field was kept flooded and when it was drained.

Soil CO_2 flux was increased by drainage (Table 9). Estimated contribution of soil CO_2 to gross photosynthesis was 5 percent for the flooded plots and 7 percent for the drained plots. The effect of drainage may in part account for the "mid-season drainage" effect on rice yield. The contribution of soil CO_2 could be greater when a soil is higher in organic matter content or when crop growth rate is smaller on cloudy days. The results of this experiment along with other information indicate that the atmosphere is the most important source of CO_2 for photosynthesis of the rice plant, soil CO_2 released into atmosphere is of secondary importance, and CO_2 absorbed by roots is the least important.

NITROGEN FERTILIZERS AND NUTRITIONAL DISORDERS

Zinc deficiency or sulfur deficiency may be induced by continuous and intensive rice cropping in a field. Since different nitrogen fertilizers have different chemical compositions, they may

Table 8. Effect of nitrogen supply on photosynthesis and stomatal resistance of single leaves.

Treatment[a] (ppm N)	Photosynthetic rate ($mg\ CO_2 \cdot dm^{-2} \cdot h^{-1}$) 0 days	4 days	7 days	Stomatal resistance (s/cm) 0 days	4 days	7 days	Specific leaf wt (mg/cm^2) 0 days	4 days	7 days	Nitrogen content of leaf (mg/dm^2) 0 days	4 days	7 days
					Second leaf							
10– 10	27.1	24.5	20.4	3.8	4.4	4.1	2.35	2.41	2.27	8.1	7.9	7.0
100–100	43.6	41.6	42.4	3.1	2.7	3.1	2.69	2.85	2.80	15.5	15.5	15.5
100– 0	43.6	34.7	30.8	3.1	4.1	5.5	2.69	2.65	2.56	15.5	11.2	10.6
10–100	27.1	38.8	35.2	3.8	3.2	3.2	2.35	2.50	2.59	8.1	12.1	12.4
					Fourth leaf							
10– 10	11.4	9.8	—	15.4	27.5	—	2.02	2.12	—	5.8	5.0	—
100–100	37.1	30.8	31.5	3.9	4.6	6.8	2.61	2.83	2.53	14.1	13.5	13.0
100– 0	37.1	17.8	13.8	3.9	12.1	16.2	2.61	2.61	2.42	14.1	8.9	7.7
10–100	11.4	21.3	25.1	15.4	5.0	3.4	2.02	2.37	2.30	5.8	9.6	9.6

[a]The plants were grown in culture solutions of different nitrogen concentrations as indicated in the first column for 4 weeks and then were transferred to those as indicated in the second column.

differentially affect the incidence of zinc deficiency or sulfur deficiency or other problems.

To test effects of three nitrogen fertilizers, ammonium sulfate, ammonium chloride, and urea, on yield, total dry matter production, and possible nutritional problems, we set up a long-term field experiment at the IRRI farm. Data on total dry weight as well as grain yield were collected to provide a realistic measure of photosynthetic production.

Grain yield ranged from about 19 to 24 tons per year while total dry matter production ranged from about 46 to 51 tons per year (Table 10). Ammonium sulfate produced slightly higher total dry matter and grain yield than ammonium chloride or urea. But none of the crops so far had any visible indication of nutritional problems.

UPLAND RICE

Characteristics of upland rice. The differences between upland and lowland varieties and the value of these differences for upland conditions must be understood in order to improve upland varieties. We studied nine upland and nine lowland varieties and found that the upland varieties have certain characteristics distinct from those of lowland varieties (Table 11). Whether these characteristics are necessary for drought tolerance and compatible with requirements for high grain yields must be evaluated in detail. The answers may lead to a better understanding of what the ideal plant type for upland conditions is.

Plant height at harvest. The upland group was about 36 cm taller than the lowland group. The height of the upland rice varieties makes them susceptible to lodging although lodging is not serious under upland conditions. Tall varieties, however, may be better able to compete with weeds, an important problem in upland culture. With the use of herbicides in modern agriculture, however, this advantage may no longer be so great. It is also possible that among the drought-resistant types, the tall varieties have higher grain yields.

Tiller number. The upland varieties tested tended to have fewer tillers than the lowland varieties. Some workers have recommended therefore that the tiller number of the upland

Table 9. Carbon balance between rice photosynthesis and soil CO_2 flux.

Soil condition	Rate ($g\ CH_2O \cdot m^{-2} \cdot day^{-1}$) Net dry matter production	Gross photosynthesis	Daytime soil CO_2 flux	Estimated contribution (%) of soil CO_2 to Net dry matter production	Gross photosynthesis
Flooded	22	36	2.0	9	5
Drained	26	44	3.2	12	7

Table 10. Grain yield and total dry matter of four continuous crops a year with different kinds of nitrogen fertilizers, IRRI, 1972 and 1973.

Crop no.	Month planted	Variety	Yield (t/ha)			Total dry wt (t/ha)		
			Ammonium sulfate	Ammonium chloride	Urea	Ammonium sulfate	Ammonium chloride	Urea
				1972				
1	January	IR8	9.1	8.9	8.8	17.9	18.3	17.1
2	May	IR747B2-6	4.2	3.7	3.1	10.6	10.2	9.9
3	July	IR1561-228-3	6.1	6.1	6.4	12.9	12.9	12.4
4	October	IR747B2-6	4.7	4.3	4.5	9.6	8.9	9.1
Total			24.1	23.0	22.8	51.0	50.3	48.5
				1973				
5	January	IR8	7.7	7.6	7.7	16.3	16.0	16.2
6	May	IR747B2-6	5.0	4.0	4.2	11.3	11.5	12.0
7	July	IR1561-228-3	5.1	4.5	4.8	12.2	11.3	11.7
8	October	IR747B2-6	3.3	3.0	3.2	7.2	6.8	7.0
Total			21.1	19.1	19.9	47.0	45.6	46.9

varieties be increased. This recommendation should be carefully studied since low tiller number may have a definite advantage when water stress is severe.

Leaf characters. Upland varieties have fewer leaves per plant than the lowland varieties, a consequence of fewer tillers per plant. Upland varieties also have bigger and thicker leaves than the lowland varieties. The big leaves possibly indicate that more photosynthate is available per tiller of the upland variety, accounting for the heavier tiller, thicker culm, and taller plant.

The reduction in weight of leaves 2 hours after detachment showed that the upland varieties lose moderately less weight than the lowland varieties. This indicates that upland varieties have better control of transpiration.

From the few characters measured it is apparent that the upland varieties have definite characters which distinguish them from the lowland varieties. These and other characters should be evaluated carefully in terms of their contribution to drought tolerance and grain yield.

Leaf area and drought resistance. Leaf area may be an important aspect of drought resistance in the existing upland rice varieties. The greater the transpiring surface of a plant, the more water that is lost and the greater the effect of moisture stress on the plant. A large leaf area, however, does not necessarily mean a high transpiration rate per plant since the plant may have other ways to reduce transpiration or increase water-absorbing capacity.

An experiment was set up to examine leaf area in relation to plant damage when moisture stress is imposed. M1-48, a tall, low-tillering upland variety, and IR442-2-58, a short, high-tillering lowland variety which has shown reasonably high yields under upland conditions, were used. The leaf area of one set of plants was reduced by 20 percent by removing all lower blades. In another set, leaf area was varied by planting four seeds per pot instead of only one seed per pot. Watering of the plants was stopped for 9 days at 40 days after sowing.

Plants in which the leaf area was reduced by cutting showed moisture stress symptoms much later than the intact plants. This is mainly the result of small transpiring surface. Moisture stress reduced the leaf area of the IR442-2-58 line more than that of M1-48 (Table 12). With no stress (control), IR442-2-58 plants whose

Table 11. Differences between upland and lowland rice varieties.

Variety type	Plant ht (cm)		Tillers (no./hill)		Leaves (no./hill)		Leaf size (sq cm)		Specific leaf wt (mg/sq cm)		Reduction in fresh wt of detached leaves (%)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Upland	118	107-142	8.6	4.7-19.5	40	25-82	45	29-59	3.05	2.3-3.6	17.5	15.2-24.8
Lowland	82	68-102	18.2	14.0-23.5	84	70-101	24	19-31	2.67	2.2-3.0	20.7	17.2-23.5
Difference	36**	—	−9.6**	—	−44**	—	21**	—	0.38**	—	−3.2**	—

lower blades were removed had a significantly greater leaf area than comparably treated M1-48 plants, but moisture stress made the leaf areas the same. Moisture stress also reduced the leaf area of intact IR442-2-58 plants more than that of IR442-2-58 plants that had the lower blades removed.

Thus a large leaf area has little advantage for plants subjected to moisture stress because moisture stress reduces the leaf area to a level comparable to that of varieties that start with much smaller leaf areas.

Leaf area, especially under field conditions, can also be changed through the seeding rate. An increase in tiller number per unit area with higher seeding rate usually increases the leaf area. The effect of seeding rate on drought resistance was tested using one and four seeds per pot. With no stress, sowing four seeds per pot was definitely superior to one seed per pot, as measured by dry matter production at field capacity. When moisture stress was imposed, however, plants in the pots with four seeds showed the symptoms of moisture stress earlier than the plants in the pots planted with only one seed. Compared with the corresponding control, the decrease in dry matter production was 59 percent in the four-seed pots and 45 percent in the one-seed pots. After the moisture stress period, the difference in total dry weight between one and four seeds per pot was insignificant.

For the two plant densities, the decrease in leaf area as a result of the moisture stress was higher in the IR442-2-58 line (58%) than in M1-48 (46%). Although IR442-2-58 plants had a larger leaf area before the moisture stress treatment, afterwards it became smaller than that of M1-48. The difference is greater when based on leaf area per tiller.

Moisture stress decreased the tiller number per pot regardless of the number of the seedlings per pot or the variety used. But the four-seed pots had a relatively larger reduction than the one-seed pots.

Under moisture stress, IR442-2-58 had more tillers per unit area than M1-48, but for drought tolerance high tillering capacity or a high seeding rate may actually be a disadvantage. Upland varieties generally have low tiller number. To increase grain yields, medium-tillering varieties are needed. Plant density is usually critical under upland conditions, however. Since soil moisture is the main limiting factor under upland conditions, plant density must be adjusted to available moisture and not to available solar radiation and nutrients for high yield nor for control of weeds. Increasing the tiller number or leaf area for greater yield potential will make the upland varieties more susceptible to drought unless the increase is accompanied by other factors that will increase the variety's water-use efficiency or resistance to drought.

Table 12. Moisture stress and reduction in leaf area of plants with intact leaves and plants with 20 percent reduction in leaf area.

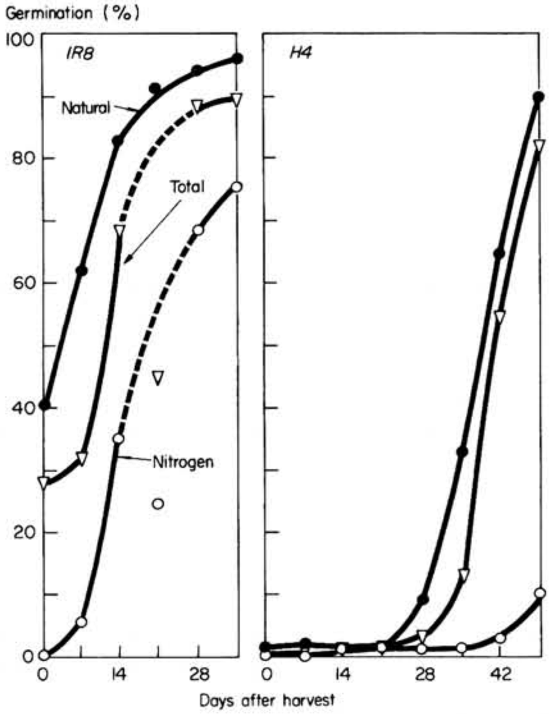
Leaf treatment	Leaf area[a] (sq cm/hill) Moisture stress	Control	Reduction (%)
	M1-48		
Intact	1410	2780	49
20% removed	1810	2430	26
	IR442-2-58		
Intact	9840	4300	77
20% removed	1700	4120	59

[a]LSD (5%) = 540.

VOLUNTEER RICE

Effect of planting methods. Previous studies showed that rice seeds buried in the paddy soil can germinate and grow as volunteer rice plants even after three cropping seasons. Our data showed, however, that volunteer rice will not be a problem in transplanted rice provided the volunteer variety and the planted variety do not have the same plant type and growth duration.

With the mechanization of rice culture, broadcast and drilled sowing may become increasingly widespread. Under these conditions the problems of volunteer rice may be serious. A field trial indicated that the competitive character of volunteer rice is not enhanced by drill-planting (0.8 volunteer plants/sq m) as compared with the transplanted method (0.9 plants/sq m). Both planting methods resulted in less volunteer rice than the uncropped plot (2.8 plants/sq m). The volunteer rice plants growing in the cropped plots had few tillers compared with those growing in the uncropped plots. The volunteer plants suffered from competition of the planted rice crop.



10. Germination of IR8 and H-4 seeds incubated in natural air or nitrogen gas (total is germination in nitrogen plus germination in air after removal from nitrogen).

Thus in transplanted and drilled sowings, the number of volunteer plants is relatively small and should not pose a serious problem for farmers except those producing certified seed.

Survival of seeds buried in flooded soil. Previous experiments showed that IR8 and H4 seeds remain viable even after 1 year in submerged soil, but H4 has a higher proportion of viable seeds. An experiment was conducted to find out if IR8 and H4 have different oxygen requirements. In nitrogen gas, no freshly harvested IR8 seeds germinated (fig. 10). Twenty-eight days after harvest, however, the dormancy of IR8 apparently was lost and the germination in nitrogen was more than 60 percent. That is nevertheless a low level compared with the control.

Germination of H4 was low in the nitrogen gas regardless of the state of dormancy of the seeds. H4 definitely needs a higher oxygen concentration to germinate. That could mean that H4 seeds buried in the soil will not germinate and eventually die unless brought to the soil surface. On the other hand, IR8 seeds will germinate even when deeply buried and no possibility of elongating to the soil surface exists. Since the viability of IR8 seeds in submerged soil is lower than that of H4, IR8 will give a lower percentage of volunteer rice in succeeding crops.

Table 13. Germination of intact and dehulled H4 seeds (stored for 49 days after harvest) in air or nitrogen gas.

Seed	Gas	Germination[a] (%)
Dehulled	Air	96 a
	N	65 b
Intact	Air	90 a
	N	10 c

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

The role of the hull in inhibiting the germination of H4 was studied by germinating dehulled seeds in nitrogen gas. Dehulling increased the germination percentage in nitrogen, but the germination was not as high as in air (Table 13). A reaction of the nitrogen with the hull definitely inhibits germination. Probably, nitrogen has a separate reaction in the seed causing inhibition even when the seed is dehulled.

The main difference between these two varieties seems to be in the hulls and their ability to remain dormant when oxygen concentration is low.

Table 14. Flood damage to newly transplanted rice (IR253-16-1) and rice at booting stage (C4-137).

Duration of submergence (days)	Degree of submergence	Survival (%)	Tillers (no./hill)
	IR253-16-1 (seedling stage)		
21	total	1	1.2
20	total	50	2.5
16	total	90	5.7
7	total	98	8.2
2	leaf tips above water	100	20.2
	C4-137 (booting stage)		
23	total	30	1.2
20	total	90	2.5
20	leaf tips above water	100	3.7
15	leaf tips above water	100	14.0
15	most leaves above water	100	15.0

Table 15. Response of selected varieties and lines to photoperiods of 10 to 16 hours.

Designation	Days to flower				Basic vegetative phase (days)	Photoperiod-sensitive phase (days)
	10 h	12 h	14 h	16 h		
			Tested March 3, 1973			
IR480-5-9	104	74	91	117	39	43
IR930-2-6	95	82	109	122	47	40
IR262-7-1	90	77	96	120	42	43
IR272-4-1	86	80	94	112	45	32
IR1514A-E666-9	81	76	94	120	41	44
BKN6517-63-4-3	97	100	146	159	62	62
BKN6517-9-2-2	90	90	138	144	55	54
Oryza nivara						
Acc. 101508	53	52	108	107	17	56
PTB28	66	57	113	110	33	56
			Tested July 7, 1973			
Azmil	91	94	96	103	56	12
OS4	87	87	92	97	52	10

SURVIVAL OF SUBMERGED SEEDLINGS

Previous greenhouse experiments indicated that the longer the duration of submergence and the younger the rice plants, the greater damage submergence does. In August 1972, Luzon, Philippines, suffered from a serious flooding. We surveyed crop growth at different levels of submergence in farmers' fields to verify our findings in the greenhouse.

The survey was made at Cabuyao, Laguna, where the rice lands slope gradually toward a 100-km-long lake. Since transplanting in the area was made at the same time, plants suffering different durations of submergence could be easily found as the floodwater receded. Plants submerged for longer time were also submerged deeper, however.

We found that the longer the plants were submerged, the lower their survival, and the greater the damage measured by tiller number per hill (Table 14). Findings at the booting stage are not directly comparable to those at the seedling stage since the varieties used and the degree of submergence were not the same. But there is an indication that survival is greater at later stages of growth.

PHOTOPERIOD

Another set of promising IRRI lines together with selected varieties were tested for their response to photoperiod. All the IRRI lines tested flowered under all photoperiodic treatments used (Table 15).

We also tested *Oryza nivara* for photoperiodic response. Unlike most of the wild species of rice, *O. nivara* is not strongly sensitive to photoperiod. It has a very short basic vegetative phase. The two upland varieties tested, M1-48 and OS4, were both insensitive to photoperiod.

AUTECOLOGY OF *SCIRPUS MARITIMUS* L.

Scirpus maritimus L. is a sedge that is rapidly spreading in the rice fields in the Philippines. It is a perennial weed that has proven to be difficult to control by ordinary measures. Ecological studies on this weed were continued.

Flowering. Under field conditions we observed that many shoots of *S. maritimus* bear inflorescences in the regrowth after the rice crop has been harvested. Previous attempts to make this plant flower in pot culture by manipulation of the photoperiod or moisture conditions of the soil failed. Since flowering shoots are only observed in the field after harvest, the cutting of the shoots during harvesting of the rice crop appeared to be connected with the flowering of this species. To test this hypothesis, *S. maritimus* shoots were cut at ground level at 100, 110, 120, 130, and 140 days after sowing.

Cutting the old shoots induced regrowth (Table 16). Only three new shoots per pot emerged from the uncut plants compared with

Table 16. Influence of cutting the shoots of *Scirpus maritimus* on flowering.

Age of cutting (days)	Total regrowth (shoots/pot)	Flower-bearing shoots (%)	Pots with flowers (%)
100	37	0	0
110	40	6	60
120	31	14	80
130	20	15	80
140	27	13	100
Uncut	3	0	0

Table 17. Height, tiller or shoot number, leaf area index (LAI), dry weight of leaves, and total dry weight of pure and mixed population of IR20 and *Scirpus maritimus*.

Population	Plant ht (cm)	Tillers or shoots (no./sq m)	LAI	Dry wt (g)	
				Leaves	Total
Rice	71	650	3.31	108	245
Scirpus	114	459	4.60	201	395
Rice + *Scirpus*	—	—	8.00	276	545
Rice	76	306	2.42	70	134
Scirpus	122	420	5.58	206	411

an average of 31 in the cut plants. This shows that the old shoots somewhat inhibit the germination of the tubers. Plants cut 100 days after sowing did not flower. Flowering started in the plants cut 110 days after sowing. Although many shoots grew as a result of cutting, only a small percentage produced inflorescences. Based on the number of pots that produced inflorescences, however, the cut 140-day-old plants had 100 percent flowering.

Competition with rice. *S. maritimus* is a vigorously growing weed. Under field conditions it can take over a transplanted rice crop. To study the competitive ability of this weed, six tanks, 1 sq m each, were used. Two tanks contained only rice, two had only *S. maritimus*, and two had rice and *S. maritimus*.

Competition between the rice plants and the weeds increased the height of both (Table 17). The percentage increase was greater in the rice plants than in the weeds, but the weeds were taller so that the rice plants may have suffered from shading more than the weeds.

Weed competition decreased the number of rice tillers per unit area by 53 percent. Competition with rice decreased the number of weed shoots by only 9 percent. The number of weed shoots was greater than the number of rice tillers per square meter and the shoots were distributed so that the weeds covered a greater area.

S. maritimus accumulated dry matter faster than rice whether in pure stand or mixed crop-weed population. In a pure stand the rice crop accumulated 245 g/sq m in 40 days compared with 395 g/sq m in *S. maritimus*. When the two species were grown together the weed species grew better at the expense of the rice crop. As a result of the competition the dry matter production of the rice crop was reduced by 46 percent but that of *S. maritimus* stayed the same. Another indication of the efficient competitive ability of the weed is its contribution to the total dry matter in the mixed crop-weed population: the rice crop contributed 24 percent while *S. maritimus* contributed 76 percent. Similarly, the rice crop contributed a lower percentage of total leaf area than the *S. maritimus* crop. There were actually fewer *S. maritimus* plants than the rice plants at the start of the experiment and *S. maritimus* had to start from the tuber rather than from a growing seedling.

Light intensity and plant growth. The increasing dominance of *S. maritimus* in the rice fields may be the result of the adoption of the shorter improved rice varieties. To test the effect of light intensity, *S. maritimus* plants were grown in pots under three light intensities, 100, 60, and 30 percent of the full sunlight. Low light intensity greatly affected the growth of this species (Table

Table 18. Effects of shading *Scirpus maritimus* 40 days after sowing.

Light transmittance (%)	Dry weight (g)						Shoots (no.)	Tubers (no.)
	Total	Leaves	Culms	Stolons	Roots	Tubers		
100	33.9	15.5	13.0	1.2	1.3	3.0	34	57
60	20.8	10.9	7.7	0.6	0.6	0.9	23	31
30	10.9	6.0	3.9	0.4	0.3	0.4	15	18

18). The total dry matter 40 days after sowing was reduced by 39 percent when light intensity was reduced to 60 percent of the sunlight, and by 68 percent under 30 percent of sunlight. The greatest reduction in weight occurred in the tubers, indicating that at lower photosynthetic rates the underground parts are affected first and that development of tubers is secondary to the development of the shoots. The plants under shaded conditions also had less leaf area, thinner leaves, and less shoots. The number of tubers was definitely decreased by shading.

The results show that shading or low light intensity will drastically decrease the growth of this weed and its potential for vegetative reproduction. A fast-growing, relatively tall, high-yielding rice variety such as IR5 or C4-63 might compete better than short varieties like IR20 and hence minimize the severity of this weed in areas where it is the main weed population.

Agronomy

Greater emphasis was placed on upland rice research by increasing test sites in the Philippines and in other cooperating countries. Based on Philippine data, the following lines looked highly promising for upland rice culture: IR1545-339 and IR1480-147-3, among early maturing lines; IR879-314-2 and MRC 172-9 among the intermediate-maturing group; and IR937-55-3 and IR1416-131-5 among the relatively late-maturing group. Several of these lines yielded over 6 t/ha in experiments in farmers' fields in Batangas. For control of the annual weeds in upland rice, oxadiazon and USB 3584 looked highly promising. For the first time, a herbicide called K-223 was able to control perennial nutsedge in upland rice. □ For the lowland perennial sedge, *S. maritimus*, a low-cost herbicide, silvex, was identified as a good alternative to the relatively expensive herbicide bentazon identified earlier. □ For rainfed lowland and upland areas, we have developed methods of screening rices for drought tolerance by maintaining continual soil moisture tension in pots. In the greenhouse, IR1529-430-3 looked tolerant to soil moisture stress. In the field, IR1646-623-2 was the most drought-tolerant line although its yield potential was not the highest in that trial. □ Iron-deficiency symptoms were observed for the first time on acid soil (pH 5.1 to 5.8) planted to upland rice. Drought tolerance and soil problems should be considered together in evaluating rices for upland culture. □ For the first time, IR480-5-9 produced 0.7 to 1.1 t/ha higher grain yield than IR8 and 2.8 to 3.5 percentage points higher protein, confirming earlier results which show it is the best line to use in developing high-yielding, high-protein rices.

NITROGEN RESPONSE IN IRRIGATED RICE

Experiments were continued at the IRRI farm and in farmers' fields to study the nitrogen response, growth characteristics, and field reactions to diseases or insects of varieties or lines developed by IRRI and by breeders elsewhere.

Promising lines. Several promising lines from the IRRI breeding program were compared with IR8, IR20, and Peta. In the dry season, IR579-92-2 produced the highest grain yield, 7.0 t/ha (Table 1). The early-maturing line IR1561-228-3 matured in 106 days and produced 6.5 t/ha. This line is resistant to brown planthoppers, which were a major problem at the IRRI farm. High-yielding, early maturing lines, such as IR1561-228-3, with high levels of disease and insect resistance will have considerable value for increasing productivity per hectare per day in irrigated areas and for escaping drought in areas with a short rainy season.

In the wet season, IR26 produced the highest yield (Table 1). IR1514A-E597-2 and two IR2061 lines produced over 5 t/ha and were resistant to brown planthoppers. Repeated applications of insecticides did not completely protect the lines susceptible to brown planthopper from damage. That was why the yields of IR8, IR1487-372-4, and IR442-2-58 were poor.

International varieties. Among 12 varieties from several countries tested at the IRRI farm, Pelita I/1 from Indonesia yielded the most, 7.2 t/ha, during the 1972 dry season (Table 2). The other high-yielders were IR8, IR20, the Thai variety RD1, and the Indian variety Vijaya.

In the wet season, most of the varieties did not respond significantly to nitrogen fertilization (Table 2). Low grain yields and lack of nitrogen response were caused by heavy infestation of brown planthoppers (9 to 12 planthoppers/hill in every variety) and grassy stunt virus which is transmitted by brown planthoppers. Most varieties were susceptible to both the grassy stunt virus and the vector.

Farmers' fields. As in previous years, experiments were conducted in farmers' fields to study varietal reactions to nitrogen fertilizers under management conditions that are within reach of most Asian farmers. In the dry season, IR8 and IR1514A-E597-2 produced the highest yields, 7.4 t/ha, at 150 kg/ha N (Table 3). IR8, IR20, and IR442-2-58 had significantly lower yields than IR1514A-E597-2 (Table 3). Because of low level of insect protection, the resistance

Table 1. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines (avg of three replications). IRRI, 1973.

Designation	Dry season						Wet season					
	Maturity (days)	Yield[b] (t/ha)					Maturity (days)	Yield[c] (t/ha)				
		0 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N	150 kg/ha N		0 kg/ha N	30 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N
IR8	127	3.0	3.9	5.3	5.6	6.3	123	1.8	1.9	2.2	2.4	2.5
IR20	108	3.6	4.5	5.3	5.3	5.4	122	2.9	3.4	3.8	3.5	3.3
IR442-2-58	133	3.2	4.0	4.7	5.3	5.3	118	2.6	2.9	3.1	2.9	3.2
IR579-92-2	127	4.2	5.5	6.0	7.0	6.9	123	3.7	3.5	3.8	3.4	3.9
IR1487-372-4	115	3.6	4.9	4.7	5.7	6.0	122	2.8	2.4	2.7	3.0	3.2
IR1514A-E597-2	109	3.8	4.7	5.0	6.0	5.8	122	4.1	4.5	5.2	5.0	4.9
IR1529-430-3	119	4.1	5.6	5.2	6.5	6.3	124	3.3	4.2	3.2	3.0	3.2
-680-3	127	4.3	4.8	6.4	6.5	6.4	123	3.6	3.2	3.4	2.8	3.0
IR1541-76-3	115	4.2	5.3	5.4	5.7	6.4	122	3.5	4.0	4.4	4.1	4.2
IR1561-228-3	106	4.9	5.1	5.8	6.1	6.5	111	4.4	4.7	4.7	4.8	4.7
Peta	139	3.5	3.2	4.7	4.3	2.8	142	1.3	1.8	0.9	1.0	1.3
IR577-24-1	119	2.4	4.3	4.9	6.6	5.5	—	—	—	—	—	—
IR1110-43-3	115	4.7	4.7	5.9	6.6	6.7	—	—	—	—	—	—
C-12	136	3.8	4.0	4.4	4.5	4.1	—	—	—	—	—	—
IR26	—	—	—	—	—	—	123	4.5	4.9	5.5	5.6	5.8
IR2061-213-2	—	—	—	—	—	—	118	4.7	5.0	5.0	4.7	4.8
-464-2	—	—	—	—	—	—	115	4.4[d]	4.7	5.0	5.1[d]	4.7

[a]Includes 30 kg/ha N topdressed at panicle initiation in dry season and 20 kg/ha N at panicle initiation in wet season except for 0 kg/ha N treatment. [b]LSD (5%): 1.7 t/ha. [c]LSD (5%): 0.7 t/ha. [d]Avg of two replications.

Table 2. Effects of levels of nitrogen[a] on the grain yield of new rice varieties from several countries (avg. of three replications). IRRI, 1973.

Designation	Dry season						Wet season					
		Yield[b] (t/ha)						Yield[c] (t/ha)				
	Maturity (days)	0 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N	150 kg/ha N	Maturity (days)	0 kg/ha N	30 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N
IR8	124	3.9	5.1	6.5	6.4	6.8	125	2.2	2.1	3.0	2.6	2.9
IR20	111	3.8	5.4	6.1	6.4	6.5	118	3.1	2.9	3.5	2.9	3.4
IR442-2-58	132	3.7	5.1	5.3	5.3	5.0	118	2.3	2.5	3.3	3.1	3.4
Cica 4	116	3.1	4.3	4.9	5.4	5.6	115	2.8	3.4	3.5	3.4	3.6
C4-63G	131	3.9	5.3	5.4	5.6	5.3	125	2.4	3.0	3.1	2.3	2.4
RD1	124	3.4	6.0	6.7	6.7	6.3	125	1.5	3.1	2.6	2.8	3.4
Azral (IR480-5-9)	117	3.7	4.4	6.0	6.2	6.1	115	2.4	3.3	3.4	3.1	3.4
Pelita I/1	131	4.3	5.4	6.6	5.9	7.2	118	1.6	3.0	3.1	3.2	3.1
Peta	139	4.0	3.9	4.2	3.1	2.6	139	1.3	1.1	1.1	0.9	0.9[d]
Tongil	102	3.1	4.3	4.9	5.4	5.6	—	—	—	—	—	—
Sinaloa	125	3.8	5.0	5.7	5.3	6.3	—	—	—	—	—	—
Vijaya	124	3.8	5.8	6.3	6.6	6.5	—	—	—	—	—	—
IET 1991	—	—	—	—	—	—	115	2.2	3.0	3.4	3.6	3.3[d]
Chianung Sen-yu 6	—	—	—	—	—	—	120	2.5	3.4[d]	2.9	3.6	3.7
Novalato A 71	—	—	—	—	—	—	118	2.8	3.0	2.6	2.8[d]	2.9

[a]Includes 30 kg/ha N topdressed at panicle initiation in dry season and 20 kg/ha N at panicle initiation in wet season except for 0 kg/ha N treatment. [b]LSD (5%): 0.9 t/ha. [c]LSD (5%): 0.9 t/ha. [d]Avg of two replications.

of IR1514A-E597-2 to insect pests, particularly to brown planthoppers, proved highly valuable in the farmer's field.

In the wet season, we grew four promising lines plus IR20 and IR8 as controls. Insecticides and herbicides were applied at minimum levels. In this experiment, the highest grain yield, 6.1 t/ha, was obtained with IR1514A-E597-2 (Table 3). IR442-2-58 and IR20 produced statistically similar yields. IR1529-680-3 and IR8 produced poor yields because of hopperburn and grassy stunt virus. This is the first year that grassy stunt virus has occurred in farmers' fields in Calamba, Laguna, and the results show the importance of having grassy stunt resistance in all varieties grown under the year-round rice culture practiced in Calamba.

Long-term fertility experiment. The 18th and 19th crops in the long-term fertility experiment were grown at the IRRI farm in 1973. In the dry season, when either phosphorus or potassium was applied alone (Table 4), both IR8 and IR20 yielded significantly more than when no fertilizer was used. But when nitrogen was applied, the differences in the grain yields between plots with or without phosphorus or potassium were not significant. Thus in the absence of nitrogen, phosphorus or potassium may help to produce higher yields, probably because of better rooting depth or greater use of soil nitrogen.

Table 3. Effects of levels of nitrogen[a] on the grain yield of irrigated rice in a farmer's field (avg of two replications). Laguna, Philippines, 1973.

Designation	Dry season						Wet season					
		Yield (t/ha)						Yield (t/ha)				
	Maturity (days)	0 kg/ha N	50 kg/ha N	100 kg/ha N	150 kg/ha N	Mean[b]	Maturity (days)	0 kg/ha N	40 kg/ha N	80 kg/ha N	120 kg/ha N	Mean[b]
IR8	127	4.9	5.6	6.2	7.4	5.8 c	123	1.2	1.4	1.2	1.6	1.4 e
IR20	111	4.7	6.1	6.3	5.6	5.7 c	117	3.4	3.4	4.1	4.1	3.7 bc
IR442-2-58	130	5.4	5.7	6.5	6.1	6.0 bc	117	3.0	4.2	3.4	3.4	3.5 c
IR1514A-E597-2	111	5.3	7.0	7.2	7.4	6.7 a	123	4.9	5.3	6.1	5.9	5.6 a
IR1529-680-3	125	5.3	7.1	7.0	6.7	6.5 ab	123	2.3	2.1	3.1	2.8	2.6 d
IR1541-76-3	119	4.6	6.5	7.2	6.7	6.2 abc	117	3.5	4.8	4.6	4.8	4.4 b

[a]Includes 20 kg/ha N topdressed at panicle initiation except for 0 kg/ha N treatment. [b]Any two means followed by the same letter are not significantly different at the 5% level.

Table 4. Effects of NPK fertilization on the grain yield of IR8, IR22, and IR20 in the 18th (dry season) and 19th (wet season) consecutive crops (mean of four replications). IRRI, 1973.

Fertilizer treatment (kg/ha)			Yield[b] (t/ha)			
N	P_2O_5	K_2O	IR8	IR22	IR20	Mean
		Dry season				
0	0	0	2.7	4.3	3.6	3.6
0	30	0	4.7	4.5	5.2	4.8
0	0	30	4.9	4.5	5.3	4.9
140[a]	0	0	6.7	6.4	7.0	6.7
140[a]	30	0	6.4	6.1	7.4	6.6
140[a]	0	30	6.4	6.2	7.1	6.6
140[a]	30	30	6.9	5.7	7.6	6.8
140[a,c]	30	30	6.3	5.3	7.0	6.2
		Wet season				
0	0	0	2.8	2.2	1.5	2.1
140[a]	0	0	3.7	2.7	3.3	3.3
0	30	0	2.7	2.9	2.1	2.6
0	0	30	3.0	3.2	2.8	3.0
140[a]	30	0	3.6	3.4	3.2	3.4
140[a]	0	30	3.7	3.7	3.1	3.5
140[a]	30	30	3.7	3.5	3.2	3.5
140[a,c]	30	30	3.8	4.0	3.3	3.7

[a]Includes 40 kg/ha N applied at panicle initiation. [b]Avg of four replications. LSD (5%): 1.2 t/ha in dry season and 0.3 t/ha in wet season. [c]Compost plus inorganic.

In the wet season, the responses to phosphorus or to potassium alone were significant in IR20 and IR22, but not in IR8 (Table 4). As in the dry season, the response to phosphorus or potassium in the presence of nitrogen was not significant. Grain yields were generally low because of the severe outbreak of brown planthoppers.

The two-season data seem to show complete fertilizers may soon be needed to obtain high grain yields at the IRRI farm.

PRACTICES FOR IRRIGATED RICE

N sources and time of application. The short supply of nitrogen fertilizers and the sudden rise in costs call for a search for more efficient sources of nitrogen under poor water-management conditions. Sulfur-coated urea fertilizers with different release rates were compared with standard urea and ammonium sulfate fertilizers under two water management conditions at the IRRI farm and in a farmer's field in Nueva Ecija, Philippines. The moisture treatments were continual flooding at 5 cm or intermittent irrigation. For intermittent irrigation, water was supplied to 5 cm depth whenever the soil moisture tension at 15 cm soil depth reached 50 centibars. IR24 was the test variety.

At the IRRI farm, sulfur-coated urea with release rates of 21 and 26 percent, gave the highest yield, 8.8 t/ha. Under continual flooding when fertilizers were incorporated before planting, two sulfur-coated ureas gave significantly higher yields than ammonium sulfate or ordinary urea (Table 5). Similar results obtained with one sulfur-coated urea under intermittent irrigation indicated the superior performance of sulfur-coated urea over ordinary urea or ammonium sulfate at any water management condition.

The advantage of split application over basal application was highest with ordinary urea and declined gradually as the dissolution rate was reduced (Table 5). Even sulfur-coated urea fertilizers with slow dissolution rate (21% and 26%) produced higher grain yields when applied

Table 5. Effect of different sources of nitrogen (150 kg/ha N) on the grain yield of IR24 under two water managements. IRRI, 1973 dry season.

Nitrogen source	Yield[a] (t/ha)						
	Continual flooding		Continual stress[b]		Avg		
	Basal	Split	Basal	Split	Basal	Split	Difference
Ammonium sulfate	7.1 c	8.0 ab	6.1 b	7.3 a	6.6 b	7.7 ab	1.1**
Urea	7.3 bc	8.3 ab	5.8 b	7.5 a	6.6 b	8.0 ab	1.4**
Sulfur-coated urea[c]							
6% R	8.7 a	8.4 ab	6.9 ab	6.7 a	7.8 a	7.5 ab	0.3
17% R	8.2 ab	8.4 ab	7.4 a	7.5 a	7.8 a	8.0 ab	0.2
21% R	8.4 a	8.8 a	6.7 ab	7.7 a	7.6 a	8.3 a	0.7*
26% R	7.8 abc	8.8 a	6.4 ab	7.6 a	7.1 ab	8.2 a	1.1**
Isobutylidene diurea	7.1 c	7.7 b	6.0 b	6.8 a	6.5 b	7.3 b	0.8*
Unfertilized control	5.4 d	5.5 c	4.3 c	4.5 b	4.8 c	5.0 c	0.2

[a]For each column, means followed by a common letter are not significantly different at the 5% level. [b]Continual stress of 50 cb, irrigated up to saturation. [c]R = dissolution rate in 2 weeks.

Table 6. Effect of different sources of nitrogen at 150 kg/ha N on the grain yield of IR24 in farmer's field. Maligaya, Muñoz, Philippines, 1973 dry season.

Nitrogen source	Yield[a] (t/ha)		
	Basal	Split	Mean
Ammonium sulfate	8.2 b	9.8 a	9.1
Urea	9.1 ab	9.5 ab	9.3
Sulfur-coated urea			
6% R	8.7 ab	7.4 c	8.0
17% R	9.9 ab	8.3 abc	9.0
21% R	9.8 ab	8.0 bc	8.8
26% R	9.7 ab	8.6 abc	9.1
Isobutylidene diurea	10.2 a	10.0 a	10.1
Unfertilized control	4.8 c	4.8 d	4.8

[a]For each time of application, means followed by a common letter are not significantly different at the 5% level using Duncan's multiple range test.

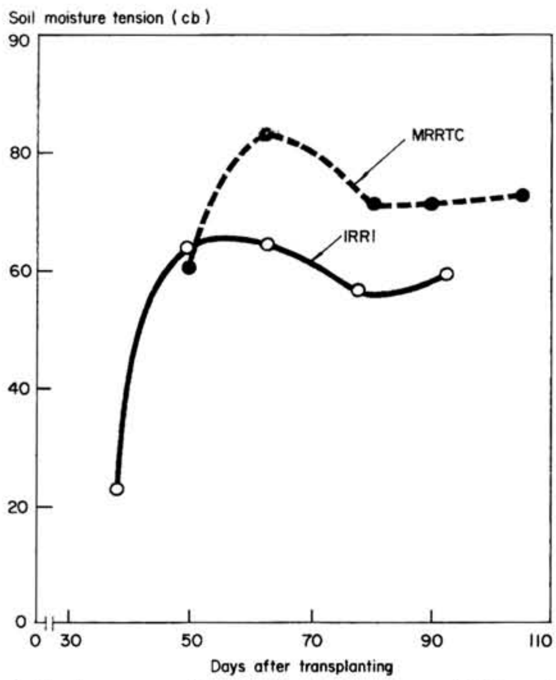
in split doses than when basally applied, indicating that losses cannot be entirely eliminated with sulfur coating, although they can be minimized with the proper slow-release fertilizer applied in split doses.

In the experiment in Nueva Ecija on a silty clay soil (pH 6.8; organic matter, 1.2%; total nitrogen, 0.07%; cation exchange capacity, 33 meq/100 g), it was impossible to maintain standing water. Nevertheless, the highest yield of IR24 was 10.2 t/ha (Table 6), indicating that moisture stress was not severe. The results are, therefore, summarized as an average for the two water management treatments. Both ammonium sulfate and ordinary urea produced higher grain yields when applied in split doses. For sulfur-coated urea, the yields were higher with basal application. These results show that when continuous flooding cannot be maintained, it is better to use ordinary fertilizers in split doses or slow-release fertilizers applied all at one time. Since, in Asia, fertilizer is relatively expensive and labor for applying it is relatively cheap, ordinary fertilizers applied in split doses still have more merit than expensive slow-release fertilizers, like sulfur-coated urea.

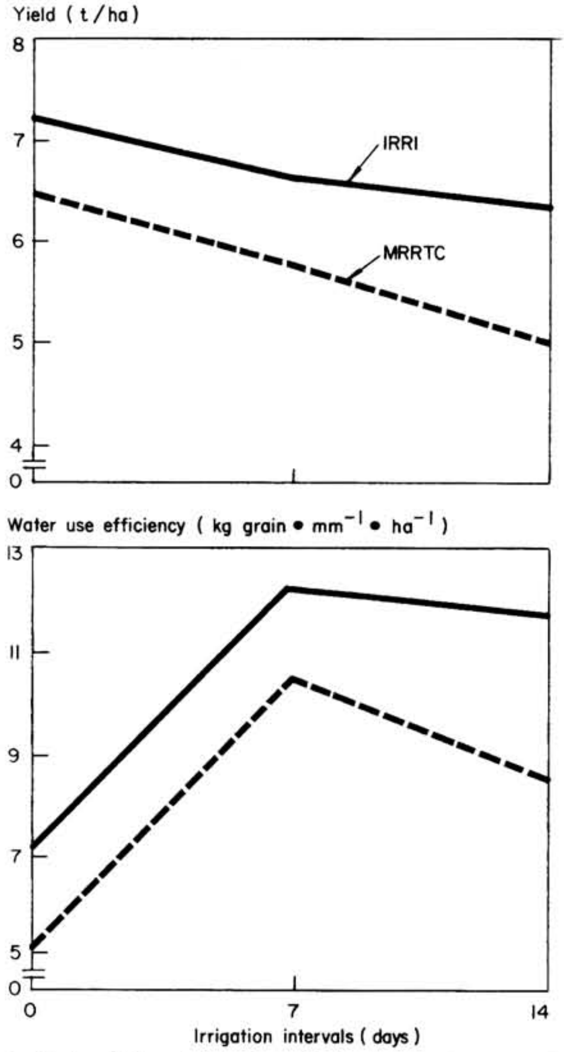
Rotational irrigation. A project started during 1971 was continued during the 1973 dry season but at the Maligaya Rice Research and Training Center in the Philippines, in addition to the IRRI farm. IR20, IR442-2-58, IR1529-430-2, and IR1541-76-3 were tested at 4, 6, and 8 mm/day for the 7-day irrigation interval and 4, 8, and 12 mm/day for the 14-day irrigation interval. Plots continually flooded at 5 cm were used as controls. Because of lower rainfall and higher pan evaporation values, the soil moisture tensions at Maligaya were higher than at the IRRI farm (fig. 1). Thus, deeper and bigger cracks developed in the plots with 14-day irrigation intervals. And consequently, most of the irrigation water applied, regardless of the amount, percolated through the cracks.

In both locations, the grain yield was reduced as the irrigation interval was lengthened, but the reduction was greater at the Maligaya station than at the IRRI farm (fig. 2). The average irrigation efficiency was highest at the 7-day irrigation interval and lowest under continual flooding. When the irrigation interval was increased from 7 to 14 days, irrigation efficiency was reduced, more so at the Maligaya station.

In both locations, IR1529-430-2 outyielded the rest of the varieties at all irrigation intervals (fig. 3). However, IR442-2-58 produced the highest yield at 14-day irrigation interval at Maligaya, indicating its tolerance to droughty conditions.



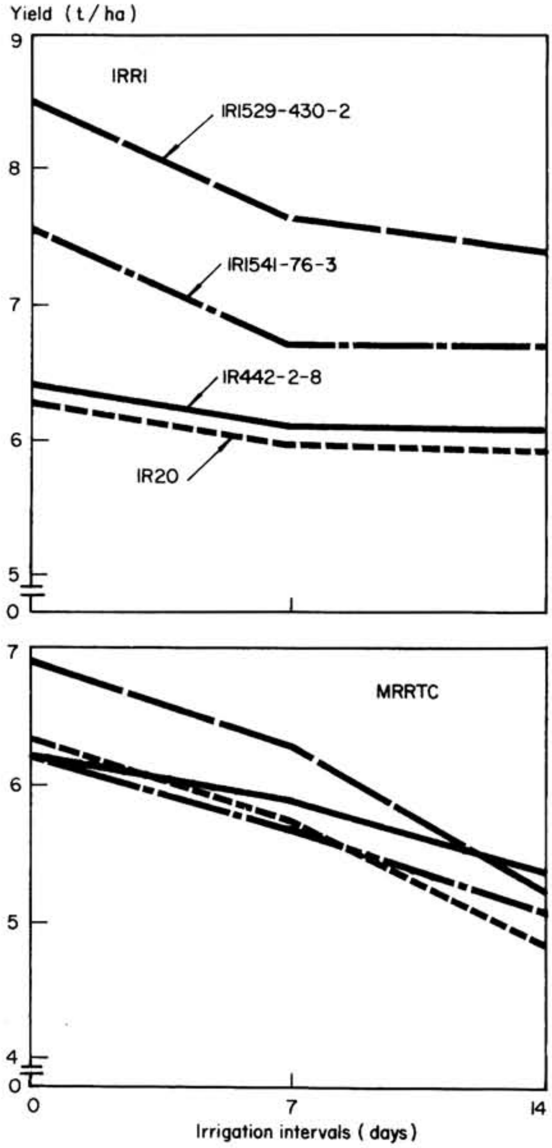
1. Tensiometer readings in plots irrigated every 14 days at the rate of 4 mm/day. Measurements were taken just before irrigation. IRRI and Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, Philippines, 1973 dry season.



2. Grain yield and irrigation efficiency as a function of irrigation intervals. Each value is the average of four varieties, two irrigation rates for the 7-day and 14-day irrigation interval, and two replications. IRRI and Maligaya Rice Research and Training Center, 1973 dry season.

Weed control in transplanted rice. Experiments at IRRI, at Bureau of Plant Industry stations, and in farmers' fields continue to demonstrate that 2,4-D is effective against most annual weeds. Although most 2,4-D users still consider it a post-emergence herbicide for controlling broadleaved weeds and sedges on rice fields, it has been used as a pre-emergence herbicide (applied before weeds emerge) in transplanted rice on over 10,000 hectares in Bulacan province, Philippines. This is because 2,4-D is inexpensive and in the granular formulation is easy to apply and totally effective against most common weeds in lowland rice fields. Selective herbicides like butachlor, benthiocarb with 2, 4-D, or C-288, which control annual weeds in transplanted rice whether applied before or after the weeds emerge are somewhat more effective against a wide spectrum of weeds. But, their higher prices make their advantage over 2,4-D alone less than clear-cut.

Trials at IRRI and at three Bureau of Plant



3. Grain yield of four rice varieties as a function of irrigation intervals. IRRI and Maligaya Rice Research and Training Center, 1973 dry season.

Table 7. Grain yield of transplanted rice (IR442-2-58) as affected by granular herbicides applied before weeds emerge (4 days after transplanting) at IRRI farm and in cooperative experiments at three Bureau of Plant Industry stations. 1973.

Chemical[a]	Rate (kg/ha a.i.)	Yield[b] (t/ha)							
		Dry season				Wet season			
		IRRI	Maligaya[c]	Bicol[d]	Iloilo[e]	IRRI[f]	Maligaya	Bicol	Iloilo
A-820 + 2,4-D EE	2.0 + 0.5	4.6 a	6.3 a	7.2 a	5.4 ab	3.0 b	4.7 abc	1.7 cd	5.4 b
USB 3153	1.5	4.9 a	6.8 a	6.4 b	6.5 a	3.4 ab	4.6 bc	2.8 bc	4.4 c
USB 3584	1.5	4.9 a	6.7 a	7.2 a	6.2 a	3.2 ab	4.8 ab	3.5 ab	6.0 ab
C-19490/2,4-D IPE	0.75	4.9 a	6.6 a	7.1 ab	6.1 a	3.6 ab	4.8 ab	3.0 abc	6.3 a
C-288	0.75	4.7 a	6.6 a	7.1 ab	6.5 a	3.3 ab	4.9 ab	3.4 ab	6.0 ab
2,4-D IPE	0.8	4.8 a	5.2 bc	7.2 a	4.6 b	3.1 b	5.0 a	2.5 bc	5.4 b
Benthiocarb/2,4-D IPE	1.0/0.5	5.0 a	5.9 ab	7.1 ab	6.2 a	3.5 ab	4.8 ab	4.2 a	5.8 ab
Butachlor + 2,4-D IPE	0.75 + 0.5	5.2 a	6.4 a	6.9 ab	5.4 ab	3.6 a	4.4 cd	3.1 ab	5.4 b
Hand weeding	twice	5.2 a	4.4 bc	6.6 ab	5.9 a	3.3 ab	4.7 abc	3.8 ab	5.4 b
Untreated control	—	2.3 b	0.0 d	0.8 c	1.7 c	0 c	4.0 d	0.8 d	1.6 d

[a]EE = ethyl ester; IPE = isopropyl ester; + = chemicals applied in immediate succession. [b]Any two means followed by the same letter are not significantly different at the 5% level. [c]Maligaya Rice Research and Training Center. [d]Bicol Rice and Corn Experiment Station. [e]Visayas Rice Experiment Station. [f]IR20.

Industry stations in the Philippines permit promising herbicides to be evaluated under different soil and climatic conditions. Weed flora also vary in different agroclimatic regions. The granular herbicides USB 3584 from U.S. Borax, C-19490/2,4-D, and C-288 from Ciba-Geigy gave excellent weed control, especially in the wet season, and resulted in grain yields similar to those of the hand-weeded controls (Table 7). These results confirm our earlier findings. USB 3584, C-19490/2,4-D, and C-288 should be considered for farmers' use if they are made available at prices within the reach of Asian farmers.

Herbicides were also evaluated in farmers' fields in Laguna and Quezon provinces in the Philippines. In both seasons, the natural weed infestation was heavy and herbicide applications resulted in at least 2 t/ha higher yields than the unweeded controls (Table 8). Except for the MCPA spray in Quezon province in the wet season, all herbicide treatments produced similar yields to those of the twice-hand-weeded plots in both locations. Farmers in the locality surrounding the experimental sites practice hand-weeding. Our results clearly demonstrate that 2,4-D or MCPA can be used effectively as an alternative to hand weeding.

Weed control in direct-seeded flooded rice. The selective herbicides we identified earlier for direct-seeded flooded rice continued to look promising. In our cooperative experiments at

Table 8. Grain yield of transplanted rice trials in farmers' fields as affected by application of herbicides 4 days after transplanting. Famy, Laguna, and Candelaria, Quezon, Philippines, 1973.

Chemical[a]	Rate (kg/ha a.i.)	Yield[b] (t/ha)					
		Dry season			Wet season		
		Laguna IR442-2-58	Quezon IR1541-76-3	Mean	Laguna IR20	Quezon IR20	Mean
2, 4-D IPE (G)	0.8	8.4 a	6.3 ab	7.4	4.8 a	5.9 ab	5.4
2, 4-D IPE (L)	0.8	8.3 a	6.3 ab	7.3	5.0 a	6.0 ab	5.5
MCPA-K (G)	0.8	8.2 a	6.7 ab	7.4	4.6 a	5.5 ab	5.0
MCPA-K (L)	0.8	8.0 a	6.1 ab	7.0	5.2 a	5.2 b	5.2
Benthiocarb/2, 4-D IPE (G)	1.0/0.5	7.9 a	5.9 b	6.9	5.1 a	5.9 ab	5.5
Butachlor (G) + 2, 4-D IPE (G)	1.0 + 0.5	8.6 a	6.4 ab	7.5	4.4 a	5.9 ab	5.2
Hand weeding	twice	8.4 a	7.0 a	7.7	4.6 a	6.1 a	5.4
Untreated control	—	3.0 b	2.7 c	2.8	2.5 b	4.0 c	3.2

[a]IPE = isopropyl ester; G = granule; L = liquid; K = potassium salt. [b]Any two treatment means followed by the same letter are not significantly different at the 5% level.

the Maligaya station, two Ciba-Geigy herbicides, C-288 and C-19490 + 2, 4-D, performed as well as the commercially available Monsanto herbicide butachlor (Table 9).

We are looking into zero-tillage technique as a possibility for growing direct-seeded flooded rice in some situations. In an experiment conducted during the 1973 dry season, glyphosate followed by paraquat applied on no-tillage plots gave grain yields similar to those obtained with one plowing and two harrowings (Table 10). What we need to find out is the probability of success under this system. Until now the frequency of success with the zero-tillage technique has not justified its wide-scale adoption in Asia. Zero tillage or minimum tillage will find a place in rice culture in Asia when the pressure on land further increases and a need arises for shorter time in preparing land for intensive rice culture.

Control of a perennial sedge. The perennial sedge *Scirpus maritimus* causes serious problems in flooded rice fields in the Philippines and other Asian countries. In trials at IRRI and in farmers' fields in the Cagayan Valley, Philippines, the selective chemicals bentazon and silvex [2-(2, 4, 5-trichlorophenoxy) propionic acid] gave outstanding perennial sedge control in both transplanted and broadcast-seeded flooded rice (Table 11). Bentazon also performed well in 1972 tests.

Our current results with mixed populations of annual weeds and the perennial sedge *S. maritimus* show that no single chemical can control both groups of weeds. The best results were obtained when herbicides for annual weeds like butachlor or C-288 were followed with bentazon or silvex for controlling *S. maritimus* (Table 12). Furthermore, we found that an intermediate-statured rice line like IR442-2-58 can compete better with annual weeds or with a mixed population of annual and perennial weeds than a semidwarf like IR20 (Table 12). This finding was substantiated in these experiments in farmers' fields in Nueva Vizcaya, Philippines (Table 13). Last year, the semidwarf varieties IR20 and IR24 gave significant yield response to herbicides used for controlling *S. maritimus* in Isabela and Nueva Vizcaya provinces in the Philippines. This year, with IR442-2-58 in only one out of two locations in Nueva Vizcaya, did the herbicide bentazon produce significantly higher yield than untreated controls (Table 13). Thus in areas where difficult weeds like *S. maritimus* are present, it is better to grow an intermediate-statured variety (about 130 cm tall) than semidwarf rice varieties (about 100 cm).

RAINFED PADDY CULTURE

Varietal differences. During the 1973 wet season, 93 varieties and lines were grown under rainfed paddy conditions and continual flooding (5 cm deep throughout the cropping season). Rainfall throughout the cropping season was adequate

Table 9. Grain yield of broadcast-seeded flooded IR1541-76-3 as affected by granular herbicides applied at the one- to two-leaf stage of grasses. Maligaya Rice Research and Training Center, 1973 dry season (IRRI-BPI cooperative experiments).

Chemical	Type	Rate (kg/ha a.i.)	Yield[a] (t/ha)
Butachlor	Granular	1.0	5.8 bc
C-288	Granular	1.0	6.4 ab
C-19490 + 2,4-D IPE	Granular	0.75 + 0.5	7.0 a
A-820 + 2,4-D IPE	Liquid	2.0 + 0.5	5.1 cd
USB 3153 + 2,4-D IPE	Liquid	1.0 + 0.5	3.4 ef
CRD 71-6388	Granular	0.5	3.0 f
MON 0385	Liquid	1.0	0.0 g
Ordram B	Granular	1.5/0.43	4.5 de
M 3432	Liquid	2.0	4.4 de
Untreated control	—	—	0.0 g

[a]Avg of four replications. Any two means followed by the same letter are not significantly different at the 5% level.

Table 10. Effect of chemical substitution for tillage on the grain yield of direct-seeded flooded IR22. IRRI, 1973 dry season.

Chemical	Tillage	Yield[a] (t/ha)
Glyphosate[b]	—	5.1 bc
Glyphosate[c] fb Paraquat[d]	—	6.5 ab
Glyphosate[c]	one plowing	4.7 bc
Dalapon[b] + 2,4-D[e] fb Paraquat[d]	—	3.3 cd
Paraquat[d]	one plowing	3.4 cd
	one plowing	1.4 d
	one plowing + one harrowing	5.4 bc
	one plowing + two harrowings	7.7 a

[a]Avg of four replications. Any two means followed by the same letter are not significantly different at the 5% level. [b]3 kg/ha a.i. [c]2 kg/ha a.i. [d]1 kg/ha a.i. [e]0.5 kg/ha a.i.

Table 11. Effect of post-emergence application of liquid herbicides on weed (*Scirpus maritimus*) control, crop tolerance, and grain yield of broadcast and transplanted IR22 rice. 1973 late dry season.

Chemical[a]	Rate (kg/ha a.i.)	Transplant: Yield[b] (t/ha)	Transplant: Control rating[c] 19 DH[f]	Transplant: Control rating[c] Heading of rice	Transplant: Toxicity rating[d] 19 DH	Transplant: Toxicity rating[d] Heading of rice	Transplant: Weed wt[e] (g/sq m)	Broadcast: Yield[b] (t/ha)	Broadcast: Control rating[c] 19 DH	Broadcast: Control rating[c] Heading of rice	Broadcast: Toxicity rating[d] 19 DH	Broadcast: Toxicity rating[d] Heading of rice	Broadcast: Weed wt[e] (g/sq m)
Bentazon	1.5	5.5 a	4	9	0	0	5	5.2 ab	4	9	0	0	0
Bentazon	3.0	5.4 a	3	9	0	0	0	5.2 ab	5	9	0	0	2
Silvex	0.75	5.2 a	3	9	0	0	1	5.6 a	4	9	0	0	3
Silvex	1.25	5.2 a	4	9	0	0	0	5.6 a	5	10	0	1	1
MCPP	0.75	4.3 b	4	6	0	1	55	4.2 c	4	6	0	0	62
MCPP	1.0	4.2 b	4	6	0	2	39	4.6 bc	4	6	0	0	28
Butachlor[g] fb MCPP	0.75 fb 0.75	4.0 b	4	6	0	3	46	4.6 bc	5	6	0	2	30
Weed-free control	—	5.6 a	3	9	0	0	0	5.4 a	9	0	0	0	1
Untreated control	—	2.5 c	4	4	0	0	234	0.8 d	4	1	0	0	386

[a]Applied 25 days after transplanting or seeding, except butachlor. [b]Avg of four replications. Any two treatment means followed by the same letter are not significantly different at the 5% level. [c]Scale: 0 = no control; 10 = complete control. [d]Scale: 0 = no toxicity; 10 = complete kill. [e]62 days after transplanting or seeding. [f]DH = days after herbicide application. fb = followed by. [g]Butachlor granules applied 6 days after transplanting or seeding.

and, in many instances, the grain yield differences between rice varieties were primarily due to differential lodging resistance since high winds and rain on November 19 caused many experimental lines to lodge severely. Under rainfed lowland conditions, IR1561-38 matured in 110 days and produced the highest yield of 4.7 t/ha. Other early maturing lines (110-115 days) which looked promising were IR1561-149, IR1561-228, IR1514A-E666, IR2061-464-2, and IR2153-330 (Table 14).

Nitrogen response. Twelve promising lines and four varieties were grown at IRRI under rainfed lowland conditions at five levels of nitrogen. Rainfall distribution was favorable throughout the wet season and the crop did not suffer from moisture stress at any time. Brown planthopper infestation was heavy. Therefore, most of the grain yield differences can be explained primarily by the differential reactions to brown planthopper infestation.

The highest yield, 5.6 t/ha, was obtained with

Table 12. Effect of promising herbicides on a mixed population of annual weeds and perennial sedge on weed control and grain yield of two rice varieties. IRRI, 1973 dry season.

Chemical[a]	Rate (kg/ha a.i.)	Time of application (DT)	IR20: Grain yield[b] (t/ha)	IR20: Weed wt[c] (g/sq m) SM	EC	S	B	IR442-2-58: Grain yield[b] (t/ha)	IR442-2-58: Weed wt[c] (g/sq m) SM	EC	S	B
Butachlor (G)	1	3	3.7 cd	347	0	0	0	4.4 c	250	3	0	0
C-288 (G)	1	3	2.3 e	465	0	0	0	3.0 d	432	0	0	0
Bentazon (L)	2	20	5.0 b	5	307	0	2	4.7 bc	12	212	5	5
Silvex (L)	1	20	5.0 b	2	345	0	0	5.7 ab	0	243	0	0
Butachlor fb Bentazon	1 fb 2	3 fb 20	7.5 a	25	0	0	0	5.4 ab	15	0	0	0
Butachlor fb Silvex	1 fb 1	3 fb 20	7.0 a	17	0	0	0	6.2 a	12	0	0	0
C-288 fb Bentazon	1 fb 2	3 fb 20	7.0 a	20	0	0	0	5.7 ab	7	0	0	0
C-288 fb Silvex	1 fb 1	3 fb 20	6.8 a	23	0	0	0	5.4 abc	20	0	0	0
Hand weeding twice		20 fb 30	6.8 a	3	0	2	0	5.6 ab	2	10	0	2
Annual weeds only	—	—	4.5 bc	0	247	55	7	5.1 abc	0	200	42	3
Scirpus maritimus only	—	—	3.0 de	420	0	0	0	3.3 d	408	0	0	0
Annual weeds + *S. maritimus*		—	2.2 e	418	135	17	2	2.8 d	362	133	10	3

[a]G = granule; L = liquid; fb = followed by; DT = days after transplanting. [b]Avg of three replications. Any two treatment means followed by the same letter are not significantly different at the 5% level. [c]Taken at 62 days after transplanting; SM = *Scirpus maritimus*; EC = *Echinochloa crusgalli* and similar species; S = annual sedges; B = broadleaved weeds.

IR26 (Table 15). IR1539-823-1 has a suitable plant type for rainfed areas and it is resistant to the brown planthopper, but because it has longer duration than most other lines tested, it may not be suitable for widescale adoption in farmers' fields. IR1721-11-6 produced similar yields to those of IR26 and IR1539-823-1. Its resistance to grassy stunt virus gave the IR1721 line an advantage over many other varieties. The lines susceptible to brown planthopper like IR442-2-58, C4-63, and C-12 suffered yield reductions despite frequent application of insecticides (Table 15).

Table 13. Grain yield of transplanted rice (IR442-2-58) as affected by promising herbicides for the control of *Scirpus maritimus* in a trial. Farmers' fields. Bayombong, Nueva Vizcaya, Philippines, 1973 dry season.

Chemical	Rate	Yield[a] (t/ha)	
	(kg/ha a.i.)	Location 1	Location 2
Bentazon	1.0	4.8 a	5.3 a
Bentazon	2.0	5.2 a	5.1 ab
Silvex	0.5	5.2 a	5.1 ab
Silvex	1.0	5.2 a	4.9 ab
Rotary weeding	twice	4.8 a	5.1 ab
Untreated control	—	4.5 a	4.4 b

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

Table 14. Growth duration and grain yield of rice varieties under irrigated and rainfed lowland conditions. IRRI, 1973 wet season.

Designation	Growth duration	Yield (t/ha)	
	(days)	Irrigated	Rainfed
IR8	121	1.4	2.2
IR5	128	2.6	3.3
IR20	118	3.2	3.6
IR22	115	2.2	3.1
IR24	115	1.6	2.1
C4-63G	128	2.1	2.3
C-22	128	2.1	1.7
Pelita I/1	118	1.4	1.9
Ratna	110	2.9	3.0
Vijaya	118	3.2	3.2
IR665-8-3	115	3.0	3.9
IR788-21-3	121	3.6	3.8
IR1514A-E666	115	4.3	3.9
IR1539-823-1	128	3.6	3.9
IR1561-38	115	4.4	4.7
-149	110	4.2	4.1
-228	115	4.4	4.1
IR1721-7-8	121	3.4	3.9
-11-6	125	4.6	3.8
-11-8	121	4.1	4.2
-11-12	125	3.1	3.7
IR2031-283-4	128	3.8	3.8
-426-1	121	4.5	3.7
IR2035-708-3	128	2.4	3.9
-712-2	121	3.7	3.6
IR2039-104-1	121	3.0	3.6
-133-2	125	3.4	3.7
IR2061-464-2	115	1.9	4.0
IR2153-330	110	4.0	3.8
IR4520-76-90	128	3.3	4.3

Nitrogen sources and time of application. Slow-release nitrogen fertilizers were evaluated under rainfed conditions at the IRRI farm and in farmers' fields in Nueva Ecija province in Central Luzon and in Camarines Sur province in the Bicol region. At the IRRI farm, nitrogen sources were compared under continuous flooding and rainfed conditions. The experiments in farmers' fields were conducted on a silty clay soil (pH 6.8; organic matter, 1.2%; total nitrogen, 0.07%; cation exchange capacity, 33 meq/100 g) in Muñoz, Nueva Ecija, and on a loamy soil (pH 6.0; organic matter, 2.0%; total nitrogen, 0.14%; cation exchange capacity, 45 meq/100 g) in Naga City, in Camarines Sur.

At the IRRI farm, IR442-2-58 had suffered from blast and it produced somewhat lower grain yields than IR20. With rainfed IR20, sulfur-coated urea in a single application produced significantly higher yield than ammonium sulfate or urea in single or split doses (Table 16). With irrigated IR20, the grain yields obtained with sulfur-coated urea were no better than those with either ammonium sulfate or urea.

In experiments in farmers' fields, IR20 produced higher yields than IR442-2-58. These two experiments did not show the advantage of sulfur-coated urea over ordinary urea or ammonium sulfate (Table 16). The results show that sulfur-coated urea or other slow-release fertilizers can have an advantage over ordinary fertilizers like urea or ammonium sulfate only when the rainfall distribution is less uniform than that of the 1973 wet season and the soil is alternately dry and wet.

UPLAND RICE

Varietal differences. During the 1973 wet season, about 75 lines and varieties, including several upland varieties from the Philippines, Africa, and Latin America, were grown under upland conditions at nine locations throughout the

Philippines. Two seeding dates, about a month apart, were used in all except one location. A randomized complete block design was used for some trials and, where experimental sites had appropriate field sizes and shapes, the triple lattice design was used. All except one trial had three replications. For each trial, 120 kg/ha N was applied in three equal doses during land preparation, 30 days after first application, and at panicle initiation. At seeding time, 40 kg/ha P_2O_5 was applied.

We attach considerable importance to the experiments in farmers' fields in Batangas province, the second most important upland rice area in the Philippines. The locations represent somewhat typical upland soils (Table 17). The soil in Santo Tomas, Batangas belongs to the Lipa series. Lipa soil (Lipa clay loam) is derived from residual soils of volcanic tuff. The surface soil is a dark-brown to light-brown, mellow, friable, loose, fine granular loam. Lipa soils are Alfisols. In Cuenca, Batangas, the soil belongs to Ibaan series. The surface soil is a light reddish-brown, friable, blocky, coarse granular clay loam to loam. It is also an Alfisol.

In most locations, rainfall distribution was favorable for high yields (fig. 4). In Cuenca, Batangas, a dry spell occurred for 3 weeks during the early vegetative stage. Most lines and varieties recovered from the early drought,

Table 15. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines under rainfed conditions. IRRI, 1973 wet season.

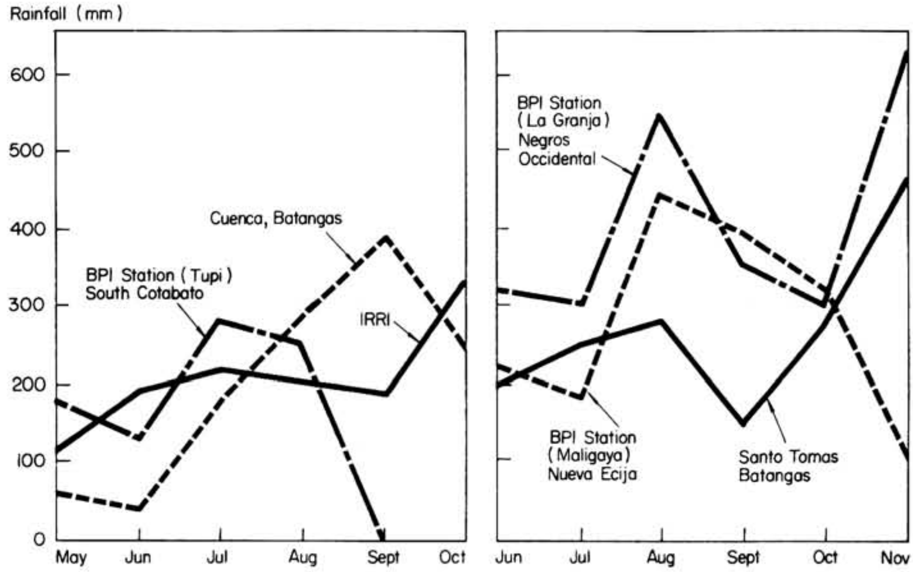
Designation	Maturity (days)	Yield[b] (t/ha) 0 kg/ha N	30 kg/ha N	60 kg/ha N	90 kg/ha N	120 kg/ha N
IR5	131	3.1	3.0	2.9	3.4	3.4
IR20	118	3.5	3.9	4.1	4.7	4.3
IR26	120	4.3	4.9	5.5	5.5	5.6
IR442-2-58	120	3.4	3.9	3.8	3.5	3.7
IR577-24-1	120	3.0	3.1	3.3	3.8	3.7
IR1110-43-3	116	3.6	4.0	4.4	4.4	4.8
IR1487-372-4	118	2.7	3.9	3.8	4.0	4.7
IR1529-430-3	120	4.1	4.9	4.1	4.7	4.5
-680-3	120	3.6	3.7	3.9	4.1	4.5
IR1539-823-1	131	3.1	4.6	4.5	4.9	5.0
IR1541-76-3	120	4.8	4.4	4.8	4.7	4.8
IR1561-228-3	114	3.2	4.1	4.4[c]	4.2[c]	4.3
IR1721-11-6	120	3.1	4.0	4.5	4.9	4.8
-14-6	120	3.2	3.5	3.8	4.1	4.3
C4-63G	125	2.6	3.1	2.9	2.6	2.5[c]
C-12	131	3.4	2.8	3.4	2.8	3.3

[a]Includes 20 kg/ha N topdressed at panicle initiation except for 0 kg/ha N treatment. [b]LSD (5%): 0.7 t/ha. [c]Avg of two replications.

Table 16. Effect of different sources of nitrogen (80 kg/ha N) on the grain yield of rainfed and irrigated IR20 and IR442-2-58. IRRI and farmers' fields, Muñoz, Nueva Ecija, and Naga City, Camarines Sur, Philippines, 1973 wet season.

Nitrogen source	Time of application	Yield[a] (t/ha) Continuous flooding IRRI IR20	IR442-2-58	Rainfed IRRI IR20	IR442-2-58	Rainfed Muñoz IR20	IR442-2-58	Rainfed Naga City IR20	IR442-2-58
Sulfur-coated urea[b]	Basal	5.0 c	3.4 b	5.8 a	4.0 a	5.2 a	2.3 a	3.7 a	2.8 b
	Split[c]	5.6 ab	4.4 a	5.4 ab	4.0 a	4.9 abc	2.2 a	3.6 ab	3.1 ab
Ammonium sulfate	Basal	5.5 abc	3.5 b	4.6 c	3.6 ab	4.3 c	2.5 a	3.2 b	3.2 ab
	Split[c]	5.7 a	3.5 b	5.0 bc	3.4 b	4.7 abc	2.3 a	3.7 a	3.4 a
Urea	Basal	5.1 bc	3.7 b	4.9 bc	3.6 ab	4.4 bc	2.5 a	3.5 ab	3.0 ab
	Split[c]	5.3 abc	3.7 b	5.2 bc	3.6 ab	5.0 ab	2.5 a	3.9 a	2.9 b
Unfertilized control		4.0 d	3.8 b	3.5 d	3.4 b	2.7 d	2.7 a	2.5 c	2.2 c

[a]For each variety, means followed by a common letter are not significantly different at the 5% level. [b]Dissolution rate: 20% in 2 weeks. [c]40 kg/ha N applied at planting, 20 kg/ha N topdressed at maximum tillering, and 20 kg/ha N at panicle initiation.



4. Monthly rainfall distribution during 1973 wet season in upland rice experimental sites.

however. Only in Nueva Ecija, Central Luzon, did a dry spell occur during the ripening period.

The highest grain yield, 6.6 t/ha, was obtained with IR3260-91-100 in the first seeding at Santo Tomas, Batangas (Table 18). In the same test, IR4520-76-90 yielded 6.4 t/ha. In another site in farmers' fields in Cuenca, Batangas, IR879-183-2, IR879-314-2, IR937-55-3, and IR937-76-2 produced from 6.0 to 6.3 t/ha. In the second seeding, IR1529-430-3 produced 5.6 t/ha at Santo Tomas.

Yields of 4 t/ha or more were obtained in all locations except Negros Occidental where heavy sheath blight infection caused severe yield reduction. Most of the yield differences in each location were due to susceptibility to diseases, particularly blast and sheath blight, and, occasionally, leaf scald, as well. Based on yield performance at all nine locations and reactions to blast and sheath blight, 24 lines have been selected for further testing (Table 18). Averaged for six locations IR1529-430-3 had the highest yield, 3.8 t/ha, except for one location, at two dates of seeding. IR937-76-2 and IR26 averaged over 3.5 t/ha, which was considerably more than the Philippine upland variety C-22 (2.4 t/ha) or IR442-2-58 (1.9 t/ha). IR1480-147-3 yielded significantly more than C-22 in seven out of nine tests and matured 9 days earlier. Two other early maturing lines, IR1154-243-1 (114 days) and IR1545-339 (118 days), were among the top 24 lines.

Table 17. Soil analyses of the upland rice experimental sites in farmers' fields in Santo Tomas and Cuenca, Batangas, Philippines.

Analysis	Santo Tomas	Cuenca
Mechanical:		
Sand (%)	33.4	35.3
Silt (%)	34.3	42.8
Clay (%)	32.4	21.9
Soil texture	clay loam	loam
Soil series	Lipa clay loam	Ibaan loam
Chemical:		
pH	5.1	5.7
Total nitrogen (%)	0.12	0.12
Organic matter (%)	1.9	2.1
Available phosphorus (ppm)	12.5	5.9
Cation exchange capacity (meq/100 g soil)	26	35

The plant height of IR1545-339 (104 cm under upland conditions) is desirable for poor moisture and soil fertility conditions. The selection MRC 172-9 (115 cm) is taller than is desirable for a lodging-resistant variety. Nevertheless, it performed well overall.

Among the 24 top-yielding lines, only IR937-55-3 was free from both blast and sheath blight (Table 18).

The most promising lines tested this year:

Table 18. Grain yield and agronomic performance of promising lines for upland conditions. Santo Tomas and Cuenca, Batangas, 1973 wet season.

Designation	Yield (t/ha)				Growth duration[a] (days)	Plant ht[a] (cm)	Disease reaction[b]	
	Santo Tomas		Cuenca					
	May 28 seeding	June 27 seeding	April 30 seeding	June 2 seeding			Blast	Sheath blight
IR1529-430-3	5.1	5.6**	4.6*	4.1*	128	82	MS	MS
IR937-76-2	5.5*	4.5**	6.3**	4.8**	128	80	R	MS
IR26	5.5*	4.9**	—	4.2*	124	94	MS	MS
IR1416-131-5	5.1	4.0*	5.0**	4.3**	135	86	MR	MS
IR1480-147-3	5.3*	4.4**	5.2**	4.5**	118	85	MS	MS
IR879-314-2	5.6**	4.8**	6.3**	4.9**	129	97	R	MS
IR4520-76-90	6.4**	4.5**	—	4.8**	135	93	R	MS
IR879-183-2	5.3*	4.6**	6.2**	4.7**	128	82	R	S
IR1529-677-2	5.2	4.7**	5.0**	4.1*	128	82	MS	MS
IR1529-680-3	4.4	4.8**	—	4.3**	133	86	MS	MR
IR3260-91-100	6.6**	3.7	—	4.7**	135	100	R	S
IR480-5-9	4.5	5.2**	5.2**	4.8**	128	82	MS	MS
IR937-55-3	5.4*	4.9**	6.0**	4.9**	134	89	R	R
IR1539-823-1	4.8	5.1**	—	3.7	130	84	MR	S
IR1614-332-1	4.1	4.2*	4.9**	3.7	127	82	MS	MS
IR944-102-2	4.1	4.3**	4.0	3.2	127	79	MR	MS
IR1487-141-6	4.7	3.6	5.0**	3.4	127	87	MS	MS
IR577-24-1	4.6	4.5**	4.3	4.2*	126	75	S	MS
IR1154-243-1	3.8	4.6**	3.1	3.0	114	90	MS	MS
IR661-1-170	5.3*	5.4**	3.9	3.8	124	86	MS	S
IR1163-135-2	3.8	4.0*	3.6	3.7	125	90	MS	MS
IR1545-339	4.8	4.8**	4.4*	4.5**	118	104	MR	S
BPI-76/9 × Dawn	3.9	3.6	4.7**	4.0	127	114	MR	MS
MRC 172-9	4.5	2.8	5.5**	3.6	128	115	R	MS
			Check varieties					
IR5	3.5	3.6	4.0	3.5	146	105	MS	S
IR442-2-58	2.3	2.2	2.5	2.1	135	86	S	R
C-22	4.4	3.3	3.3	3.2	127	139	MS	R
M1-48	3.5	2.7	3.2	2.1	127	156	MS	S

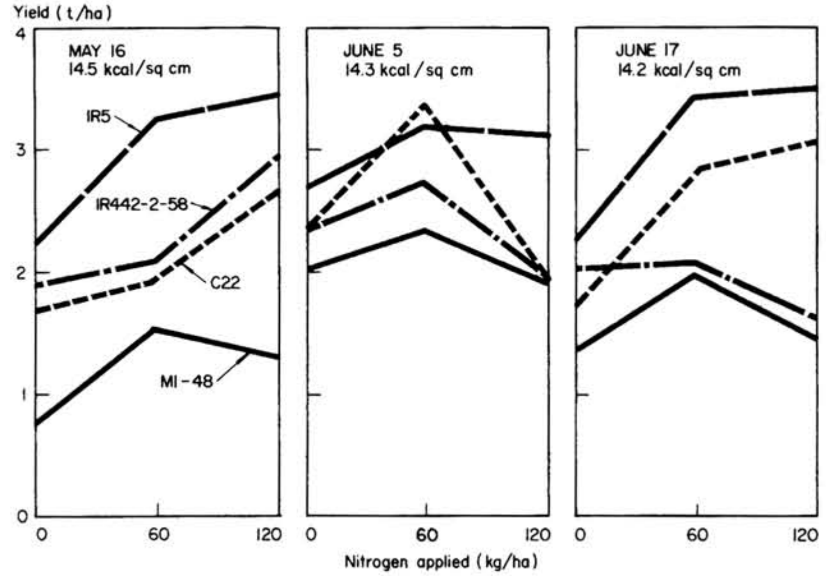
*Significantly better than C-22 at the 5% level. **Significantly better than C-22 at the 1% level. [a]May 28 seeding at Santo Tomas. [b]Worst reaction at any location. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.

early maturing, IR1545-339 and IR1480-147-3; intermediate duration, IR879-314-2 and MRC 172-9; late maturing, IR937-55-3, IR1416-131-5, IR1529-677-2, and IR1539-823-1 (Table 18).

Date-of-seeding. The performance of rice varieties under upland conditions cannot be evaluated properly unless the interrelationships between variety, soil moisture, solar energy, and nitrogen are studied.

During the 1973 wet season, date-of-seeding experiments were installed at five locations but by the end of the year results were available only for the IRRI farm and a trial in a farmer's field in Batangas province. IR5, IR442-2-58, C-22, and M1-48 were grown with 0, 60, or 120 kg/ha N applied as ammonium sulfate in three equal split doses: at seeding, at 30 days after seeding, and at panicle initiation stage. We used four dates of seeding at 2-week intervals, the first seeding corresponded with the beginning of the planting as practiced by the neighboring farmers. A split-split plot design with three replications was used with nitrogen levels as the main plots, date-of-seeding as the sub-plots, and variety as the sub-sub-plots.

At the IRRI farm, grain yield varied significantly between nitrogen levels, between dates of seeding, and between varieties. There were significant interactions between nitrogen and date of seeding and between variety and date of seeding. Nitrogen response to 60 kg/ha N was significant only in a few seedings (fig. 5). At the second seeding date, C-22 with 120 kg/ha N lodged early and produced significantly lower yield than when it received 60 kg/ha N. The crop in the first date of seeding produced relatively low yields because of poor stand establishment as a result of the poor moisture supply (40 to 45



5. Nitrogen response of three varieties and a promising line grown under upland conditions at three dates of seeding with solar radiation total for the reproductive and ripening stages. IRRI, 1973 wet season.

cb soil moisture tension) during the first week after seeding (fig. 6). IR5, however, produced the best yields (fig. 5) even under the dry spell that occurred during the first seeding (fig. 6). M1-48 which was severely infected with sheath blight, and IR442-2-58, with blast, yielded poorly. Solar radiation values (fig. 5) did not differ during the three dates of seeding because rainfall distribution was fairly uniform.

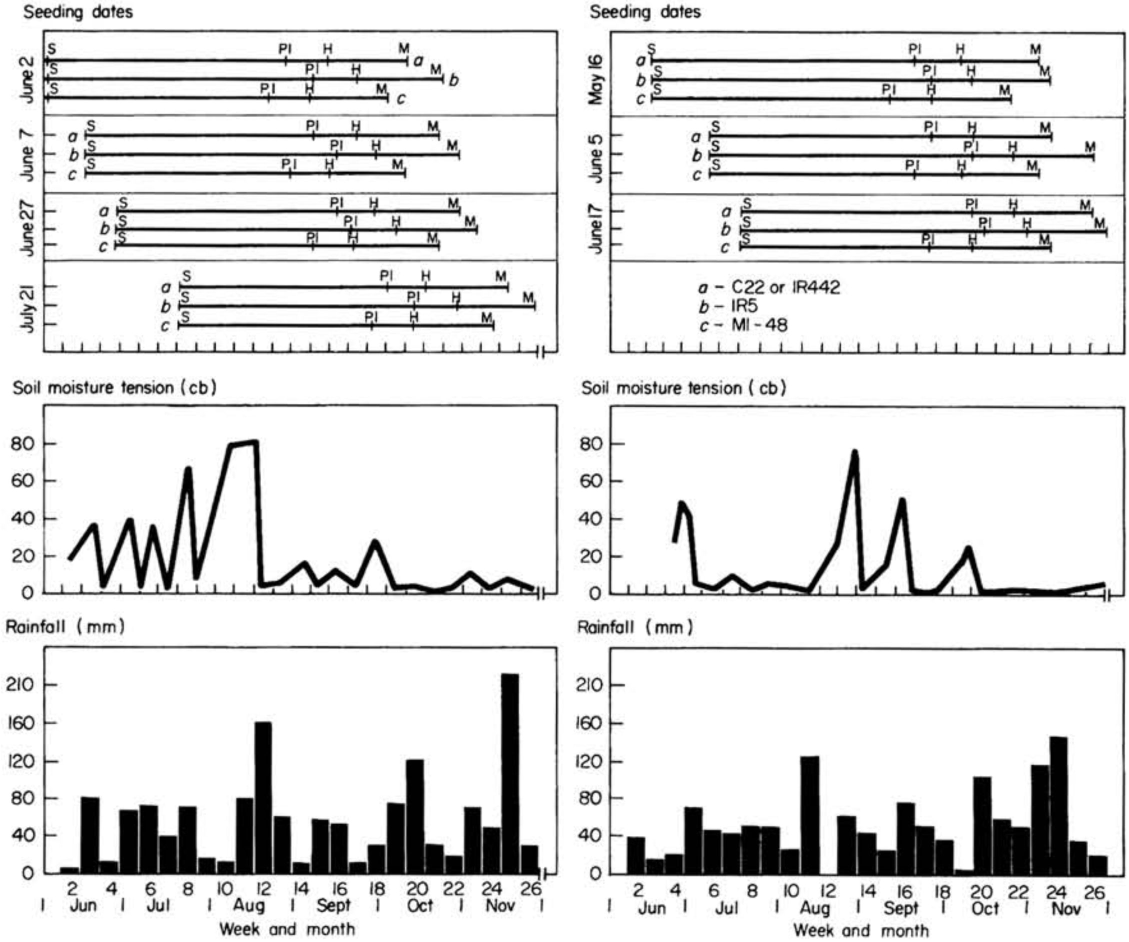
In a farmer's field in Santo Tomas, grain yields differed significantly between nitrogen levels, between dates of seeding, and between varieties. Interactions among the three factors were also significant. Grain-yield increases at 60 kg/ha N usually were significant (fig. 7). At 120 kg/ha N, C-22 lodged early in the June 17 seeding and yielded poorly. IR5 and M1-48 lodged in the June 2, June 17, and June 27 (first to third) seedings and their grain yields were affected.

Solar radiation values during the ripening periods were higher for the two latter seedings than for the two earlier seedings (fig. 7). Moisture supply was uniform for the later plantings, as indicated by even rainfall distribution and low soil moisture tensions (fig. 6). Therefore, relatively low yields in the last two seedings were not due to poor environmental conditions, but to susceptibility to diseases, such as blast in M1-48 and IR442-2-58, and sheath blight in IR5 and M1-48.

The results from the two sites demonstrate that early seeding is desirable with such late-maturing lines as IR5 which can recover from dry spells. Moisture distribution from rain is more critical for the early-to medium-maturing lines than for the late-maturing line once the crop is fully established.

Nutsedge control. Weeds in upland rice consist of both annuals and perennials such as *Cyperus rotundus* (purple nutsedge). *C. rotundus* is a problem wherever upland rice is grown. It is more difficult to control perennial nutsedge than annual weeds because its extensive underground system of basal bulbs, roots, and tubers permits rapid and vigorous vegetative propagation. Shoots from seeds, tubers, or underground stems can emerge from a depth of 1 meter. Many dormant or inactive buds are not affected by chemicals sprayed aboveground, and dormant tubers even tend to tolerate soil-incorporated herbicides. Also, *C. rotundus* is a problem in upland rice because it germinates and grows simultaneously with upland rice.

Since upland rice cultivators use fair amounts of nitrogen in fields commonly infested with nutsedge, experiments were conducted at IRRI

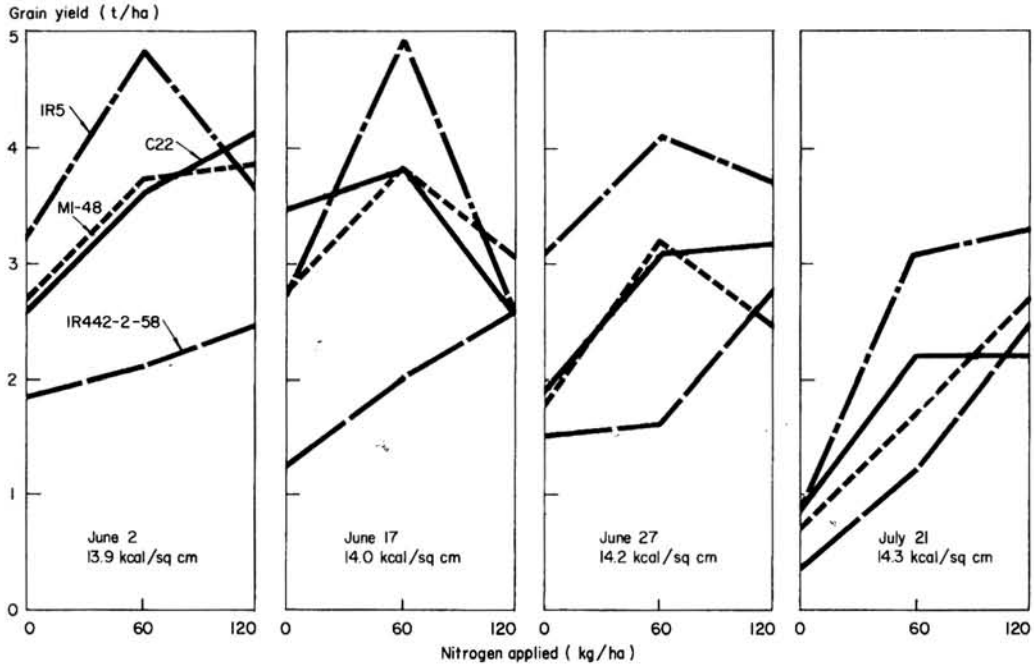


6. Growth stages of rices in upland rice date-of-seeding experiment in relation to soil moisture tension (centibars) and rainfall (S = seeding, PI = panicle initiation, H = heading, M = maturity). IRRI and Santo Tomas, Batangas, Philippines, 1973 wet season.

to investigate the effect of cultural practices, such as nitrogen level, on the competition between varying population densities of *C. rotundus* and upland rice, and on grain yield. We found highly significant negative correlation between dry weights of perennial nutsedge and grain yield of IR5 as affected by nitrogen level (fig. 8). Dry weight of nutsedge increased with increase in nutsedge population density. The application of 60 or 120 kg/ha N significantly increased the grain yield of IR5 compared with 0 kg/ha N. But the yield of IR5 decreased significantly as dry weight of nutsedge increased, hence, the increased nutsedge competition as the nutsedge population density increased.

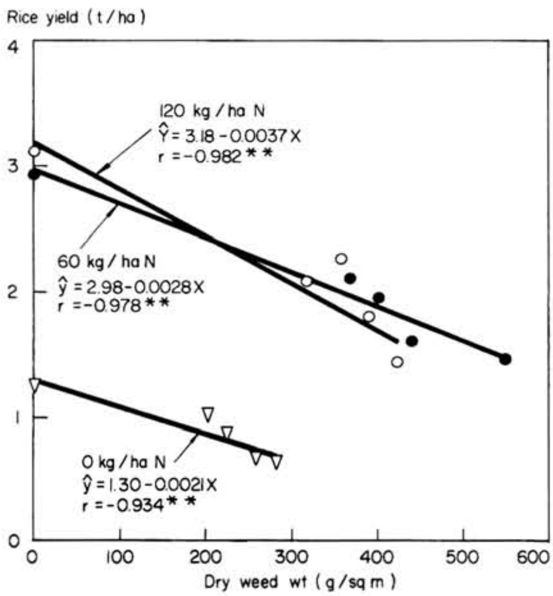
The application of 60 and 120 kg/ha N increased nutsedge population density and reduced IR5 yield (fig. 9). Yield losses from nutsedge competition in upland rice were greater under high nutsedge population density and high soil fertility than under low nutsedge population density and low soil fertility. The significantly higher grain yields of IR5 associated with increasing nitrogen level were accompanied by increases in nutsedge dry weight, suggesting that nutsedge control should be more important under high soil fertility than under low fertility.

Nutsedge and upland rice competed keenly for moisture, and the competition was much more serious with increased nitrogen fertilization up to 60 kg/ha. As a result of higher nutsedge population (750/sq m), soil moisture tension



7. Nitrogen response of three varieties and a promising line grown under upland condition at four dates of seeding with solar radiation total for reproductive and ripening stages. Santo Tomas, Batangas, Philippines, 1973 wet season.

without fertilizer nitrogen rose to about 70 cb in contrast with 25 cb under weed-free conditions (fig. 10). At 60 kg/ha N, the differences in soil moisture tensions between weed-free and weedy plots narrowed. The demand for moisture apparently increases at higher soil fertility since weeds plus rice or the vigorously growing rice alone depletes the limited moisture supply faster under upland conditions.



8. Correlation between weed weight and grain yield of upland rice (IR5) as influenced by nitrogen level. IRRI, 1972 wet season.

At higher nitrogen levels, perennial nutsedge competition significantly reduced light transmission ratio (LTR). The reduction was proportional to the increase in nutsedge competition or population density (Table 19).

These results demonstrate that competition for nitrogen and moisture seriously affect grain yield of upland rice as a result of nutsedge competition. Although intermediate-statured rice varieties can grow faster than perennial nutsedge, early competition for light, as evidenced by low LTR values, also contributes to the reduction in grain yield.

Annual weed control. Weeds are far more serious in upland rice than in lowland rice. For the control of annual weeds, butachlor, fluorodifen, USB 3153, and MC 4379 continued to look promising at the Maligaya station in Central Luzon (Table 20). The low yields were partly due to a high infestation of perennial nutsedge in addition to annual weeds. Further-

Table 19. Effects of nutsedge population densities on light transmission ratio at the panicle initiation stage of IR442-2-58 grown under simulated upland conditions. IRRI, 1973 dry season.

Nutsedge population (no./sq m)	Light transmission ratio[a]			
	0 kg/ha N	60 kg/ha N	120 kg/ha N	Mean
0	44 a	3 a	2 a	16
250	36 b	2 a	1 a	13
500	29 c	2 a	1 a	11
750	24 d	2 a	1 a	9
1000	19 e	1 a	1 a	7
Mean	30	2	1	

[a]Any two means followed by a common letter are not significantly different at the 5% level (Duncan's multiple range test).

more, IR442-2-58 had suffered from blast disease which explains some yield reduction. Among the promising chemicals only liquid butachlor is marketed in the Philippines. Its price, US$22/ha, is about one-third the cost of hand weeding twice.

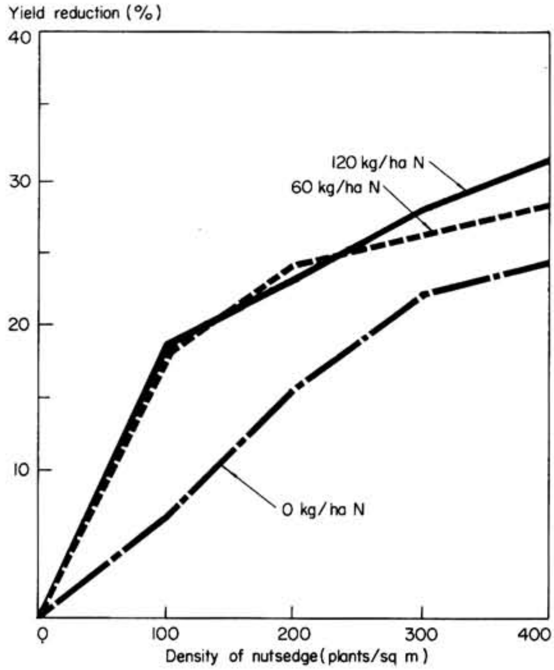
Among the chemicals we tested for the first time, oxadiazon (2-tert-butyl-4 (2, 4-dichloro-5-isopropyloxyphenyl)-Δ^2-1, 3, 4-oxadiazolin-5-one) from Rhone-Poulenc, France, and USB 3584 (N^3, N^3-diethyl-2, 4-dinitro-6-trifluoro methyl-m-phenylenediamine) from U.S. Borax Co., looked outstanding in controlling annual weeds (Table 21) at IRRI. Figure 11 shows USB 3584-treated plots relatively weed free compared with untreated control in the experiment conducted at the IRRI farm under upland culture.

Control of annuals and perennial nutsedge. During the 1972 and 1973 dry seasons, experi-

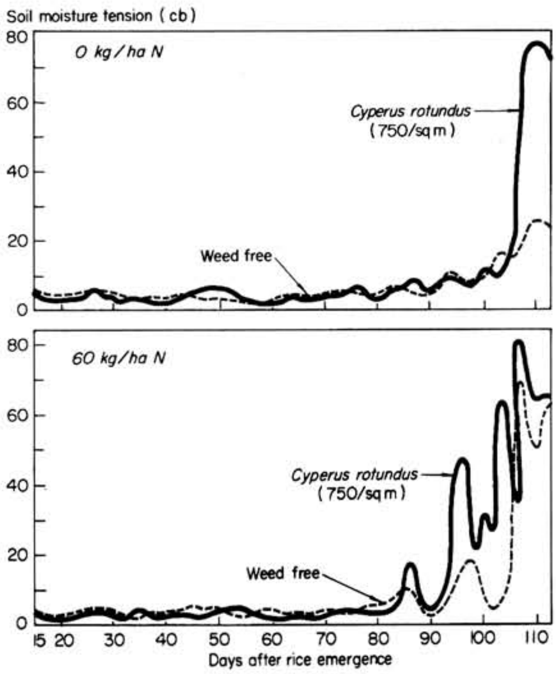
Table 20. Promising liquid herbicides for upland rice (IR442-2-58). Maligaya Rice Research and Training Center, Nueva Ecija, Philippines, 1973 wet season.

Chemical	Rate (kg/ha a.i.)	Applied (DS[a])	Grain yield[b] (t/ha)
Benthiocarb	2	4	1.4 abc
Butachlor	2	4	2.4 ab
C-288	2	4	0.6 bc
Fluorodifen	2	4	1.1 bc
A-820	2	4	1.7 ab
USB 3153	2	4	1.2 bc
MC 4379	2	4	1.8 ab
Hand weeding	twice	20 & 40[c]	3.5 a
Untreated control	—	—	0.0 c

[a]Days after seeding. [b]Avg of four replications. Any two means followed by a common letter are not significantly different at the 5% level. [c]Days after rice emerged.



9. Effect of nitrogen level on the reduction in grain yield of upland rice (IR5) competing with perennial nutsedge (*C. rotundus* L.). IRRI, 1972 wet season.



10. Soil moisture tension (at 30 cm) in upland rice culture (IR442-2-58) as affected by nutsedge (*C. rotundus*) competition at two nitrogen levels. IRRI, 1972 wet season.

Table 21. Promising herbicides for upland rice (IR442-2-58). IRRI, 1973 wet season.

Chemical	Rate (kg/ha a.i.)	Yield[a] (t/ha)
Benthiocarb	2.0	2.7 a
Butachlor	2.0	2.7 a
C-288	2.0	2.6 a
Fluorodifen	2.0	3.0 a
A-820	2.0	2.8 a
USB 3153	2.0	3.1 a
USB 3584	2.0	3.3 a
MC 4379	2.0	3.1 a
AC 84319	2.0	1.0 bc
AC 92390	2.0	2.6 a
AC 92553	2.0	2.9 a
Actril D	2.0	1.5 b
BAS 3517 H	2.0	0.0 c
Fenormone	2.0	1.0 bc
Oxadiazon	0.5	3.1 a
Oxadiazon	1.0	3.0 a
Oxadiazon	2.0	3.3 a
Oxadiazon	3.0	3.0 a
U 46 KV	4.0	0.4 bc
MBR 8251	2.0	0.0 c
Butachlor fb MBR 8251	2.0 fb 2.0	2.7 a
Propanil	3.0	0.7 bc
Hand weeding	twice	3.6 a
Untreated control	—	0.0 c

[a]Avg of four replications. Any two means followed by at least one common letter are not significantly different at the 5% level.

ments were conducted at the IRRI farm under simulated upland conditions to identify herbicides that would control both perennial nutsedge and annual weeds in upland rice. In the 1972 dry season, all treated plots gave significantly higher grain yields than the untreated control (Table 22). The highest grain yield, 4.8 t/ha, was obtained with the combination of USB 3153 (chemical formula not yet disclosed) at 1 kg/ha a.i. applied 3 days after seeding, followed by MCPP [2-(2-methyl-4-chlorophenoxy) propionic acid] at 1 kg/ha a.i. 20 days after crop emergence. USB 3153 controlled annual weeds completely while MCPP effectively controlled perennial nutsedge. This yield was not significantly different from that obtained by hand weeding twice. Butachlor, USB 3584, A-820, U-27, 267, Propanil, and MON 843 controlled annual weeds adequately and, in combination with MCPP, their control of nutsedge gave as good yields as hand weeding twice. In similarly treated plots, but without MCPP, grain yields were reduced by 7 to 40 percent because of nutsedge competition with rice. Although the effect of MCPP on nutsedge control varied with the pre-emergence herbicides applied before it, MCPP appeared promising for the control of *Cyperus rotundus* in upland rice.

During the 1973 dry season, all treated plots gave significantly higher grain yields than the untreated control. The highest grain yield was obtained with K-223 [N-(αα-Dimethylbenzyl)-N'-p-totyl urea] at 10 kg/ha a.i. incorporated before planting, followed by 2 kg/ha a.i. butachlor applied 3 days after seeding, and by bentazon at 2 kg/ha a.i. 7 days after crop emergence (Table 23). This yield was not significantly different from that of hand weeding twice.

K-223 at 8 and 10 kg/ha a.i. provided excellent control of nutsedge with no visible crop injury, and when coupled with good control of annual weeds by butachlor, resulted in high yields (Table

11. While untreated control plots were completely taken over by weeds and produced no yield, USB 3584 herbicide sprayed 3 days after seeding upland rice (IR442-2-58) controlled weeds adequately and resulted in a yield of over 3 t/ha. IRRI, 1973 wet season.

23). The follow-up application of bentazon after K-223 at 8 or 10 kg/ha a.i. for nutsedge control, did not increase yields significantly and, therefore, appeared to have no advantage under the conditions of this experiment. Bentazon at 2 kg/ha a.i. also showed a high degree of selectivity but was less effective in nutsedge control at this concentration than K-223.

Table 22. Control of perennial nutsedge (*Cyperus rotundus*) and annual weeds by various herbicides and their effects on grain yield of IR442-2-58 under simulated upland conditions. IRRI, 1972 dry season.

Chemical	Rate (kg/ha a.i.)	Perennial nutsedge control[a] (%)	Yield[b] (t/ha)
USB 3153 fb MCPP	1 fb 1	41	4.8 a
USB 3584 fb MCPP	2 fb 1	27	4.5[c]
A-820 fb MCPP	2 fb 1	50	4.5[c]
Butachlor fb MCPP	2 fb 1	41	4.1 ab
Butachlor fb MCPP	4 fb 1	28	3.8 ab
U-27, 267 fb MCPP	2 fb 1	54	3.8 ab
MON 843 fb MCPP	3 fb 1	71	3.3 ab
Hand weeding	twice	100	3.8 ab
Untreated control	—	0	0.4 d

[a]Measured 30 days after crop emergence. [b]Means followed by a common letter are not significantly different at the 5% level. [c]From one replication and were not included in the statistical analysis.

DROUGHT TOLERANCE

Because of the complexity of the problems of drought tolerance, our initial emphasis has been on the soil-water aspects of the soil-water-plant-atmosphere continuum. At present we are using soil moisture tension as the criteria for the moisture-supplying capacity of soil at a particular evaporative demand. During 1973 we continued developing techniques or modifications of our earlier techniques for screening genetic lines for drought tolerance, as well as screening a genetic line for drought tolerance.

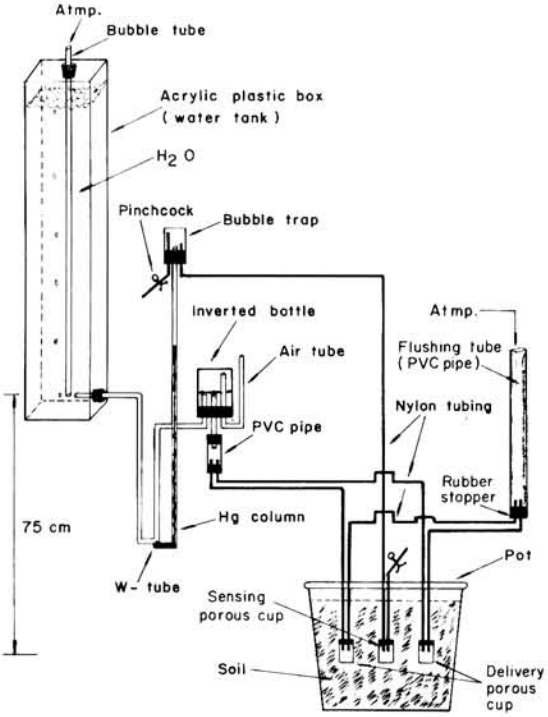
Techniques for screening breeding lines. We have designed two kinds of set-ups for maintaining various soil moisture tensions. The set-up for saturation treatment is composed of a water tank (acrylic plastic box), a delivery unit (tygon tubing and perforated PVC pipe containing glass wool), and pots. The water tank has a bubble tube to maintain a constant head at the tip of the tube near the bottom of the tank. The position of the constant head corresponds to 7 cm below the surface of the soil in the pot.

The set-up for supplying water at relatively constant soil moisture tension in pots is composed of five major parts—water tank, a W-tube, water distribution system, soil moisture tension sensors, and pots (fig. 12). The water tank has a bubble tube that maintains a constant head at the tip of the tube near the bottom of the tank. The delivery porous cups are 75 cm below the level of the constant head to facilitate the movement of water from the water tank to the soil through the porous cup. The W-tube, which contains a predetermined amount of mercury, controls the soil moisture tension in the pot. When the height of mercury in the W-tube is equivalent to the soil moisture tension in the pot, all the mercury is pulled up to the left side of the tube which is in turn connected to the bubble trap of the tensiometer. Thus, the water can flow freely from the tank to the inverted bottle of the distribution system. Finally, water is

Table 23. Effects of a substituted urea herbicide (K-223) on the control of perennial nutsedge under simulated upland conditions (rice variety: IR442-2-58). IRRI, 1973 dry season.

Chemical[a]	Rate (kg/ha a.i.)	Total weed wt (g/sq m)	Dry wt of nutsedge (g/sq m)	Grain yield (t/ha)
K-223 fb butachlor fb bentazon	10 fb 2 fb 2	98 a	2 a	4.1 a
K-223 fb butachlor fb bentazon	8 fb 2 fb 2	92 a	5 a	4.0 ab
K-223 fb butachlor	10 fb 2	77 a	3 a	4.0 ab
K-223 fb butachlor	8 fb 2	54 a	6 a	3.8 bc
K-223 fb butachlor fb bentazon	6 fb 2 fb 2	79 a	12 a	3.5 cd
Butachlor fb bentazon	2 fb 2	62 a	18 a	3.5 cd
K-223 fb butachlor	6 fb 2	64 a	14 a	3.4 d
Hand weeding	twice	27 a	2 a	4.0 a
Untreated control	—	666 b	58 b	0.4 e

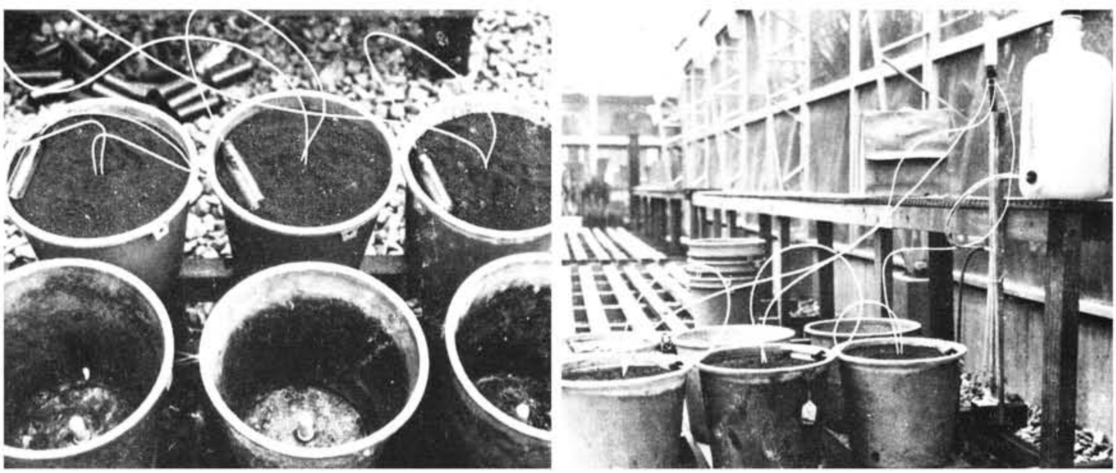
[a]K-223, applied pre-planting, butachlor, 3 days after seeding, bentazon, 7 days after crop emergence.



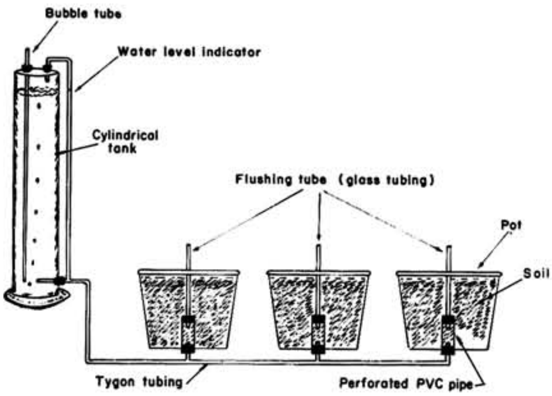
12. Set-up for measuring drought tolerance in rice by maintaining a constant soil moisture tension throughout the cropping season.

distributed in each pot through the delivery porous cups. Thus, the soil moisture tension in the pot is relieved and the mercury level in the left side of the tube moves down to close the system. This process repeats itself to provide water more or less instantaneously to the plant in each pot. Three pots are connected parallel to the inverted bottle of the system. Figure 13 shows the actual set-up in the greenhouse for screening rice varieties for drought tolerance. The height of water in the tank is measured every morning to estimate the daily evapotranspiration.

Although frequent leaks in the acrylic plastic box could be corrected with sealing agents (silicon sealer or silastic) and clogging of the nylon tubing caused by growth of algae in the distributor system could be removed by pumping in water through the flushing tube using a wash bottle, we modified the set-ups to circumvent these problems. No change was made in the set-up for saturation except that the acrylic plastic box was replaced with an air-tight cylindrical tank (fig. 14). The set-up used to maintain a relatively constant soil moisture tension was modified somewhat, but the principle involved remained the same (fig. 15). The acrylic plastic box was replaced with a cylindrical tank to prevent leaks. The inverted bottle was removed and the delivery nylon tubing with an inside diameter of 3 mm (three times bigger than the nylon tubing used in the previous set-up) was connected directly to the W-tube with a PVC pipe. The delivery porous cups were made thinner with an electric grinding stone to facilitate movement of water from the tank to



13. Greenhouse set-up for measuring drought tolerance: left photo shows delivery porous cups in each pot and nylon tubing which connects the bubble trap and the sensing tensiometers placed at 10 cm soil depth; right photo shows that each set-up can maintain a predetermined soil moisture tension in three pots.

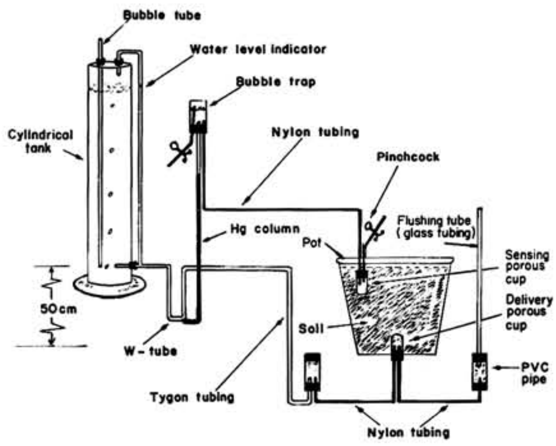


14. Modified set-up for maintaining soil saturation for measuring evapotranspiration in rices. IRRI, 1973.

the soil in the pot. This system can also be used to instantaneously determine water used by different varieties.

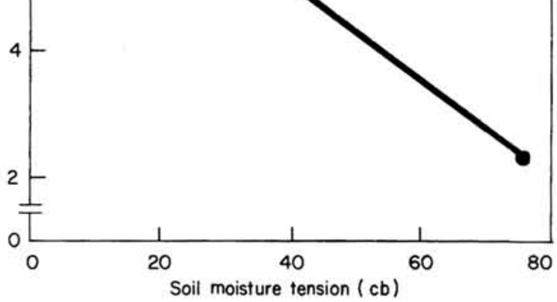
The modified technique was tested on 12 varieties. Eight experimental lines and four varieties were grown in pots at three relatively constant soil moisture tensions, 0, 33, or 75 centibars (cb). Evapotranspiration was higher from plants in saturated soil than from plants in soil at 33 cb (fig. 16), indicating the good performance of our set-up in the study of drought tolerance at a constant level of soil moisture tension. Figure 17 shows the growth differences between the Philippine upland variety C-22, the experimental line IR1487-372-4, and the lowland variety IR20 at 75 cb soil moisture tension demonstrating that IR1487-372-4 has better drought tolerance than IR20, and confirming the results of 2 years of field experiments. IR442-2-58, IR1487-372-4, and IR1529-430-3 gave the highest yields (13.5, 13.4, and 12.6 g/pot, respectively) at 33 cb, indicating their moderate level of drought tolerance. At 33 cb, the African upland variety OS6 gave the lowest yield, 2.8 g/pot.

Screening varieties for drought tolerance. A field experiment was conducted under simulated upland conditions during the 1973 dry season to study the effects of moisture stress on upland rice. Figure 18 shows the moisture retention curve for the Maahas clay loam soil (pH 5.8; cation exchange capacity, 37 meq/100 g; total N, 0.15%, organic matter, 2.63%; available P, 0.72%) collected from the upland rice experi-

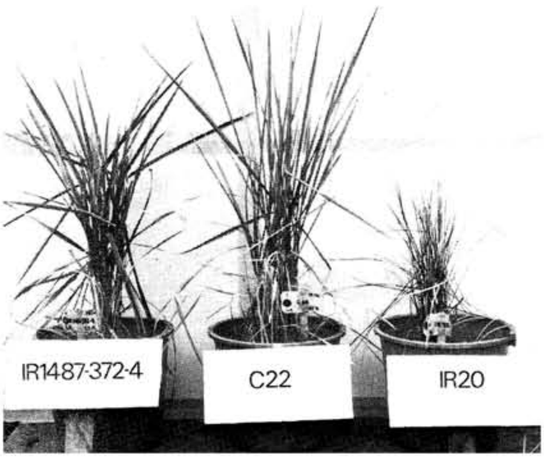


15. Modified set-up for maintaining a predetermined level of soil moisture tension for studying drought tolerance in rices. IRRI, 1973.

mental area at the IRRI farm. Forty-eight varieties and experimental lines were subjected to three moisture treatments 14 days after germination: 1) continual saturation throughout crop growth, maintained by adding 5.5 mm of water daily; 2) early stress--soil moisture tension of 75 cb during the first 60 days after seedling establishment, after which soil was kept saturated (the plots were irrigated with 8.25 mm of water whenever the soil moisture tension reached 75 cb); 3) late stress—continual saturation was maintained during the vegetative stage and soil



16. Evapotranspiration values as affected by soil moisture tension. Each value is an average of 12 varieties.



17. Compared with IR20, the growth of IR1487-372-4 and of the Philippine upland variety C-22 was better when they were subjected to continual soil moisture tension of 75 cb using the IRRI-devised system.

moisture tension of 75 cb maintained during the panicle initiation stage and harvest (plots received 8.25 mm of water in response to soil moisture tension of 75 cb).

Of the upland varieties tested, only E-425 and Moroberekan were unaffected by the various soil moisture tensions as indicated by changes in height, tiller number, and dry matter production (Table 24). All these varieties are tall and low tillering, so they do not produce high yields under upland rice culture. On the other hand, the plant characters of improved lines such as IR661-1-170, IR1531-86-2, IR1646-623-2, and IR1721-11-6 were also unaffected by stress, but had considerably higher tillering capacity. Only IR1531-86-2 had the 100-cm plant height under upland conditions which we believe desirable for the low moisture and fertility conditions that prevail in most farmers' upland fields.

Under saturation, the highest grain yield (635 g/sq m) was obtained with IR1529-677-2 which was reported earlier to be one of the promising lines for upland rice (1972 annual report). The Philippine upland variety Dinalaga produced the lowest yield (198 g/sq m). In the early stress treatment, IR5 produced the highest grain yield (456 g/sq m), confirming our earlier results. IR5 is one of the best for droughty upland conditions if stress is relieved before panicle initiation. Dinalaga once again produced the lowest yield (156 g/sq m). Among the 46 varieties or lines tested, the African upland variety OS6 ranked 25th (325 g/sq m) which was,

Table 24. Plant height, tiller number, and dry weight at harvest of some selected rice varieties and lines under continual saturation and percent reduction of the same growth characters due to soil moisture stress (75 cb) during the vegetative or reproductive stage. IRRI, 1973 dry season.

Designation	Plant ht			Tillers			Dry wt		
	Continual saturation (cm)	Change (%) Early stress	Change (%) Late stress	Continual saturation (no./1-m row)	Change (%) Early stress	Change (%) Late stress	Continual saturation (g/1-m row)	Change (%) Early stress	Change (%) Late stress
M1-48	105	-18**	-2	77	-21	-4	156	-33**	-11
Dinalaga	124	-6	-15**	90	-26	-7	205	-34**	-16
E-425	108	-4	-2	95	-14	-1	155	-16	5
OS6	110	-22**	-15**	119	-17	-1	242	-50**	-38**
Moroberekan	109	-4	-4	75	-32	-3	145	-28	-10
C-22	123	-4	-18**	131	-2	2	236	-38**	-17
IR5	113	-5	13**	224	-3	-17	486	-36**	-48**
IR661-1-170	66	-0	-0	197	-10	-13	162	-21	-11
IR938-35-2	69	-6	-1	232	-11	-2	199	-24*	-9
IR1487-372-4	77	-17*	-14	208	-2	-10	177	-24	-11
IR1529-430-3	76	-5	-9	215	-22*	3	180	-2	-0
-677-2	77	-1	-10*	215	-6	-14	211	-14	-16
-680-3	82	-20	-17	209	-44**	-1	203	-45**	1
IR1531-86-2	100	3	-7	156	-17	4	196	-31	-9
IR1544-238-2	64	-0	-2	218	-17	-9	136	-32	-16
IR1561-149-5	67	-10	-3	247	-10	-4	140	-21	-3
IR1646-623-2	71	-1	-0	180	-14	12	146	-21	18
IR1721-11-6	76	1	-5	238	-12	-5	165	-20	-7

*Significantly different from the value at saturation at the 5% level. **Significantly different from the value at saturation at the 1% level.

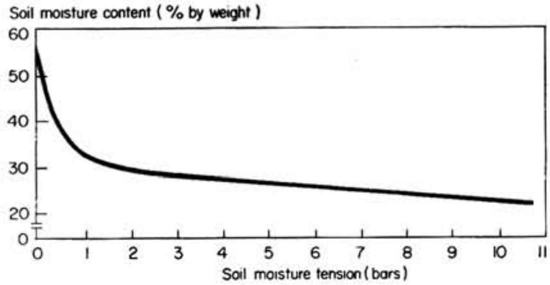
however, the highest among the upland varieties. All the top-yielding lines were from the IRRI general breeding program. IR442-2-58 once again ranked as one of the best under upland condition (576 g/sq m). For the late stress treatment, both IR5 (201 g/sq m) and IR442-2-58 (123 g/sq m) gave poor yields similar to those of upland rice varieties OS6 (196 g/sq m) and M1-48 (147 g/sq m). For the same treatment, the best yielding lines were IR1544-238-21 (360 g/sq m), IR1721-11-13 (351 g/sq m), and IR1646-623-2 (319 g/sq m).

By averaging grain yields of all varieties or lines, we found that the later the stress treatment, the greater the reduction in grain yield, indicating the vulnerability of rices during reproductive and ripening stages (fig. 19). More varieties were susceptible to high soil moisture tension at the reproductive and ripening stages than to stress during vegatative period. Late stress resulted in poorer performance than early stress when the data were averaged for all varieties and lines.

To give a quantitative means of determining the susceptibility of the crop to a given stress level, we used the formula proposed by Hiler and Clark, $CS_{vm} = (X-M)/X$, where CS is the crop susceptibility factor as a function of variety (v) and growth stage (m), X is the yield where no stress was imposed throughout the crop growth, M is the yield when stress was imposed only at a particular growth stage. Crop susceptibility values increased at later stages of rice growth. In other words, as crop susceptible values increased at later stages of crop growth, the grain yield decreased linearly (fig. 19).

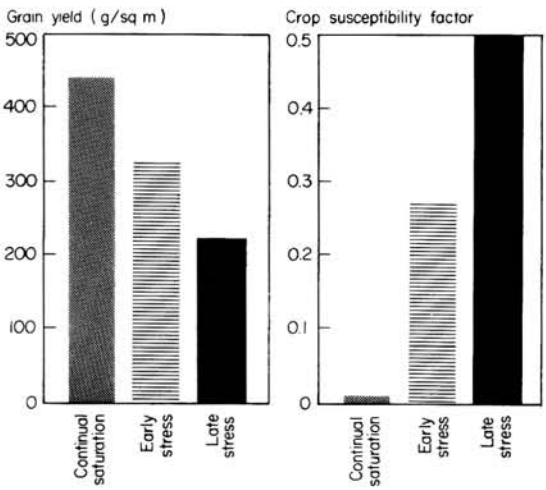
Based on the crop susceptibility concept, the varieties and lines were classified into four groups: 1) varieties and lines susceptible to both vegetative and reproductive stress; 2) lines tolerant to vegetative stress but susceptible to reproductive stress; 3) lines tolerant to both vegetative and reproductive stress; and 4) lines resistant (tolerance plus avoidance capabilities and capacity to recover from drought) to both vegetative and reproductive stress.

In this experiment, IR1646-623-2, which yielded significantly less than did IR1721-11-6 and IR1542-43-2, the top yielders in all treatments, was the most tolerant to moisture stress at all growth stages. Therefore, drought tolerance should not be equated entirely with grain yield since many soil and nutritional problems affect the overall performance of a rice variety under sub-optimal moisture level.

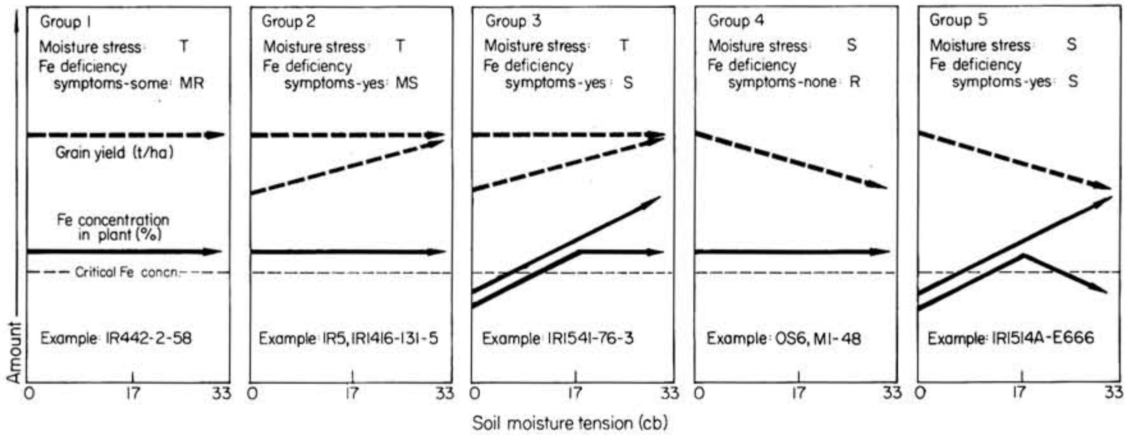


18. Desorption curve of Maahas clay loam soil (sand: 27.7%, silt: 35.2%, clay: 37.1%) from upper MN block, upland rice experimental area at the IRRI farm.

Soil-water relations in upland rice. A greenhouse experiment was conducted to study the varietal response to various levels of relatively constant soil moisture tension imposed continually throughout the growing period. Maahas clay soil was collected, air dried, and ground to pass through a 2-mm sieve. We placed 850 g soil in plastic pots, 30 cm in diameter and 30 cm deep, and applied 150 kg/ha N and 80 kg/ha P_2O_5, based on surface area. The nitrogen was applied in three equal split doses. The phosphorus and the first dose of nitrogen were mixed with the soil. Additional doses of



19. Grain yield and crop susceptibility factor as affected by 75 centibars soil moisture tension during the vegetative (early stress) and reproductive (late stress) stages of rice growth under upland culture (avg of 48 varieties or lines).



20. Schematic classification of rice varieties according to their susceptibility or resistance to moisture stress and iron deficiency under upland rice culture.

nitrogen were applied at maximum tillering and at panicle initiation. Seventy-five rice varieties or lines were tested in three replications. Ten seeds of each variety were dibbled in pairs in a circular manner about 3 cm deep. Enough water (400 ml) was added daily to ensure good germination. When the plants were 10 days old, they were thinned to five per pot. Moisture treatments were imposed when the seedlings were 14 days old.

Tensiometers were installed at 10 cm soil depth in one replication. The soil moisture tension treatments were 0 cb (saturation), 17 cb, 33 cb, and 75 cb. In the saturation treatment, water was added daily to maintain a thin film of water. For the 17-cb and 33-cb treatments, 400 ml of water was applied whenever the soil moisture tension in a given pot reached those tensions. For the 75-cb treatment, the tensiometer was disconnected for 48 hours when the soil moisture tension reached 75 cb. Water was added and tensiometers were connected again.

Iron deficiency symptoms were observed in the saturated as well as in the stress treatments. The degree and expression of symptoms differed between treatments and varieties. The symptoms varied even among lines from the same cross.

A schematic diagram of classification of rice varieties according to their susceptibility or tolerance to moisture stress and iron deficiency under upland rice culture is shown in figure 20. For example, we classified as tolerant those varieties whose grain yields increased or remained high and stable at various soil moisture tensions. We classified as susceptible those whose grain yields decreased with increase in soil moisture tension. Studies by IRRI physiologists have shown that rice plants suffer from iron deficiency when the concentration of iron in the straw is below 70 ppm. If the iron concentration in rice plants remained stable at various soil moisture tensions and above the critical level (70 ppm) and the plants showed no symptoms of iron deficiency, we considered the variety resistant to iron deficiency. On the other hand, we considered the variety that had lower than critical level of iron in the plant tissue at soil saturation (0 cb) and showed iron deficiency symptoms susceptible to iron deficiency (fig. 20).

The upland varieties such as M1-48 and OS6, accumulated the largest amount of iron at saturation and showed no symptoms of iron deficiency (Table 25). In IR1416-131-5, iron concentration was lower and iron deficiency symptoms were greater at higher moisture level. Iron concentration in straw was increased with increased soil moisture tension. As a result of higher iron availability, the grain yield increased with increased soil moisture tension. IR442-2-58, which had above the critical level of iron concentration in the straw, but exhibited slight symptoms of iron deficiency, produced grain fairly well at all stress levels, nevertheless. The extremely low concentration of iron in the straw at saturation in IR1541-76-3 in Group 3 and

Table 25. Grain yield and nutrient content of representative varieties and lines grouped by resistance to moisture stress, as affected by different levels of soil moisture tension.

Designation	Yield (g/pot)			Fe (ppm)			Mn (ppm)			P (%)		
	0 cb	17 cb	33 cb	0 cb	17 cb	33 cb	0 cb	17 cb	33 cb	0 cb	17 cb	33 cb
					Group 1							
IR442-2-58	22	19	19	112	99	90	795	775	722	0.17	0.14	0.13
					Group 2							
IR5	15	18	24	76	108	141	575	470	215	.19	.18	.14
IR1416-131-5	5	7	17	71	80	120	725	335	290	.14	.14	.13
					Group 3							
IR1541-76-3	10	18	16	52	147	75	585	630	225	.29	.22	.18
					Group 4							
OS6	17	9	9	165	161	157	320	565	730	.11	.16	.19
M1-48	20	7	6	182	165	115	445	440	600	.12	.14	.17
					Group 5							
IR1514A-E666	11	13	6	22	221	36	1260	845	650	.10	.10	.12

IR1514-E666 in Group 5 were reflected in grain yields.

We believe high manganese concentration in plant tissue at soil saturation aggravated iron deficiency in plants. These high manganese concentrations are not high enough to cause manganese toxicity in rice but high enough to cause reduction in iron uptake by rice plants.

Thus reduction in grain yield due to increased soil moisture tension may be due to soil moisture stress alone, to moisture-stress induced soil problems such as iron deficiency, or to both. Therefore, moisture stress and soil problems should be considered together in evaluating suitability of rices for upland culture.

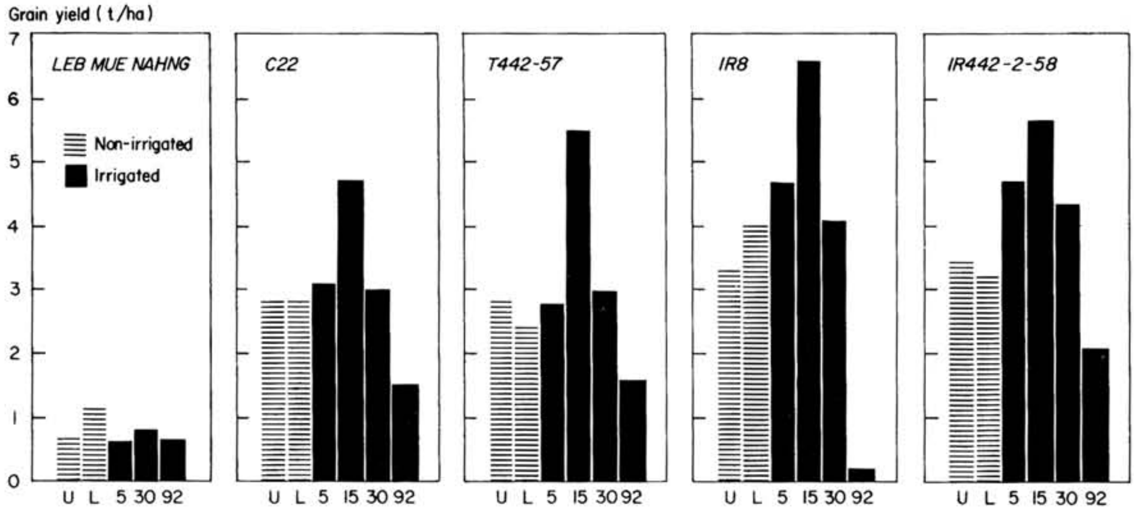
Results further indicate that iron deficiency occurs in upland rice even on acid soils of pH 5.1. In our field experiments conducted in farmers' fields in Batangas, Philippines, a large number of rice varieties and experimental lines showed iron deficiency symptoms in upland rice grown on acid soils (pH 5.1 to 5.7). Iron deficiency has previously been reported to be a problem only on neutral and alkaline soils. Our results show that iron deficiency in upland rice occurs widely on acid soils as well and is closely associated with moisture status of soil.

VARIETAL ADAPTATION TO WATER CONDITIONS

Experiments were conducted for three cropping seasons in 1972 and 1973 to study varietal adaptation to various water conditions. The varieties used were those which are well suited for specific water and land management systems. Varieties elongated differentially at different water management treatments. Based on data from two seasons, IR8 when grown in 92 cm of water was about 40 cm taller than when grown in 5 cm of water. T442-57 had the greatest increase, about 85 cm. The T442 line was about 14 cm taller than IR442-2-58. Tiller production was not severely affected with increased water depth although panicle production was reduced.

Based on grain yields for three cropping seasons, IR8 and IR442-2-58 yielded the most under upland conditions and IR8 the most under 5 cm of continuous irrigation. At 30- and 92-cm water depths, IR442-2-58 outyielded all other varieties (fig. 21). IR8 virtually yielded nothing at 92 cm of water while IR442-2-58 produced over 2.5 t/ha.

These results with IR442-2-58 substantiate the idea of breeding a variety which could adjust its growth characteristics depending on the land and water management systems (upland, lowland, and moderately deep water) in rainfed areas. Moisture adaptability in rices will provide insurance against total crop failure if the moisture supply from rain in a given year is not typical for the specific water and land management system. Naturally, under any water conditions, disease and insect resistance and resistance to drought should be built in rice varieties for high, stable yields. Furthermore, photoperiod sensitivity in rice varieties would be desirable under certain deep water conditions.



21. Grain yield of rice varieties grown at IRRI under upland conditions (U), rainfed lowland conditions (L), and irrigated at 5, 15, 30, and 92 cm water depth (Upland: 1972 wet season; rainfed lowland: 1972 and 1973 wet seasons; 5, 30, and 92 cm: 1972 wet season and 1973 dry and wet seasons; 15 cm: 1973 dry season).

HIGH-PROTEIN RICES

Experiments were conducted at the IRRI farm during the 1973 dry and wet seasons to evaluate relationship between protein content of rice grains and grain yields as affected by time of nitrogen application. In the dry season, the nitrogen treatments were 0 kg/ha N, 150 kg/ha N all basal, or 120 kg/ha N basal, and 30 kg/ha N topdressed at panicle initiation stage. The data are summarized for seven out of 10 varieties and lines tested. The experimental lines IR160-27-3, IR480-5-9, and EPJI-13-B-10 produced the highest grain yields (Table 26). Split applications of 150 kg/ha N gave significantly higher protein content than the same amount applied at planting. The protein contents of IR1126-39-3, IR1550-16-2, and EPJI-13-B-10 were not significantly different from the protein content of the high protein check line, IR480-5-9 (Table 26).

In the wet season, 20 varieties and lines were evaluated for the relative protein content and yield potential. Nitrogen treatments were 0 kg/ha N, 100 kg/ha N basal, or 70 + 30 kg/ha N applied at planting and panicle initiation. Data are summarized for seven varieties and lines (Table 27). IR8 not only had significantly lower protein content than IR480-5-9 but also produced significantly lower grain yield at all nitrogen treatments. IR1737-19-7 and IR1514A-E597-4 produced significantly higher grain yield but significantly lower protein content than IR480-5-9 (Table 27). The yields of IR1737-19-7 would have been higher if the crop had not

Table 26. Grain yield and protein content of rices with three nitrogen treatments. IRRI, 1973 dry season.

Designation	Yield[a] (t/ha)			Brown rice protein[b] (%)		
	0 kg/ha N	150 kg/ha N[c]	120 + 30 kg/ha N[d]	0 kg/ha N	150 kg/ha N[c]	120 + 30 kg/ha N[d]
IR8	1.8	3.6	4.2	7.5	6.9	7.9
EPJ1-13-B-55	2.9	5.1	5.4	8.0	8.5	9.2
IR160-27-3	3.4	5.8	6.0	8.0	7.8	7.9
IR480-5-9	3.4	5.0	5.5	7.6	8.4	8.7
IR1126-39-3	2.7	4.0	4.4	8.9	7.9	8.8
IR1550-16-2	2.3	4.0	4.4	7.9	8.0	8.8
IR1552-57-2	2.8	3.8	4.4	8.1	8.7	8.6

[a]LSD (5%): 0.5 t/ha for comparing variety means and 0.8 t/ha for comparing nitrogen means. [b]LSD (5%): 0.6% for comparing variety means and 0.6% for comparing nitrogen means. [c]All basal. [d]Basal + panicle initiation.

Table 27. Grain yield and protein content of rices with three nitrogen treatments. IRRI, 1973 wet season.

Designation	Yield[a] (t/ha)			Brown rice protein[b] (%)		
	0 kg/ha N	100 kg/ha N[c]	70 + 30 kg/ha N[d]	0 kg/ha N	100 kg/ha N[c]	70 + 30 kg/ha N[d]
IR8	2.1	2.7	2.8	7.5	8.7	9.2
IR20	3.3	3.5	3.6	8.8	10.3	10.4
EPJ1-13-B-55	2.4	3.6	3.6	9.4	10.9	11.2
IR480-5-9	3.0	3.6	3.7	9.4	11.6	11.8
IR1514A-E597-4	4.0	4.4	4.2	8.7	9.6	10.7
IR1702-158-3	3.5	3.2	3.1	9.6	10.7	11.4
IR1737-19-7	3.9	4.4	4.5	8.8	9.3	10.2

[a]LSD (5%) = 0.7 t/ha for comparing variety means and 0.9 t/ha for comparing nitrogen means. [b]LSD (5%) = 0.8% for comparing variety means and 0.9% for comparing nitrogen means. [c]All basal. [d]Basal + panicle initiation.

lodged at the heading stage. IR1702-150-3 had statistically similar protein content to IR480-5-9 but produced significantly higher grain yield without fertilizer, it had similar protein content but significantly lower grain yield with basal application, and it had similar protein content and grain yield with split application of nitrogen (Table 27). The low yield of IR1702-150-3 at higher nitrogen levels were due to heavy infection of sheath blight.

In an experiment conducted in two farmers' fields in Batangas, Philippines, IR480-5-9 produced between 0.7 to 1.1 t/ha higher grain yields than IR8 and 2.8 to 3.5 percentage points higher protein (Table 28). These and other results in 1973 and earlier years suggest that the high protein content in IR480-5-9 is genetic and not environmental. The variability in grain yields is more serious in IR480-5-9 than the variability in the protein content because grain yields of IR480-5-9 are often adversely affected by susceptibility to bacterial blight. During the 1973 wet season, IR480-5-9 did not suffer from any bacterial blight and was relatively free from blast. Therefore, its grain yield and high protein content under disease-free conditions clearly demonstrate that it is an excellent material for developing high-yielding, high-protein rices.

The IRRI breeding program has used IR480-5-9 for developing high protein rices. Large numbers of crosses with IR480-5-9 with highly disease- and insect-resistant lines like IR2061 lines should help in stabilizing yield and still retain a high protein content similar to that of IR480-5-9.

In another experiment conducted at IRRI during the 1973 dry season, phosphorus or potassium alone produced significantly higher grain yields than the unfertilized control (Table 29). An increase in grain yield and protein content from nitrogen application is well known, but a 1-t/ha increase in grain yield with 1 percentage point increase in protein content with phosphorus or potassium fertilization is an important finding worth studying further.

Table 28. Grain yield and brown rice protein content of IR8 and IR480-5-9 grown under upland conditions in farmers' fields in two locations. Batangas, Philippines, 1973 wet season.

Variety	Santo Tomas		Cuenca	
	Yield[a] (t/ha)	Protein content (%)	Yield[a] (t/ha)	Protein content (%)
IR8	3.8	7.9	4.1	8.2
IR480-5-9	4.5	10.7	5.2	11.7

[a]Avg of three replications. Nitrogen applied 120 kg/ha in equal split doses during land preparation, at tillering, and at panicle initiation.

Table 29. Grain yield and protein content of rices as affected by phosphorus and potassium applications. IRRI, 1973 dry season.

$N-P_2O_5-K_2O$ (kg/ha)	Yield[a] (t/ha)	Brown rice protein (%)
140-0-0	6.7 a	9.9 a
140-30-0	6.6 a	10.0 a
140-0-30	6.6 a	10.1 a
0-30-0	4.8 b	9.3 b
0-0-30	4.8 b	9.4 b
0-0-0	3.6 c	8.2 c

[a]Avg of three varieties (IR8, IR20, and IR22). Means followed by the same letter are not significant at the 5% level.

23). The follow-up application of bentazon after K-223 at 8 or 10 kg/ha a.i. for nutsedge control, did not increase yields significantly and, therefore, appeared to have no advantage under the conditions of this experiment. Bentazon at 2 kg/ha a.i. also showed a high degree of selectivity but was less effective in nutsedge control at this concentration than K-223.

Table 22. Control of perennial nutsedge (*Cyperus rotundus*) and annual weeds by various herbicides and their effects on grain yield of IR442-2-58 under simulated upland conditions. IRRI, 1972 dry season.

Chemical	Rate (kg/ha a.i.)	Perennial nutsedge control[a] (%)	Yield[b] (t/ha)
USB 3153 fb MCPP	1 fb 1	41	4.8 a
USB 3584 fb MCPP	2 fb 1	27	4.5[c]
A-820 fb MCPP	2 fb 1	50	4.5[c]
Butachlor fb MCPP	2 fb 1	41	4.1 ab
Butachlor fb MCPP	4 fb 1	28	3.8 ab
U-27, 267 fb MCPP	2 fb 1	54	3.8 ab
MON 843 fb MCPP	3 fb 1	71	3.3 ab
Hand weeding	twice	100	3.8 ab
Untreated control	—	0	0.4 d

[a]Measured 30 days after crop emergence. [b]Means followed by a common letter are not significantly different at the 5% level. [c]From one replication and were not included in the statistical analysis.

DROUGHT TOLERANCE

Because of the complexity of the problems of drought tolerance, our initial emphasis has been on the soil-water aspects of the soil-water-plant-atmosphere continuum. At present we are using soil moisture tension as the criteria for the moisture-supplying capacity of soil at a particular evaporative demand. During 1973 we continued developing techniques or modifications of our earlier techniques for screening genetic lines for drought tolerance, as well as screening a genetic line for drought tolerance.

Techniques for screening breeding lines. We have designed two kinds of set-ups for maintaining various soil moisture tensions. The set-up for saturation treatment is composed of a water tank (acrylic plastic box), a delivery unit (tygon tubing and perforated PVC pipe containing glass wool), and pots. The water tank has a bubble tube to maintain a constant head at the tip of the tube near the bottom of the tank. The position of the constant head corresponds to 7 cm below the surface of the soil in the pot.

The set-up for supplying water at relatively constant soil moisture tension in pots is composed of five major parts—water tank, a W-tube, water distribution system, soil moisture tension sensors, and pots (fig. 12). The water tank has a bubble tube that maintains a constant head at the tip of the tube near the bottom of the tank. The delivery porous cups are 75 cm below the level of the constant head to facilitate the movement of water from the water tank to the soil through the porous cup. The W-tube, which contains a predetermined amount of mercury, controls the soil moisture tension in the pot. When the height of mercury in the W-tube is equivalent to the soil moisture tension in the pot, all the mercury is pulled up to the left side of the tube which is in turn connected to the bubble trap of the tensiometer. Thus, the water can flow freely from the tank to the inverted bottle of the distribution system. Finally, water is

Table 23. Effects of a substituted urea herbicide (K-223) on the control of perennial nutsedge under simulated upland conditions (rice variety: IR442-2-58). IRRI, 1973 dry season.

Chemical[a]	Rate (kg/ha a.i.)	Total weed wt (g/sq m)	Dry wt of nutsedge (g/sq m)	Grain yield (t/ha)
K-223 fb butachlor fb bentazon	10 fb 2 fb 2	98 a	2 a	4.1 a
K-223 fb butachlor fb bentazon	8 fb 2 fb 2	92 a	5 a	4.0 ab
K-223 fb butachlor	10 fb 2	77 a	3 a	4.0 ab
K-223 fb butachlor	8 fb 2	54 a	6 a	3.8 bc
K-223 fb butachlor fb bentazon	6 fb 2 fb 2	79 a	12 a	3.5 cd
Butachlor fb bentazon	2 fb 2	62 a	18 a	3.5 cd
K-223 fb butachlor	6 fb 2	64 a	14 a	3.4 d
Hand weeding	twice	27 a	2 a	4.0 a
Untreated control	—	666 b	58 b	0.4 e

[a]K-223, applied pre-planting, butachlor, 3 days after seeding, bentazon, 7 days after crop emergence.

CHEMICAL KINETICS OF SUBMERGED SOILS

Temperature effects. A previous study (1972 Annual Report) showed that the kinetics of denitrification in submerged soils followed first-order kinetics and that the temperature variation of the rate constant obeyed the Arrhenius law. Further studies have revealed that the temperature coefficient of denitrification (Q_{10}) varied markedly with the soil and the temperature range (Table 1), but was of the order of that for biochemical reactions and that the collision factor A and the activation energy E_a in the Arrhenius equation were of the order for enzyme reactions (Table 2).

The kinetics of denitrification also showed that the rate of loss of nitrate varied markedly with the soil (fig. 1). At this time of synthetic nitrogen shortage, sodium nitrate may be used as nitrogen fertilizer on flooded soils in which the rate of denitrification is low. Although denitrification is generally slower in acid soils than in neutral and alkaline soils, the only sure guide is the rate constant, measured experimentally.

The greater part of the nitrogen taken up by even a fertilized rice crop comes from ammonification of soil organic matter. Since ammonification, like other enzyme reactions, is temperature dependent, temperature should greatly influence the nitrogen supply to rice.

In an anaerobic incubation study of four lowland rice soils, we observed that temperature markedly influenced the rate of ammonification (fig. 2). The rate was lowest at 15° C and highest at 45° C in all soils except Luisiana clay, in which the rate at 45° C was less than that at 35° C.

Assuming that ammonification took a roughly asymptotic course and that it followed first-order kinetics, we formulated the equation $\log (NH^+_{4\,max}\text{-}NH^+_{4t}) = \log NH^+_{4\,max}\text{-}kt$ where $NH^+_{4\,max}$ is the maximum amount of ammonia produced during anaerobic incubation, NH^+_{4t} is the amount produced after time t, and k is the rate constant. The rectilinear regression of log $(NH^+_{4\,max}\text{-}NH^+_{4t})$ on t (fig. 3) indicated that ammonification followed first-order kinetics in Casiguran sandy loam, Pila clay, and Keelung silt loam.

The Q_{10} values for ammonification varied with the soil and temperature range (Table 1), as it did for denitrification. Further, the rectilinear regression of log k on $1/t$ (fig. 4) showed that the temperature effect obeyed the Arrhenius law. The collision factor, A, the energy of activation, E_a and the heat of activation, ΔH^*, were of the order for enzyme reactions (Table 2).

Salt and alkali effects. Our previous work showed that both salt and alkali profoundly influence the chemical kinetics of submerged soils (1972 Annual Report). In an attempt to quantify these effects, we studied the kinetics of the Maahas clay amended with sodium chloride or sodium bicarbonate (Table 3). As salinity increased, the levels of NH_4^+, K^+, Ca^{2+}, Mg^{2+},

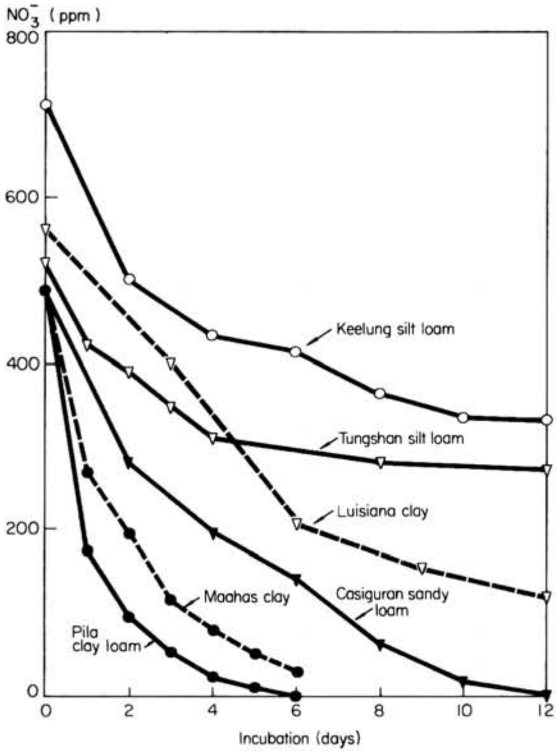
Table 1. Influence of soil and temperature range on the temperature coefficient (Q_{10}) of denitrification and ammonification.

Soil	Q_{10}		
	15–25° C	25–35° C	35–45° C
		Denitrification	
Casiguran sandy loam	1.8	3.4	1.2
Keelung silt loam	1.6	1.8	1.1
Luisiana clay	3.4	2.7	1.0
Maahas clay	2.0	2.3	1.6
Pila clay loam	3.5	1.3	1.8
Tungshan silt loam	4.0	1.2	1.6
Mean	2.7	2.1	1.4
		Ammonification	
Casiguran sandy loam	1.3	1.8	1.2
Keelung silt loam	1.3	1.3	1.0
Pila clay loam	1.6	1.5	1.1
Mean	1.4	1.5	1.1

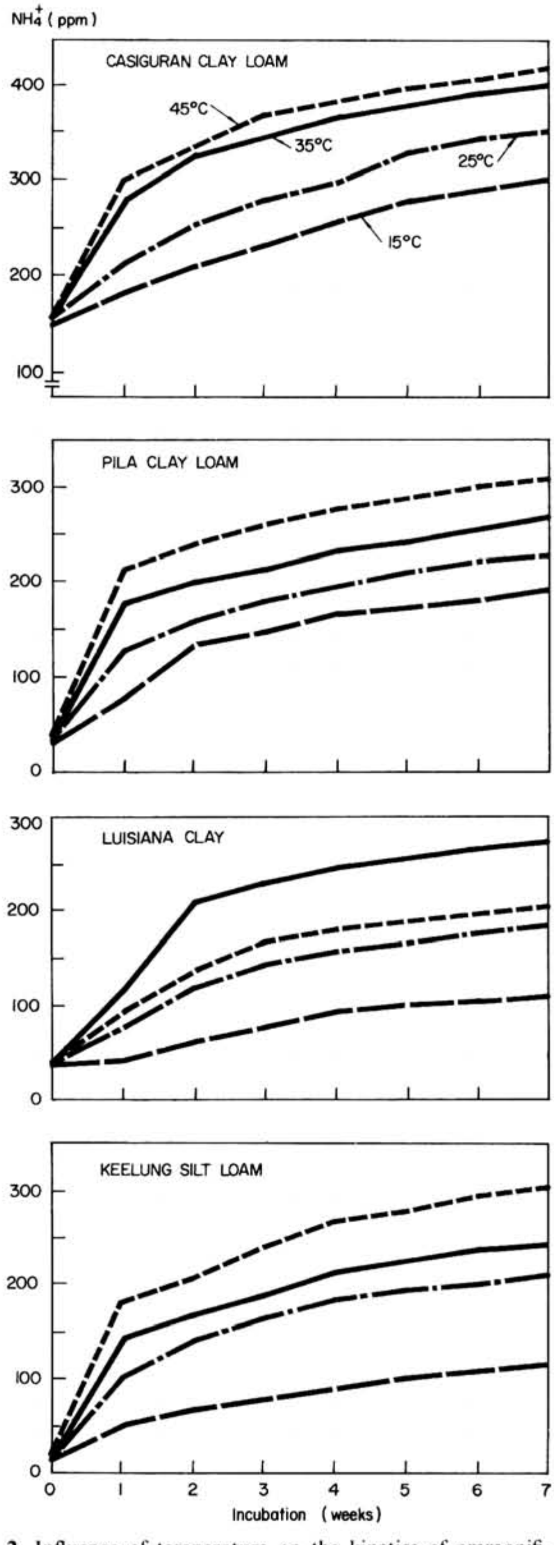
Table 2. Pre-exponential factor, activation energy, and heat of activation[a] for denitrification and ammonification.

Soil	Pre-exponential factor (liter/mol)	Activation energy (kcal/mol)	Heat of activation (kcal/mol)
		Denitrification	
Casiguran sandy loam	3.1×10^{9}	15.8	15.2
Keelung silt loam	5.2×10^{-2}	7.4	6.8
Luisiana clay	7.6×10^{9}	15.6	15.0
Maahas clay	1.0×10^{8}	13.6	13.0
Pila clay loam	1.9×10^{4}	13.1	12.5
Tungshan silt loam	5.9×10^{1}	10.2	9.6
		Ammonification	
Casiguran sandy loam	1.85×10^{6}	7.3	6.7
Keelung silt loam	3.61×10^{4}	4.2	3.6
Pila clay loam	1.54×10^{6}	6.9	6.3

[a] $\Delta H^* = (E_a - RT) \simeq (E_a - 0.6)$ in the range 15 to 45°C.



1. Kinetics of denitrification in six submerged soils at 35°C.



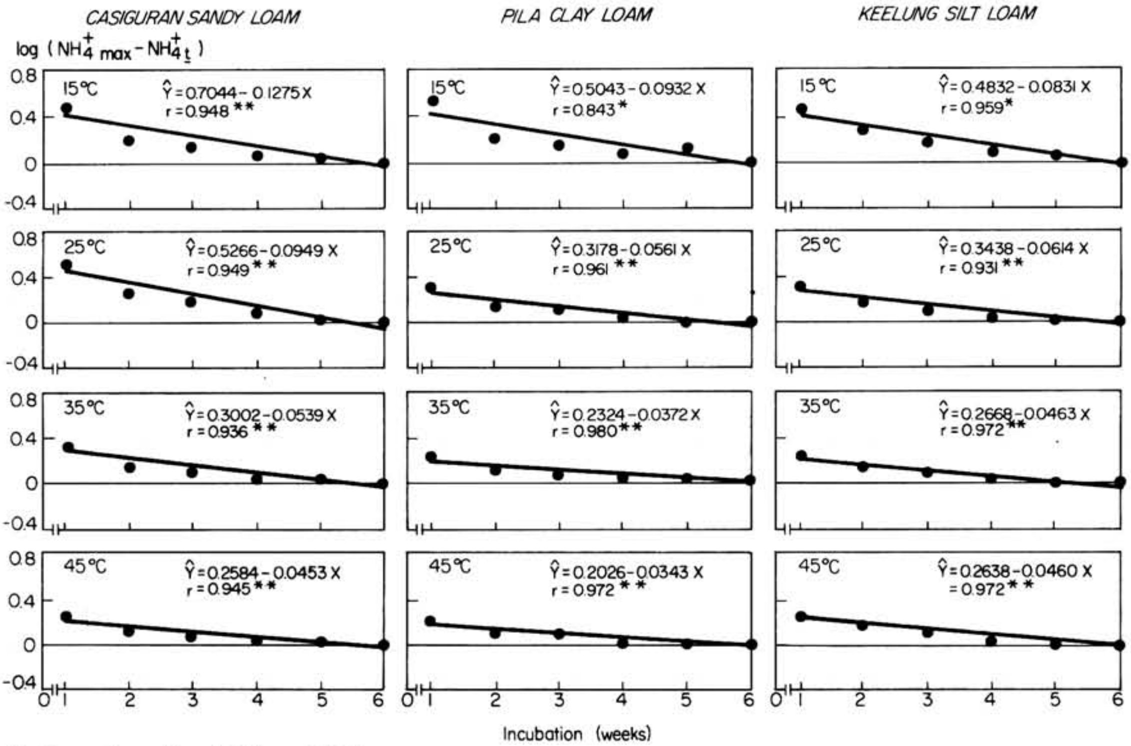
2. Influence of temperature on the kinetics of ammonification in flooded soils.

Fe^{2+}, and Mn^{2+} in the soil solutions rose markedly (fig. 5) apparently increasing the immediate supply of these nutrients to rice. Alkalinity had the opposite effect.

To determine whether the marked changes in concentration of K^+ brought about by salt or alkali affect the availability of K^+, the activity ratio of K^+, $(a_K/\sqrt{a_{Ca} + a_{Mg}})$, was determined at different levels of salt and alkali at varying periods of submergence.

The activity ratio decreased with increase in salinity in spite of the increase in K^+ concentration, but increased with alkalinity (fig. 6). The rectilinear relationship between labile K^+ (ΔEPP) and the activity ratio or the so-called Q/I function indicates that the K^+ exchange reactions obeyed the Ratio law.

Both salt and alkali also strongly influenced the concentration of water-soluble iron. To ascertain whether the main iron equilibria, $Fe(OH)_3$-Fe^{2+}, $Fe_3(OH)_8$-Fe^{2+}, and $Fe(OH)_3 - Fe_3(OH)_8$ (1965 Annual Report), still controlled the concentration of Fe^{2+}, the pEo values for each system were calculated using



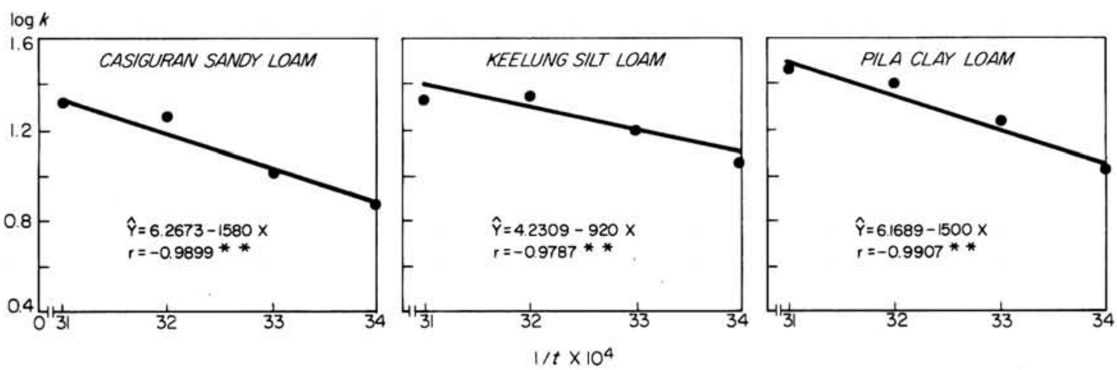
3. Regressions of log ($NH_{4\ max}^{+}$-$NH_{4\ t}^{+}$) on t.

$$pEo_1 = pE - pFe^{2+} + 3\ pH$$
$$pEo_2 = pE - 1.5\ pFe^{2+} + 4\ pH$$
$$pEo_3 = pE + pH$$

The pE value was calculated from Eh, and pFe^{2+} from the concentration of Fe^{2+} and the activity coefficient. To calculate activity coefficients, the usual form of the Debye-Huckel equation was used for ionic strengths below 0.1. Above 0.1, the Davies modification was used. The closeness of the calculated pEo values (Table 4) to the theoretical indicates that the iron hydroxide systems controlled the concentration of iron even at ionic strengths as high as 0.5 mol/liter.

FERTILIZER-SAVING CULTURAL PRACTICES

Currently, fertilizers, especially the nitrogenous ones, are scarce. Even if the supply increases in the future, prices are expected to be two or three times what they were before the world oil crisis. It is therefore timely to examine methods of



4. Relationship between log k and $1/t$ in three submerged soils.

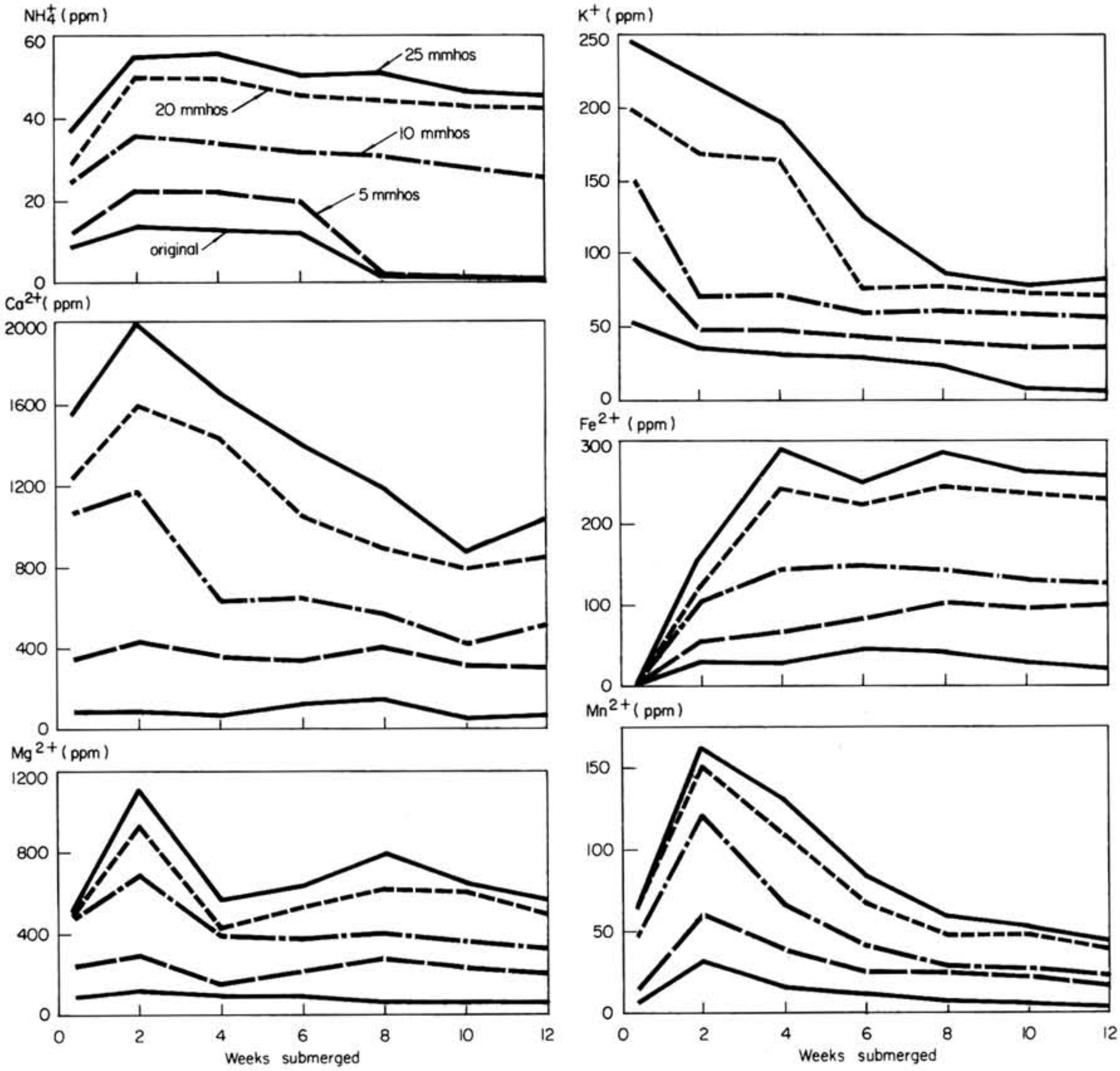
conserving and increasing the natural supply of the major nutrient elements, of rationalizing the use of fertilizers, and of exploiting genetic variability in the capacity of the rice plant to extract nutrients from the soil. Our studies show that the natural supply of some nutrients can be increased by soil and water management, that soil tests may help farmers to economize on fertilizer use, and that some varieties thrive in nutrient-deficient soils.

Water management. Our previous work (1967, 1968, 1969, 1970, 1971 Annual Reports) has shown that water management markedly influences the nutrient balance in rice soils. A long-term study of an acid, a neutral, and a calcareous soil in 200-liter drums, outdoors, revealed that 1) compared with the common practice of soil

Table 3. Levels of salinity and alkalinity.

Salinity		Alkalinity		
NaCl added (%)	Specific conductance[a] (mmhos/cm)	$NaHCO_3$ added (%)	pH[a]	ESP[b]
Original	1.2	0.025	7.7	5
0.135	5.0	.180	8.1	10
0.405	10.0	.375	8.3	15
0.950	20.0	.575	8.5	20
1.220	25.0	.800	8.7	25

[a]Of saturation extract. [b]Exchangeable sodium percentage.



5. Influence of salt on the kinetics of cations in the soil solutions of submerged Maahas clay.

Table 4. Influence of salt or alkali in submerged Maahas clay on the mean values of pEo.

Treatment	pEo_1	pEo_2	pEo_3
Salt (mmhos/cm)			
1	17.8	22.7	8.0
5	17.8	22.7	8.0
10	17.8	22.8	7.8
20	17.7	22.9	7.8
25	17.7	22.7	7.8
Alkali (ESP)			
5	17.7	22.6	7.8
10	17.7	22.7	8.0
15	17.5	22.6	7.9
20	17.5	22.5	7.8
25	17.6	22.5	7.9
Theoretical value	17.87	23.27	7.26

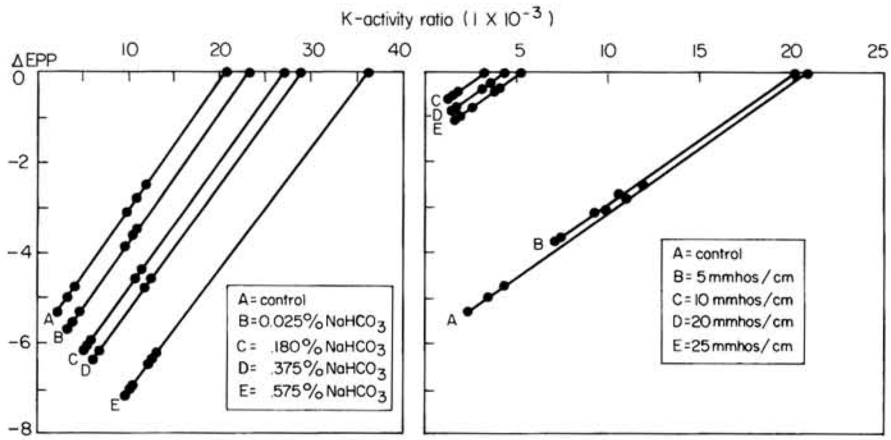
drying between two lowland rice crops (dry fallow), continuous submergence (implying flood fallow) increased the nitrogen content of the soil; 2) flooding dry-fallowed soils led to a loss of 40 to 80 kg/ha N each season (the comparable figure for 280 Philippine rice soils was 26 kg/ha); 3) dry fallow with midseason soil drying caused severe losses of N; and 4) percolation at even 1 cm/day led to a loss of 40 kg/ha N per season.

Subsequent studies have confirmed the superiority of continuous submergence (flood fallowing) to dry fallowing between crops for nitrogen accumulation but have shown that, in the absence of fertilizer nitrogen, flood fallowing with midseason soil drying followed by reflooding is better than continuous submergence for the nitrogen nutrition of the rice plant. Although chemical analysis revealed a marked accumulation of nitrogen in the soils that were continuously flooded, the yield increase on these soils relative to the soils dried in midseason or between crops was small (1969 Annual Report), apparently because the soils received 150 ppm N each season.

To ascertain whether the accumulated nitrogen was available to rice, we have grown IR20 without fertilizer nitrogen for the last 2 years. The water management history of the soils markedly affected the growth, appearance, and yield of IR20. All plants showed symptoms of nitrogen deficiency, but for each soil they were mildest in the flood-fallowed treatments, indicating that the accumulated nitrogen was benefiting rice. For each soil, the two flood fallow treatments (with and without midseason soil drying) showed no differences until midseason soil drying was completed and the soil reflooded. Then the plants in the soils that were subjected to this treatment greened up. This suggests that midseason soil drying promoted the release of some of the accumulated nitrogen. The apparent increase in the nitrogen supply increased the yield of grain in four successive seasons in Maahas clay and Luisiana clay (Table 5).

Where water control is possible, the soil should be flood fallowed between crops to conserve and add nitrogen and the soil should be allowed to dry out in midseason and then reflooded to release some of the accumulated nitrogen for the use of the rice crop.

Straw as a soil amendment. Rice straw contains about 0.6% nitrogen, 0.1% phosphorus, 3%



6. Effect of various levels of $NaHCO_3$ and NaCl on the *K-Q/I* relation of Maahas clay under submerged soil conditions.

potassium, and 8% silicon, in addition to several other plant nutrients. The common practice of burning the straw at the threshing sites in the field sends 30 to 50 kg/ha N up in smoke each season, and renders the return of phosphorus, potassium, and silica to the soil spotty. If the straw is spread over the fields or composted and incorporated in the soil, 30 to 50 kg/ha N, 4 to 7 kg/ha P, 150 to 250 kg/ha K, and 400 to 600 kg/ha Si will be returned to the soil, evenly, each season. Besides, the added organic matter will encourage nitrogen fixation by anaerobic bacteria. Since no data on the long-term effects of straw on the nutrient balance in soils and the growth of rice in the tropics were available, we started two field experiments in 1972.

One experiment was designed to ascertain the effects of the incorporation of the straw (produced in situ) in flooded soils, under three water treatments: continuous flood, dry fallow (the common practice), and dry fallow with mid-season soil drying followed by reflooding (the Japanese practice). The straw was spread on the plots and plowed in wet with 50 kg/ha N as urea and 25 kg/ha P as solophos. Four rice varieties were transplanted. As early as the third season, it was clear that straw had increased the nitrogen content of the soil, for the plants in the straw-treated plots looked greener, were taller, and had more tillers than those on the plots from which the straw was removed (Table 6). Severe typhoon damage destroyed the experiment, but the yield data of the only variety that was harvested before the typhoon indicated a small but consistent increase brought about by straw incorporation (Table 6).

In a second experiment, we studied the long-term effects of four methods of managing straw on the nutrient status of the soil and the growth of rice. As early as the third season, straw application, regardless of method, had increased the content of exchangeable potassium from 0.99 to 1.28 meq/100 g. Insect attack, lodging, and typhoon damage spoiled the experiment, but observations during the season indicated that the application of compost or straw was beneficial.

The results of these experiments suggest that leaving the straw on the fields will lead to a substantial accretion of potassium, and, over the years, to accumulation of nitrogen and phosphorus as well.

Table 5. Influence of water regime on the grain yield of IR20 on three flooded soils in four seasons, 1972 and 1973.

Season	Yield (g/drum)					
	Flood fallow			Dry fallow		
	No m.s.d.[a]	m.s.d.	Difference	No m.s.d.	m.s.d.	Difference
			Luisiana clay			
1	191	231	40*	135	129	−6
2	165	195	30**	132	131	−1
3	131	153	22**	90	82	−8
4	174	199	25*	149	148	−1
			Maahas clay			
1	143	204	61**	110	88	−22
2	166	190	24*	118	107	−11
3	109	138	29**	78	76	−2
4	175	212	37**	124	138	14
			Pila clay loam			
1	178	165	−13	67	65	−2
2	159	168	9	92	94	2
3	111	120	9	61	67	6
4	209	181	−28*	105	86	−19

[a]m.s.d. = midseason soil drying.

Soil analysis and fertilizer needs. Soil analysis can be a useful guide to the economical use of fertilizers. Our previous work enabled us to formulate certain principles on the application of nitrogen fertilizer to flooded soils (1964 Annual Report). Applying these principles to a recent study of the chemical and morphological properties of 43 lowland rice soils in the Philippines, we can provide a rough guide to the fertilizer nitrogen needs for a crop of 5 t/ha of grain in the Philippines (Table 7).

Table 6. Influence of three seasons of straw incorporation, under three methods of water management, on the mean height and tiller number of four rice varieties and the grain yield of IR773-112-2. IRRI, 1973 wet season.

Water treatment	Straw	Four varieties: Plant ht (cm)	Four varieties: Tillers (no./hill)	Yield of IR773-112-2[a] (t/ha)
Dry fallow	removed	98	12.6	4.3
	added	104	14.4	4.4
Dry fallow with m.s.d.	removed	98	12.5	3.6
	added	102	13.1	3.7
Continuous submergence	removed	101	12.7	4.5
	added	104	14.2	4.6

[a]The only variety harvested before typhoon damage.

Table 7. Available nitrogen content and the fertilizer nitrogen needs of some Philippine soils for a grain yield of 5 t/ha.

Soil example	Available N (ppm)	Fertilizer N needs Amount (kg/ha)	Applied at
Buenavista clay, Arayat clay, Isabela clay, Santa Rita clay	120-155	Nil	—
San Manuel clay, Maahas clay, Agustin clay loam, San Fernando clay, Bolinao clay, San Fabian clay	70-85	50	PPI[a]
Prenza sandy loam, San Manuel sandy loam, Mahipon clay loam	25-50	75 + 75	planting + PPI

[a]Panicle primordia initiation.

In Agusan del Norte, Philippines, Butuan clay and San Manuel clay loam contain more than 155 ppm available N, more than 15 ppm available P, more than 0.2 meq/100 g of exchangeable K, but are deficient in zinc. At six locations in the absence of N, P, K fertilizer, the application of zinc gave a mean yield of 4.5 t/ha (1972 Annual Report). In 1973, experiments at two locations in Agusan confirmed the capacity of Butuan clay and San Manuel clay loam (the most widespread soils suited to lowland rice in Agusan del Norte) to produce more than 5 t/ha of rice per season without N, P, K fertilizer if zinc is added: C4-63G gave an average yield of 7.0 t/ha for the two seasons, IR20 gave 5.5 t/ha. In view of the current fertilizer shortage, the use of N, P, K fertilizer for rice on the flat, wet soils of Agusan del Norte (and similar soils) should be discouraged. And if the goal is 5 t/ha per season, nitrogen fertilizer may be omitted on soils with more than 150 ppm available nitrogen.

Table 8. Influence of common salt and sodium carbonate on Maahas clay.

Treatment	pH	Specific conductance (mmhos/cm)	ESP
None	7.2	1.35	1.7
0.4% salt	7.1	8.3	11.9
0.8% salt	7.1	14.2	18.1
0.75% Na_2CO_3	8.2	2.55	23.2
1.25% Na_2CO_3	8.3	2.95	27.9

VARIETAL RESISTANCE TO SOIL PROBLEMS

In the past, we used symptoms, absolute grain yield, and grain yield relative to that on a good soil as criteria for assessing the resistance of varieties to soil problems. In 1973, we attempted to simplify the screening techniques for salinity and alkalinity, and we tested, by the previous methods, over 100 varieties for resistance to various soil problems.

Salinity. It is difficult to screen the resistance of large numbers of rice varieties to salinity if grain yield is one of the main criteria because of the great space and time needs. So we explored other screening methods.

The first was observing the germination, growth, and symptoms of 10 rice varieties (whose reactions to salinity and alkalinity had been established earlier) in submerged soil cultures at two salinity levels. Five-kilogram portions of Maahas clay were mixed with 50 ppm each of N, P, and K, and 0.4 percent and 0.8 percent by weight of common salt (Table 8). The treated soils were placed in plastic trays measuring 35 × 27 × 11 cm and submerged in 1 cm of demineralized water. Eight pre-soaked seeds of the 10 varieties were dibbled in four rows in half of each tray; eight 2-week-old seedlings raised in culture solution were transplanted in the other half. The treatments were replicated three times. The trays were watered uniformly with demineralized water. Observations were made 3, 9, and 18 days after seeding or transplanting. The scoring was based on degree of wilting, leaf drying, discoloration of leaves, and general appearance compared with healthy plants grown side by side on Maahas clay. At the 0.8 percent salt level, all varieties showed severe injury (only Pokkali survived after 14 days) so this treatment is excluded for the discussion.

Contrary to popular belief, rice was more susceptible to salt injury in the germination stage than at the age of 2 weeks. This is clear from the lower survival percentages (Table 9). Direct-seeded IR24, however, resisted salt injury better than the others, but when transplanted it was more susceptible than the others. There were marked varietal differences in reactions to the method of planting and the growth stage (Table 9). The rating of these 10 varieties based on observations taken 18 days after transplanting agreed best with the earlier classification based on symptoms, grain yield, and relative grain yield (1972 Annual Report).

To ascertain whether comparable results could be obtained with solution cultures, the same varieties were grown in a culture solution to which sufficient sodium chloride was added to raise its electrical conductivity to 8.5 mmhos/cm. In one set of pots, germinated seeds were placed on screens floating on the solution while 2-week-old seedlings previously grown in normal culture solution were transferred to the saline culture solution in another set of pots. Regardless of the method of planting, all seedlings except Pokkali were severely injured, and after 13 days all except Pokkali were dead. Since the total salt content of the culture solution was no greater than that of the soil solutions in the submerged soil cultures, the chemical environment in the submerged soil apparently enabled the plants to tolerate salt better than in solution culture.

Soil cultures are easy to prepare and maintain and, physiologically, they are closer to the natural root environment of rice, so we prefer soil cultures to solution cultures for screening varieties for salt tolerance. Transplanting 2-week-old seedlings raised in culture solution is superior to direct seeding because the reactions of the seedlings to salt are clearer and more consistent within a variety than those of the direct-seeded plants.

In outdoor tests of 100 varieties, only Pokkali, SR 26B, and Nagpili (a variety grown in a saline tract in Batangas, Philippines) showed promise of being good sources of resistance to salinity. SR 26B fared better than Pokkali when directly seeded, so it may be better suited than Pokkali for direct seeding. The lower tolerance to salt shown in the field, by transplanted seedlings compared with direct-seeded plants, is due probably to root injury during uprooting. Thick foliage, by increasing transpiration, aggravated salt injury in transplanted seedlings.

Alkalinity. To reduce the space and time needed for screening varieties for resistance to alkalinity, we explored the suitability of a greenhouse soil culture method. The procedure was similar to that described for salinity except that sodium carbonate was used instead of common salt (Table 8).

Regardless of the level of sodium carbonate, the planting method, or the growth stage, Pokkali was uniformly the best and, almost invariably, T26 was the worst. But smaller differences did not show up. So the experiment was repeated with the sodium carbonate level increased to 1.3 percent (pH 8.5; exchangeable sodium, 33.4 percent; conductivity of the saturation extract, 3.0 mmhos/cm).

The scoring based on the appearance of the transplanted seedlings 21 days after transfer to the alkali soil came closest to an earlier classification based on a combination of symptoms, absolute yield, and yield relative to that on a normal soil (1972 Annual Report): Pokkali was the most resistant, T26 was the least, while IR1008-14-1 and MI 273 were intermediate.

Although transplanted seedlings were more

Table 9. Reactions of 10 rice varieties to two methods of planting in a saline soil (0.4% salt).

Designation	Rating[a]						Survival[b] (%)	
	Direct seeded			Transplanted				
	3 DP[c]	9 DP	18 DP	3 DP	9 DP	18 DP	Direct-seeded	Transplanted
IR20	MR	MR	MR	MS	MR	MR	8	75
IR8	MR	MS	S	R	MR	MR	0	100
IR24	R	MS	MS	S	S	S	4	0
IR1008-14-1	S	S	S	MS	MR	S	0	21
MI 273	MR	MS	MS	MS	MS	MR	8	79
SR 26 B	R	MS	MR	MR	MR	R	17	88
M1-48	MS	S	S	MS	MR	MS	0	42
T26	S	MS	S	S	MS	S	0	0
CAS 209	MR	MS	S	R	MR	MS	0	46
Pokkali	MR	R	R	R	R	R	63	100

[a]R = resistant; MR = moderately resistant; S = susceptible; MS = moderately susceptible. [b]18 days after planting. [c]Days after planting.

uniform and healthier than direct-seeded plants in the greenhouse, both on the saline and alkaline soils, outdoors the situation was reversed. Apparently root injury during uprooting of seedlings from the wetbed nurseries caused the plants to wilt and dry out within a few days of planting. So, to evaluate the resistance of 15 varieties outdoors, we direct seeded them in a soil with an air-dry pH of 8.5. Six weeks after sowing, IR1008-14-1, IR1487-372-4, IR2031-114-2, and Dasal showed hardly any signs of injury while IR20, IR2035-224-2, SR 26 B, and Sanggumang Putih were clearly injured.

Iron toxicity. Forty-eight varieties were grown in the dry season with adequate N, P, and K on an acid oxisol which built up water-soluble iron concentrations exceeding 400 ppm (1972 Annual Report). All varieties showed symptoms of iron toxicity but the expression and severity varied with the variety and stage of growth. Omitting 17 varieties that did not flower or were infected with grassy stunt disease, and using grain yield as the criterion, we grouped the varieties as follows: resistant—IR2031-734-1, IR1529-72-5, and IR 1529-430-5; moderately resistant—IR1487-372-4, IR1529-677-2, IR2031-114-2, IR2031-130-3, IR2031-352-1, IR442-2-58, IR1561-76-3, Domzard, and Domsiah; susceptible—IR1514A-E597, IR1561-149-5, IR1561-228-3, Monolaya, and OS6.

In a test of 20 varieties on the same soil in the wet season, IR2031-731-1 and Pokkali were resistant; IR26 and IR2061-213-2 were moderately resistant while IR1529-680-3, Dasal, Monolaya, Purbachi, and BG41-2 were susceptible.

Phosphorus deficiency. Sixty varieties or selections were screened on a submerged phosphorus-deficient soil (Luisiana clay: pH, 5.0; Olsen available P, 0.3 ppm) in the greenhouse, in outdoor concrete tanks, and in a farmer's field at Pangil, Laguna, Philippines.

The greenhouse test permitted a classification into two extreme groups: resistant—IR20, IR1541-76-3, IR1514A-E666, and IR1514A-E597; and susceptible—IR2035-302-3, IR2031-238-5, IR2034-207-1, OS6, and Monolaya.

Of 15 varieties screened on a flooded phosphorus-deficient soil in concrete beds, IR1514A-E666 was the most resistant; IR20, Pelita I/1, Pelita I/2, and IR5 were moderately resistant; and M1-48 and IR878B4-220-3 were highly susceptible.

Thirty varieties were grown on the same soil in a farmer's field at Pangil, Laguna, with and without 75 kg/ha P. In the untreated plots, all varieties showed symptoms of phosphorus deficiency but the severity and degree of later recovery varied widely. The varieties were rated on the basis of grain yield without phosphate fertilizer: varieties that yielded over 4.5 t/ha were considered resistant, those that yielded less than 2.3 t/ha were considered highly susceptible (Table 10). The test confirmed the ratings of IR5, IR20, IR22, Pelita I/1, Pelita I/2, RD1, and M1-48, based on greenhouse and outdoor tank studies, but not of IR1514A-E666 and IR1514A-E597 whose yields were reduced by shattering and rat damage.

An N, P, K experiment on the same soil type in farmers' fields at four locations revealed a mean response of 1 t/ha to 50 kg/ha P for IR20 and IR1514A-E666 in the presence of 80 kg/ha N (Table 11). Both these varieties, which in other tests were rated as resistant to phosphorus deficiency, gave 4.5 t/ha even without phosphorus fertilizer.

Zinc deficiency. Sixteen varieties were grown on a zinc-deficient soil (pH 7.2; available Zn, 0.4 ppm) submerged in outdoor concrete tanks in the 1973 dry and wet seasons. All varieties showed symptoms of zinc deficiency 2 to 3 weeks after transplanting, but the severity of the symptoms and the rate of recovery varied markedly. On the basis of the degree and persistence of the symptoms, the varieties were grouped: resistant—IR20, IR1514A-E666, and Pokkali; moderately resistant—IR5 and Pelita I/1; susceptible—IR773-112-2, IR442-2-58, C4-63G, T26, and SR 26B.

One hundred varieties were directly seeded in 2- × 1-m plots on a zinc-deficient soil in farmer's field at Butuan City, Agusan del Norte, Philippines. A provisional classification of varieties at the two extremes of resistance, based on symptoms during the first 4 weeks of growth: most resistant—IR665-8-3, IR790-54-1, IR944-102-2, IR1006-28-6, IR1008-14-1, IR1110-37-2, IR1154-223-2, IR1514A-E597, IR1542-30-2,

Table 10. Yield and ratings of 20 varieties to phosphorus deficiency in a farmer's field. Laguna, Philippines, 1973 dry season.

Designation	Yield (t/ha)		Increase with P (%)	Rating[a]
	No P	With P		
IR5	4.6	7.2	57	R
IR8	5.3	7.5	41	R
IR20	4.7	6.9	47	R
IR22	4.1	6.6	60	MR
IR24	5.3	7.9	49	R
IR442-2-58	4.4	7.5	70	MR
IR626-1-112	3.6	6.9	88	MR
IR712-23-2	2.9	6.5	121	MS
IR790-28-6	4.1	7.1	74	MR
IR1168-21-3	3.6	6.3	76	MR
IR1514A-E666	3.6	6.5	81	MR
IR1514A-E597-1	3.4	6.6	95	MR
H4	4.1	6.5	57	MR
M1-48	1.3	4.2	217	S
Pelita I/1	5.1	7.5	46	R
Pelita I/2	4.6	7.5	62	R
RD1	5.0	7.8	56	R
TN1	5.2	7.1	36	R
Tadukan	4.0	4.1[b]	0	MR
T26	1.8	2.8[b]	57	—

[a]Based on yield without P. [b]Lodged.

IR1544-340-6, Bahagia, Bala, C12, C22, and Pelita I/1; most susceptible—Dima, E425, OS4 (all upland varieties), and T442-36.

Iron deficiency in upland soils. In the 1973 dry season, 16 varieties were planted in rows on aerobic Maahas clay (pH 6.6; organic matter, 2.0%) in concrete tanks as described earlier (1971 Annual Report). Eight weeks after planting, iron deficiency was severe in Peta, OS6, and IR1514A-E597; mild in IR24, IR442-2-58, M1-48, and Monolaya; and absent in IR1514A-E666, IR1008-14-1, IR712-23-2, and CAS 209. Grain yield increased as the severity of the symptoms decreased.

On Maahas clay limed to pH 7.5 and kept aerobic, the pattern of chlorosis was similar although iron deficiency was more severe. Peta and IR1514A-E597 were the worst; CAS 209 and IR712-23-2, the best.

In the wet season, when chlorosis was very severe on the limed soil IR1561-228-3 stood out as the variety most resistant to iron deficiency.

Aluminum toxicity in upland soils. Aluminum toxicity is a retarding factor on upland acid oxisols, especially when fertilized with ammonium sulfate. To induce aluminum toxicity in Luisiana clay in outdoor tanks (1971 Annual Report), we depressed the pH to 4.0 to 4.3 by adding flowers of sulfur. Then we planted 15 varieties in rows. Aluminum toxicity symptoms appeared about 4 weeks after seeding. They were severe in IR20, IR1514A-E666, IR1514A-E597, and Peta; slight in IR442-2-58, IR712-23-2, IR665-8-3, and IR1561-228-3; and least severe in IR24, IR1008-14-1, M1-48, Monolaya, and C22-51.

Susceptibility of upland varieties. Our previous studies (1969 Annual Report) suggested that upland rice varieties differ from lowland varieties in their reactions to the soil environment. To clarify the matter, we grew three typical upland varieties and three typical lowland varieties on five problem soils and on a normal soil in a replicated pot experiment in the greenhouse. The actual and the relative straw and grain yields (Table 12) show that the upland varieties E425, Palawan, and M1-48 were more severely injured than the lowland varieties by salinity, alkalinity, phosphorus deficiency, zinc deficiency, and reduction products.

Proline as an index of stress. When a plant is subjected to water stress, the content of the amino acid, proline, increases. Since plants growing on injurious soils are also subject to various stresses, we thought their proline contents should be higher than those of normal plants. We also expected varietal differences. To test these hypotheses, we compared the proline contents of six rice varieties grown on eight problem soils with those on a normal soil.

The presence of a soil stress, with a single exception, increased the proline content of the plant, regardless of the nature of the stress or the

Table 11. Mean yields of IR20 and IR1514A-E666 in a N, P, K experiment on a phosphorus-deficient soil in four farmers' fields. Laguna, Philippines, 1973 wet season.

N-P-K (kg/ha)	Yield (t/ha)	
	IR20	IR1514A-E666
0-0-0	4.2	3.9
80-0-0	4.6	4.5
80-50-0	5.5	5.7
80-50-50	5.7	5.7

Table 12. Straw and grain yields of six rice varieties on some submerged problem soils.

Designation[a]	Straw yield		Grain yield	
	Actual (g/pot)	Relative[b] (%)	Actual (g/pot)	Relative (%)
	Saline soil			
Peta	106	82	112	105
H4	89	61	96	91
IR4-11	65	79	79	95
E425	13	14	9	14
Palawan	28	26	9	14
M1-48	0	0	0	0
	Iron-toxic soil			
Peta	17	13	2	2
H4	27	18	7	7
IR4-11	15	20	15	18
E425	15	16	9	14
Palawan	13	12	5	6
M1-48	9	13	2	3
	Zinc-deficient soil			
Peta	96	74	87	81
H4	92	63	88	84
IR4-11	48	65	59	71
E425	18	20	12	19
Palawan	9	8	5	6
M1-48	25	36	19	30
	Alkali soil			
Peta	49	38	22	21
H4	56	38	33	31
IR4-11	35	47	25	30
E425	20	22	14	22
Palawan	27	25	11	12
M1-48	2	3	1	1
	Phosphorus-deficient soil			
Peta	82	64	54	51
H4	94	64	48	46
IR4-11	33	45	24	29
E425	21	23	10	16
Palawan	26	24	13	14
M1-48	11	16	5	8
	Highly reduced soil			
Peta	60	47	57	53
H4	58	40	43	41
IR4-11	33	45	37	45
E425	22	24	16	25
Palawan	20	18	13	14
M1-48	15	21	9	14

[a]Peta, H4, and IR4-11 are lowland types, the rest are upland types. [b]Relative to Maahas clay.

variety, but there were strong stress-variety interactions (Table 13). On the average, phosphorus deficiency brought about the biggest increase, while salinity and iron deficiency in the calcareous aerobic soil gave the smallest. If the relative proline content is a measure of soil stress the upland varieties, E425, M1-48, and Palawan, were apparently under much greater stress than the lowland varieties, Peta, H4, and IR4-11, in

Table 13. Influence of soil problems on the proline content of six rice varieties, 5 weeks after transplanting.

Soil	Proline (nmol/g)						
	E425	M1-48	Palawan	Peta	H4	IR4-11	Mean
Normal	23	20	17	25	14	21	20
Alkali	101	77	37	34	53	19	54
Saline	25	[a]	35	35	33	24	30
Iron-toxic	40	63	33	36	26	22	36
Highly reduced	88	76	81	19	16	20	50
P-deficient	141	181	114	105	88	56	114
Zn-deficient	184	88	234	16	20	15	93
Acid aerobic	30	26	31	30	29	63	35
Calcareous aerobic	25	25	22	30	20	23	24

[a]Plants died.

the alkali, iron-toxic, phosphorus-deficient, and zinc-deficient soils.

Sources of resistance. In the limited spectrum of germ plasm screened during the past 3 years, we have been able to identify the following sources of resistance to injurious soil conditions:

Salinity: Pokkali, SR 26B, Nagpili
Alkalinity: Pokkali
Fe toxicity: Pokkali
P deficiency: Pelita I/1, IR20
Zn deficiency: Pokkali, IR20
Fe deficiency: CAS 209, IR1561-228-3
Al toxicity: M1-48, Monolaya
Excessive soil reduction: Pokkali, H4

RAINFED RICE

Form of N fertilizer and compost. Most of the world's rice is grown on soils without an assured water supply. If the rainfall is inadequate or badly distributed, these soils dry out and become aerobic, rendering iron unavailable to rice in neutral and calcareous soils. In such circumstances, acidic nitrogen fertilizers and organic manures should help. We started a long-term experiment to compare the effects of 100 kg/ha N as ammonium sulfate and as urea, in the presence and absence of 20 t/ha of straw compost, on soil properties and on the yield of five rice varieties. In the first season, compost increased the mean yield of rice by 0.6 t/ha. The form of nitrogen made no significant difference (Table 14).

Wet soils. Physiologically, soils in which the water table is close to the surface are well suited

Table 14. Influence of two kinds of nitrogen fertilizer in the presence and absence of compost on the yield of five rice varieties, IRRI, 1973 wet season.

Nitrogen source	Compost	Grain yield (t/ha)					
		M1-48	E425	IR5	IR661-1-170	IR442-2-58	Mean
Urea	no	3.7	3.6	5.4	5.6	5.5	4.8
	yes	4.8	4.5	6.0	6.8	5.6	5.5
Ammonium sulfate	no	3.4	3.6	5.4	5.6	5.4	4.7
	yes	4.9	3.8	6.0	6.7	5.1	5.2

to rainfed rice if weeds can be controlled economically. Among such soils are 80,000 hectares of flat, continuously wet, alluvial soils in Agusan del Norte, Philippines. The widespread zinc deficiency on these soils is now easily corrected (1972 Annual Report), so rice cultivation is spreading. But much of the land is still uncultivated during the dry season because irrigation facilities are inadequate. The extensive presence of a typical marsh plant (*Cyperus imbricatus*) suggested that the soils were wet enough to support rice without irrigation. To test this hypothesis, a block of land at the Northern Mindanao National Agricultural College with a heavy growth of *Cyperus imbricatus*, was cleared and planted to 10 varieties.

The weeds were sprayed with Paraquat and removed after 5 days. The field was rotovated, plowed with a native plow, and harrowed. During these operations the soil was thoroughly puddled. Pregerminated seed was sown by hand in furrows 25 cm apart in 3- × 5-m plots replicated five times. The plots were sprayed with 2,4-D, 25 days after sowing, and hand weeded twice. A mixture of 50 kg/ha N as ammonium sulfate and 50 kg/ha K as muriate was topdressed 28 days after sowing. Another 50 kg/ha N was topdressed at panicle primordia initiation. In spite of an unusually dry season, during which the soil cracked, seven of the 10 varieties yielded 6.0 t/ha or more (Table 15). The experiment was repeated in the 1973 wet season. In spite of heavy rains from heading and lodging of some varieties, seven of the 10 varieties yielded more than 4.5 t/ha (Table 15).

Using the same cultural practices, we also installed unreplicated trials on two unirrigated farmers' fields in Agusan. At each location a 2,500-sq-m block was divided in half and IR20 and IR442-2-58 were row seeded. The mean grain yield from two 2- × 2-m sample plots at each location was 7.2 t/ha for IR20 and 8.0 t/ha for IR442-2-58.

Table 15. Mean yield of 10 rice varieties on rainfed Butuan clay, 1973 dry season.

Designation	Yield[a] (t/ha)	
	Dry season	Wet season
M1-48	6.0 b	2.5 e
E425	3.7 d	5.5 b
IR5	7.6 a	4.8 c
IR20	7.4 a	5.5 b
T442-36	4.7 c	5.5 b
IR661-1-170	7.1 a	4.7 c
IR127-80-1	6.0 b	3.3 d
IR442-2-58	7.0 a	4.4 c
OS4	4.2 cd	4.7 c
CICA 4	7.2 a	6.3 a

[a]Any two means followed by the same letter are not significantly different at the 5% level.

If these results apply widely, and the weed succession induced by growing a crop during the dry season is amenable to chemical control, two crops per year of rice can be raised on the flat, wet soils of Agusan del Norte without artificial irrigation.

Acid upland soils. M1-48, which greenhouse and field tests showed is resistant to aluminum and manganese toxicities (1971 and 1972 Annual Reports), gave a mean yield of 4.4 t/ha on four one-quarter-hectare observational plots on the sloping acid soils of Luisiana, Laguna, Philippines, during the 1973 wet season.

Soil microbiology

We continued to study atmospheric nitrogen fixation by soil micro-organisms such as the blue-green algae, certain bacteria of the rice rhizosphere, and the rhizobia found in rice soil. □ Using a tracer technique, we examined the fate of fertilizer nitrogen in submerged rice fields. The amount of broadcast fertilizer recovered in the rice plant increased when the fertilizer was applied at later growth stages, up to the booting stage. Rice yields were higher when fertilizer was applied as basal. In a submerged rice field, from 3 to 8 percent of the broadcast fertilizer was volatilized. □ A tracer study showed that the rice plant has a mechanism in the rhizosphere to absorb sulfur applied as sulfide. Arylsulfatase activities were higher in the soil of the rice rhizosphere than in the non-rhizosphere soil. □ Rice grown in submerged soils degraded ethylene that was produced in the soil. □ We examined BHC residues in rice soils and in rice plants harvested in Bulacan, Philippines.

ATMOSPHERIC NITROGEN FIXATION

Nitrogen, the essential element for animal growth and nutrition, is a limiting factor for crop production. In many developing countries, the nitrogen fertility of the soils is largely maintained by natural inputs. The ability of microbes to enrich soils by fixing atmospheric nitrogen offers considerable potential, particularly in areas where little nitrogen fertilizer is available.

We continued to study microbial nitrogen fixation in rice soils using the acetylene reduction method.

Rice rhizosphere. We earlier found that oxygen tension affects nitrogen fixation in the root zone of intact plants (1972 Annual Report). We also found that the concentration of oxygen affects the activities of nitrogen-fixing organisms in excised rice roots. We gently washed the roots of lowland-grown IR20 at milk stage to free them of soil and placed 2-g samples in Erlenmeyer flasks. In one set of samples, the air was retained in the flasks; in another, a mixture of 3-percent oxygen and argon was substituted for air; and in a third, the flasks were filled with argon. The experiment was replicated four times. After 24 hours incubation at 30°C, we measured the ethylene formed by gas chromatography to determine the nitrogenase activity. The highest amount of ethylene was produced at 0.03 atm O_2 after 24 hours incubation. Under anaerobic conditions, about half as much ethylene was produced. Ethylene formation was low under atmospheric oxygen tension.

When the roots were placed in Petri dishes containing nitrogen-free nutrient mediums, the nitrogen fixers vigorously formed visible colonies along the roots at 0.03 atm O_2, while growth was significantly less at 0.0 atm O_2.

We examined the effect of mineral nutrition on nitrogen fixation. We estimated the effect of combined nitrogen by making an acetylene reduction assay of a 2-g root sample of IR20 at 0.03 atm O_2. We added 1 ml of plain water to the first treatment as a control. We supplemented the second with 1 ml of a solution containing 20 ppm N, and the third with 1 ml of a solution containing 40 ppm N as ammonium nitrate. Table 1 shows how adding mineral nitrogen to roots affected acetylene reduction. Nitrogenase activity was diminished when combined nitrogen was added. The inhibitory effects of the two N levels are not significantly different. We added doses of only 10 μg N per gram of fresh root at the lower levels of nitrogen. The threshold for the repression of N-fixation, however, is obviously still lower.

Table 1. Effect of ammonium nitrate on an assay of C_2H_2-C_2H_4 with excised rice roots.

Incubation time (h)	Cumulative ethylene formed (nmol/g fresh root) 0 ppm N	20 ppm N	40 ppm N
4	< 0.01	< 0.01	< 0.01
7	2.58	0.09	0.12
10	14.23	1.56	1.56

Molecular nitrogen. We measured the changes in gas components in submerged rice soil in a field experiment. Twelve 5- × 8-m plots were prepared. Ammonium sulfate was applied as basal at 100 kg/ha N to six plots; the other six plots were not fertilized. Three of the fertilized plots and three of the unfertilized plots were planted to IR5 at 20- × 20-cm spacings. The other six plots were left unplanted. The plots were weeded and sampled without being entered to avoid disturbing the soil.

We collected the gas samples from the plots and analyzed them with a gas chromatograph connected to a gas sampler with a manometer. We collected less gas than last year. But, as observed last year, the amount of nitrogen gas and the percent nitrogen gas to the total gas tended to be higher in planted soil than in unplanted soil at later stages of plant growth (Table 2).

Carbon excretion. Rice roots provide organic carbon, which is essential to atmospheric nitrogen fixation in the rice rhizosphere. We examined the excretion of carbon in the rhizosphere by the radioisotope technique. We applied $^{14}CO_2$ to IR8 and IR22, grown in pots under submerged conditions, at maximum tillering stages. One mCi of ^{14}C was applied as $^{14}CO_2$ to six pots for 4 hours in a growth chamber. The soil was sampled at 1 hour after exposure to ^{14}C, at booting stage, and at harvest. About 100 ml of the soil-and-water mixture were sampled from pots from which the rice roots were carefully removed. The water was separated from the soil through a Buchner funnel and the ^{14}C content determined by liquid scintillation counter.

At booting, 1.9 percent of the total ^{14}C assimilated was excreted from IR22 roots and remained in the soil and water; at harvest, it was 3.2 percent. In IR8, 2.8 percent remained at booting, and 6.7 percent at harvest. These values were higher than those obtained under water culture conditions last year. The differences may have been partly due to invisible root fragments that remained in the soil.

A similar experiment was conducted in the greenhouse at booting stage by growing IR8 in both submerged and upland soils. At harvest, 1.6 percent of the total assimilated ^{14}C was found in the submerged soil and 1.2 percent in the upland soil.

Autoradiographs of the root zones of rice seedlings in submerged and in upland soil conditions were compared with autoradiographs of the root zones of soybean and corn seedlings. We detected radioactivity in the zones around the fine lateral roots and some of the thick primary roots; apparently these were newly developed tissues. We then examined the distribution of ^{14}C in the soil and the plants. The soil planted to rice had more ^{14}C than did the soil planted to soybean or corn.

Blue-green algae. The nitrogen-fixing blue-green algae which live on the surfaces of paddy soil and water are considered to be a source of natural nitrogen enrichment for rice soils. We studied the acetylene reduction method under field conditions to determine a technique by which we could measure the role of blue-green algae in fixing atmospheric nitrogen.

We placed plastic bottles, 7.5 cm in diameter and 18.5 cm in height, 4 cm below the surface of paddy soil, leaving above water a gas phase volume of 600 ml. We introduced 10, 20, and 30 μl of ethylene into these bottles. No ethylene was introduced into the control bottle. After the bottles had been in the field for certain periods of time, we sampled the atmospheres with a pre-evacuated B-D Vacutainer tube and a double-pointed needle. We used a syringe plunger to agitate and mix the gas inside the bottle at each sampling. The gas sample was analyzed for ethylene concentration by gas chromatography.

Table 2. Volumes of gases in submerged soils planted to IR5 and in unplanted soil.

Days after transplanting	Volume (cc/100 g dry soil)			
	N_2		CH_4	
	Planted	Unplanted	Planted	Unplanted
	No N application			
6	1.31	1.27	1.47	2.62
33	2.33	1.34	0.43	2.22
60	2.07	1.34	1.12	3.54
85	2.57	0.92	1.88	3.34
	N application			
6	1.27	1.28	1.23	0.54
33	1.53	1.80	0.09	1.63
60	2.07	1.28	1.11	1.50
85	3.13	1.06	1.52	2.98

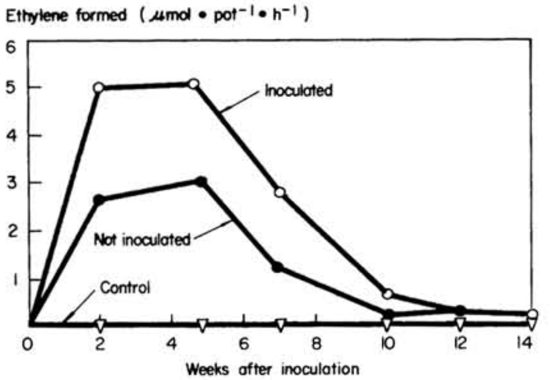
Table 3 shows that the recovery of ethylene increased with higher concentration, but decreased with increasing incubation periods. The data suggest that ethylene may possibly be produced indigenously from paddy soil, but in small amounts. More than 95 percent of ethylene added to the assay bottles was recovered after 5 hours of incubation in the field conditions. Because of the relatively high percentages of ethylene recovered, this technique seems applicable to *in situ* determination (under field conditions) of acetylene reduction by paddy soil.

Using this technique, we determined the nitrogen-fixing activity of blue-green algae in pot and field experiments. Acetylene reduction

Table 3. Recovery of ethylene at different concentrations in plastic bottles.

Incubation time	Ethylene concentration[a] (nmol)						
	Control	10 μl	Recovery (%)	20 μl	Recovery (%)	30 μl	Recovery (%)
5 min	1.85	349.4	100	685.7	100	926.8	100
2 h	1.21	341.5	97	660.8	97	903.7	100
5 h	3.05	314.6	90	597.9	88	859.6	97
24 h	3.23	234.6	67	509.3	75	702.1	79

[a]Average of five replications.



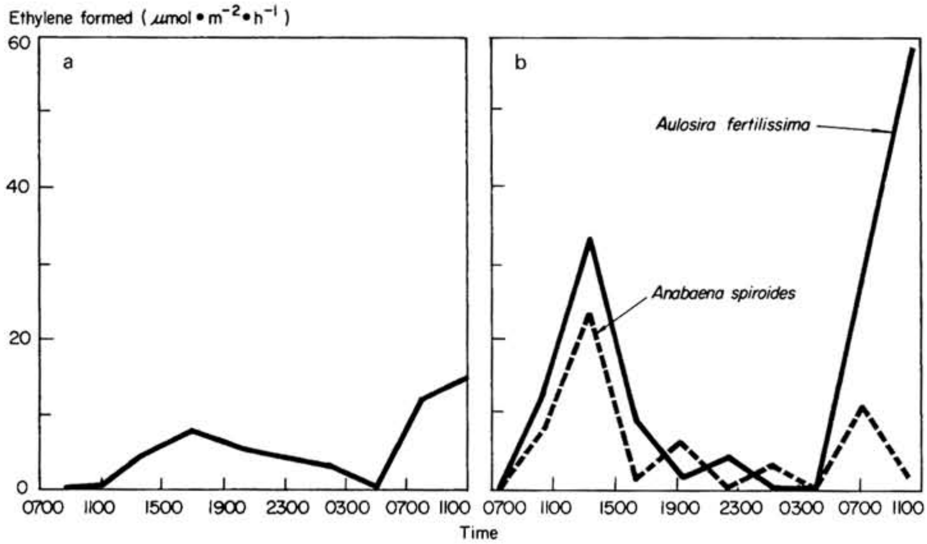
1. Acetylene reduction by N_2-fixing algae in unplanted Maahas clay soil.

in inoculated, unplanted Maahas clay soil was compared with that in the same soil, but not inoculated. Pots covered with black cloth to prevent algae growth served as the control. The treatments were replicated three times. Four plastic bottles were placed about the same positions in each pot at each time of assay. Ten percent of the gas inside the bottles was replaced with acetylene. The B-D Vacutainer tube was then used to sample gas before ethylene was determined by gas chromatography. Acetylene reduction activity was determined after incubation for 2 hours between the hours of 0830 and 1130. Figure 1 shows that no acetylene reduction activity occurred in the control pots.

But nitrogenase activity was high in the pots exposed to sunlight. Acetylene reduction was high in both treatments for about a month after submergence, but then decreased rapidly. The nitrogen-fixing activity in the pot that was inoculated with *Nostoc* was consistently higher than in the pots with naturally grown algae.

We used the same technique to examine diurnal variation of nitrogen-fixing activity of algae in the field. Three weeks after transplanting, we placed the assay bottles at random in a planted plot that was inoculated with *Aulosira fertilissima.* Gas samples were withdrawn through a B-D tube at 3-hour intervals for 26 hours. The acetylene reduction activity in the plot that was inoculated with nitrogen-fixing algae continuously increased from 0900 until about 1700, then gradually decreased until 0500 the following day, then abruptly increased once more (fig. 2).

We simultaneously examined diurnal activities by laboratory-grown algae under the same field conditions. We collected and homogenized two nitrogen-fixing blue-green algae grown in a nitrogen-free medium in the laboratory. We pipetted 100 ml of algal suspensions into plastic



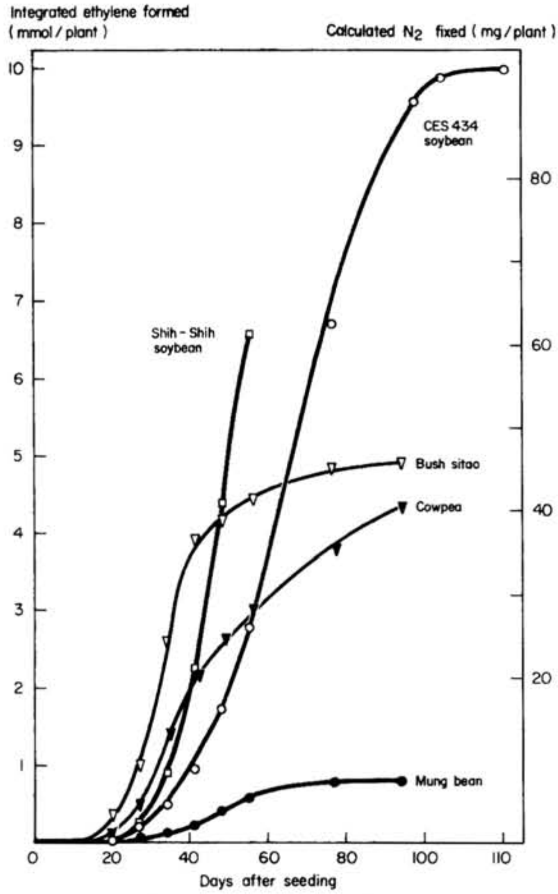
2. Diurnal changes of acetylene reduction in a field: a, acetylene reduction in an *Aulosira fertilissima*-treated plot planted to IR20 (activity determined 3 weeks after inoculation); b, acetylene reduction by laboratory-grown N_2-fixing algae under field conditions.

bottles through an opening for gas withdrawal. Ten percent of the gas inside the bottles was similarly replaced with acetylene. The bottles containing the algae were then brought to the field and examined for acetylene-reducing activity. The algae showed no significant nitrogenase activity during the night (fig. 2).

Grain legumes. We continued to study nitrogen fixation by the same grain legumes as those that we planted on the same plots last year. The order of nitrogen-fixing activities of the different legumes planted in February this year were similar to those of the April 1972 cropping (fig. 3). The amounts of nitrogen fixed by bush sitao and cowpea decreased markedly after the flowering stage. Mung bean fixed very little nitrogen because of poor nodulation and a poor stand of the crop. The dry matter production was generally lower than in the 1972 cropping season, even that of the upland rice planted in the same field. This may be because soil and weather conditions were different in the two croppings. Less soil nitrogen was available before planting in 1973 than in 1972.

The amounts of nitrogen fixed were also much lower than in 1972: Shih Shih soybean fixed an estimated 18 kg/ha N; CES434 soybean, 28 kg/ha N; bush sitao, 14 kg/ha N; cowpea, 8 kg/ha N; and mung bean, 2 kg/ha N.

We measured the acetylene-reducing activity of the nodulated roots of Shih Shih at intervals during a 27-hour period (fig. 4). We periodically measured the light intensity above the crop with a Toshiba illuminometer. Approximately 3 hours after abrupt changes in light intensity, acetylene reduction activity changed. The cloudy period in the afternoon decreased the acetylene reduction. This activity was higher during the day than at night, indicating that photosynthetic activity stimulated the nodules to fix nitrogen.



3. Amounts of nitrogen fixed by different legumes, 1973 cropping season.

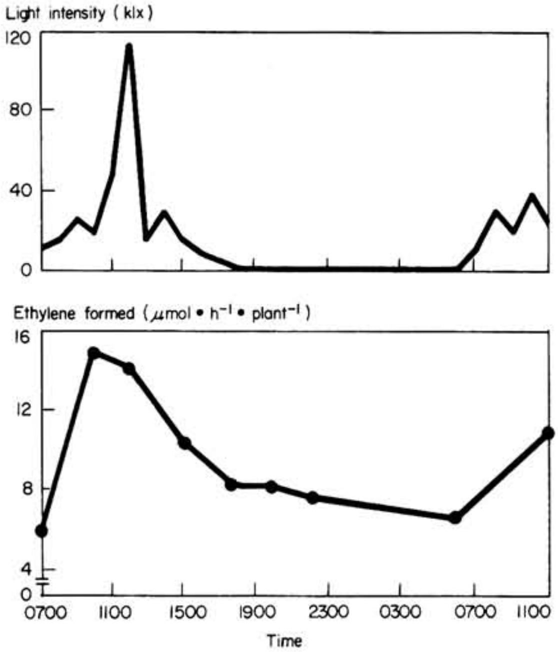
TRANSFORMATION OF NITROGEN

Fate of fertilizer nitrogen. We conducted a field experiment to determine how nitrogen fertilizer applied at different stages of plant growth affects grain yield and plant uptake of nitrogen under submerged conditions.

Treatments were applied as follows: basal-broadcast, basal-incorporated, maximum tillering, panicle initiation, booting, flowering, and no nitrogen. Ammonium sulfate was added at 50 kg/ha N and ^{15}N-tagged fertilizer was used in a 1- × 1.25-m area in each plot that was enclosed with plastic sheets. IR20 was the test variety. All treatments were replicated three times.

^{15}N content of the plants and soils was analyzed by a ^{15}N analyzer.

Ten days after nitrogen was applied at tillering, panicle initiation, booting, and flowering stages. the plants had taken up as much fertilizer nitrogen as was recovered at harvest (Table 4). We expected the low values for the basal treatments, both broadcast and incorporated, because the roots of the plants were not well developed at the time we applied fertilizer nitrogen.



4. Diurnal variation of acetylene reducing activity of the nodulated roots of the field-grown soybean Shih Shih.

By harvest, much of the fertilizer nitrogen that was applied as basal-broadcast had been lost from the plant-soil system; only 60 percent was recovered. About 15 percent was taken up by the plant. But when the fertilizer was incorporated, 32.4 percent was taken up by the plants and 51.6 percent remained in the soil. Most of the tagged nitrogen that remained in the soil was believed to be in organic form.

The uptake of fertilizer nitrogen by the rice plant increased as the fertilizer application was delayed from maximum tillering to booting or flowering stage; the amount of fertilizer nitrogen in the soil, however, remained constant. But the increased utilization of the added fertilizer did not correspondingly increase the grain yield. The nitrogen taken up at later stages did not efficiently increase either tiller number or grain number, the limiting factors for grain yield in this experiment (Table 5).

Grain yield was highest in the treatment where fertilizer was applied as basal and incorporated.

Application of fertilizer seemed to increase the availability of soil nitrogen. The total nitrogen uptake in the plot without nitrogen was 86 kg/ha.

Ammonia volatilization in flooded soils. To accurately determine the amount of volatilized ammonia in flooded soils, we measured it directly in the greenhouse and field. Glass wool was arranged to expose a large surface for ammonia absorption, then was wet with *N* H_2SO_4 and suspended inside volatilization bottles. We then quantitively measured any evolved ammonia trapped in the glass wool.

In the greenhouse, a 1-cm layer of air-dried Maahas clay topsoil was placed at the bottom of a bottle. A level of 2 cm of water was maintained in the bottle. The soil was incubated for a week, then ammonium sulfate was added. We calculated the rate of nitrogen application on the basis of surface area exposed in the container.

In a paddy field, the upper portion of a similar volatilization bottle was placed in the soil between rows of newly transplanted IR20 seedlings. A distance of 6 cm separated the acidified glass wool and the enclosed water surface.

A significant amount of ammonia was volatilized during the first 10 days after nitrogen was applied. Increasing the soil pH markedly increased ammonia volatilization. With ammo-

Table 4. Recovery of tagged fertilizer nitrogen applied at different growth stages of the rice crop.

Time of application	Tagged N recovered (kg/ha)				Total N recovered (%)
	10 days after application	At harvest			
	Plant	Plant	Soil	Plant and soil	
Basal (broadcast)	1.4	7.6	22.4	30.0	60
Basal (incorporated)	1.3	16.2	25.8	42.0	84
Maximum tillering (broadcast)	19.1	16.3	17.9	34.2	68
Panicle initiation (broadcast)	25.3	20.8	19.1	39.9	80
Booting (broadcast)	29.1	25.8	16.6	42.4	85
Flowering (broadcast)	26.9	25.1	17.0	42.1	84

Table 5. Effect of time of nitrogen application on the yield and nitrogen uptake of the rice plant.

Time of application	Grain yield[a] (t/ha)	Grains (no./sq m)	Nitrogen uptake[a] (kg/ha)		
			Fertilizer N	Soil N	Total
Basal (broadcast)	5.0 a	39103	7.6 c	93.9	101.5
Basal (incorporated)	5.9 a	41641	16.2 b	113.2	129.4
Maximum tillering (broadcast)	5.4 a	35351	16.3 b	103.0	119.3
Panicle initiation (broadcast)	5.6 a	42643	20.8 ab	97.2	117.9
Booting (broadcast)	5.3 a	33799	25.8 a	97.4	123.1
Flowering (broadcast)	4.9 a	31492	25.1 a	96.8	121.9
0 N (control)	4.5 a	28310	—	86.0	86.0

[a]Any two means followed by the same letter are not significantly different at 5% level.

nium sulfate, losses from soils with pH values of below 7.0 were small. When the soil pH was raised to 8.1, the percentage of added nitrogen volatilized was greater with lower rates of ammonium sulfate application. The active period of volatilization lengthened with lower nitrogen levels.

The losses from urea were much greater than losses from ammonium sulfate (fig. 5). When applied by broadcasting at 100 kg/ha N, 8.1 percent of the volatilized ammonia was from urea and 3 percent from ammonium sulfate for a period of 21 days. When the fertilizer materials were incorporated into the topsoil, ammonia losses decreased by 50 percent. Practically no ammonia was lost from potassium nitrate and isobutylidene diurea.

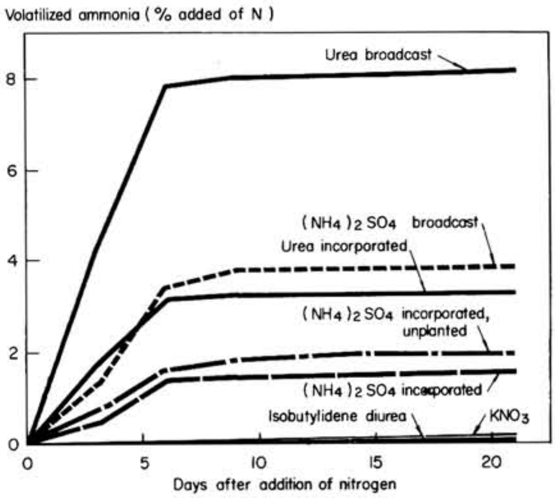
MINERAL TRANSFORMATION

Iron reduction. To determine the iron-reducing activities in the rice rhizosphere, we washed with water the roots of 1-month-old IR8 and IR20 plants grown in Maahas clay soil, Luisiana clay soil, and a Malaysian acid-sulfate soil. One gram of the roots was macerated in 100 ml of sterile distilled water by blender and 1 ml of the macerate was incubated into a glucose-peptone solution which contained limonite. Ferrous iron produced in the medium was determined anaerobically every other day during incubation at 30°C. The iron-reducing activity of the IR8 rhizosphere was higher than that of the IR20 rhizosphere. We found no statistically significant differences in the iron-reducing activities of the rhizosphere among the three soils.

Iron-reducing bacteria in the macerated roots of 1-month-old IR8 and IR20 plants were counted using Robert's glucose-asparagine medium containing 1 percent potassium ferricyanide. The IR8 rhizosphere had more iron-reducing bacteria than did the IR20 rhizosphere.

Sulfur transformation. We continued to study sulfur transformation by the tracer technique. To test whether the rice plant can take up sulfur in sulfide forms, 1 kg of presubmerged Pila soil, free of sulfate, was thoroughly mixed with ^{35}S-labelled Na_2S in a 600-ml beaker. Then the soil pH was adjusted to 7.0 to prevent the chemical oxidation of the sulfide inside the nitrogen atmosphere chamber (which had been flushed by oxygen-free nitrogen gas for 2 hours).

We prepared another set of samples, but with ^{35}S-labelled K_2SO_4 instead of Na_2S as a control. Two 14-day-old IR667 seedlings were planted in each soil. The surface of the water in the Na_2



5. Cumulative loss from different sources of added nitrogen applied by different methods (N added at 100 kg/ha on lowland Maahas clay at pH 7.1).

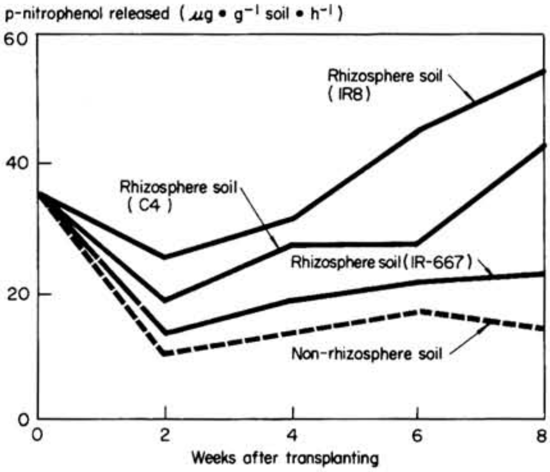
^{35}S-treated beaker was covered with liquid paraffin to prevent the diffusion of oxygen. Oxygen-free deionized water was added with a syringe. We collected plants at 30 days after transplanting and analyzed them for both total and radio-active sulfur.

Plants in soils treated with Na_2S and K_2SO_4 absorbed the sulfur in the compounds (Table 6). The data indicate that the rice plant takes up sulfide sulfur, apparently after oxidizing it to sulfate in the rhizosphere.

Many soil microorganisms or enzymes can also release sulfur by degrading organic sulfur in soil. We measured the activity of arylsulfatase, an enzyme which hydrolyzes arylsulfate through fission of the O-S bond. We also measured hydriodic acid (HI) reducible sulfur, a fraction consisting largely of organic sulfur not directly bonded to carbon.

In determining arylsulfatase, we measured p-nitrophenol production after adding 0.005 *M* p-nitrophenol sulfate to the submerged soils. We found through enzymatic hydrolysis that p-nitrophenol and incubation time were linearly related and that enzymatic activity was higher in Pila soil than in Maahas clay soil.

The arylsulfatase activities of IR8, IR667, and C-4 plants were higher in rhizosphere soils than in non-rhizosphere soils throughout rice growth (fig. 6). The enzymatic activities of IR8 and C-4 in rhizosphere soils were much higher than those of IR667. The enzymatic activity in the rhizosphere generally increased as the rice plants aged. Arylsulfatase activity was higher in Pila soil than in Maahas clay soil. Application of sulfate decreased the enzymatic activity in the rhizosphere soils.



6. Arylsulfatase activity of different rices in rhizosphere and non-rhizosphere Pila soil.

Table 6. Sulfur uptake by rice plants from two sources of ^{35}S-labelled sulfur compounds in Pila clay loam under submerged soil conditions.

Replication	Radioactivity[a] (cpm)	
	Potassium sulfate	Sodium sulfide
1	1035	923
2	1086	913
3	1040	972
4	984	1015
Mean	1036	956

[a]The counting was corrected by recovery rate. Recovery measurement on the conversion of $K_2{}^{35}SO_4$ to $Na_2{}^{35}S$ with Johnson-Nishita's apparatus was 89%.

Table 7. Ethylene formation in Ampayon and Maahas soils with and without the addition of 1 percent glucose under different soil conditions 4 days after incubation at 30°C.

Soil treatment	Ethylene formed (nmol/100 g dry soil)	
	Control	Glucose added
Submerged Ampayon in N_2 atmosphere	25.2	55.9
Submerged Ampayon in air	19.9	70.5
Upland Ampayon in air	18.6	99.2
Submerged Maahas in N_2 atmosphere	25.0	32.3

The rhizosphere soils had more HI-reducible sulfur than did the non-rhizosphere soils. A plate count showed that the total number of bacteria was much higher in the rhizosphere soils than in the non-rhizosphere soils, particularly at later stages of rice growth. The number of sulfate-reducing bacteria in the rhizosphere was less than that in the non-rhizosphere soils and it decreased with plant age.

ORGANIC MATTER TRANSFORMATION

We further studied the formation of ethylene in rice soil by the method reported in the 1972 Annual Report. Even in upland conditions, Ampayon soil produced ethylene gas and it produced a greater amount if it received 1 per-

Table 8. Ethylene formation and degradation by washed crop roots incubated without soil at 30°C.

Crop and stage	Growth condition	Amount of ethylene (nmol/10 g root)					
		Incubation time (h)					
		1	5	10	15	20	25
		Control					
Rice IR8, seeding	Tapwater	0.0	0.0	0.2	—	—	1.4
Rice IR8, heading	Submerged	0.0	0.0	0.0	0.0	0.2	0.2
Rice IR747, panicle initiation	Upland	0.0	0.5	0.5	1.0	1.0	1.5
Sorghum, flowering	Upland	1.7	8.0	11.5	14.4	14.0	12.0
Soybean, maturity	Upland	0.2	0.7	1.0	1.5	1.5	1.5
		Ethylene gas added					
Rice IR8, seedling	Tapwater	38.4	40.7	39.6	—	—	41.2
Rice IR8, heading	Submerged	34.0	18.6	10.4	5.9	8.4	6.4
Rice IR747, panicle initiation	Upland	37.0	37.6	37.4	39.6	39.4	38.6
Sorghum, flowering	Upland	39.3	46.1	48.4	51.1	51.9	51.4
Soybean, maturity	Upland	38.0	39.6	39.6	40.8	38.9	41.2

cent glucose (Table 7). The concentration of ethylene gas in the atmosphere of flasks ranged from 1.7 to 2.4 ppm in control soils and from 3.0 to 9.3 ppm in soils with glucose, higher than the toxic levels for some plants.

We reported last year that the rice rhizosphere degrades ethylene. This year we tested ethylene degradation in the roots of: a rice plant (IR8) that was grown in submerged soil; a rice plant (IR747) that was grown in an upland soil; a sorghum plant grown in the IRRI experimental fields; and a soybean plant from the IRRI experimental fields. The roots were washed thoroughly, separated from the tops, and rinsed several times with distilled water; excess water around the roots was removed with filter paper. Ten grams of fresh roots were placed in a 50-ml Erlenmeyer flask and sealed with a rubber stopper that could be punctured by a needle. A small test tube containing 0.5 ml of 20-percent sodium hydroxide was placed in the flask to absorb carbon dioxide evolved during incubation. The air in the flask was replaced with a mixture of argon and oxygen gases. A portion of the atmosphere was then replaced with ethylene. The flask was incubated in the dark for 24 hours at 30°C. Ethylene concentration in the atmosphere was analyzed periodically by gas chromatography.

Only the roots of rice grown in submerged soil markedly degraded ethylene (Table 8). Much of the ethylene which was initially applied disappeared within 15 hours of incubation. Roots of other crops did not degrade ethylene. Furthermore, the ethylene-degrading activity of the rice roots was examined at 0, 0.05, and 0.2 atm O_2. More ethylene was degraded at 0.2 atm O_2 than in anaerobic conditions.

PESTICIDE RESIDUES

We determined residues of BHC isomers in soil, plant, water, and seeds sampled from different rice fields in the Philippines. Analyses of soil,

Table 9. Residues of BHC isomers in soil, plant, and rice seeds from rice fields in Bulacan, Philippines.

BHC isomer	Content[a] (ppb)	
	Mean	Range
	Soil	
α	11	T to 40
γ	7	T to 36
β	22	T to 50
δ	8	T to 10
	Plant	
α	33	T to 113
γ	22	T to 78
β	55	T to 148
δ	30	T to 91
	Hull	
α	33	T to 56
γ	30	T to 57
β	16	T to 25
δ	17	T to 30
	Grain	
α	3	T to 5
γ	3	T to 6
β	T	T
δ	T	T

[a]T = less than 1 ppb for α, γ, δ; less than 5 ppb for β.

plant, and water from Iloilo appear in the 1972 Annual Report. The amount of γ-BHC in the rice grains was 5 ppb and that in the hulls was 11 ppb.

In Bulacan, we took samples from farmers' fields, most of which received γ-BHC treatment about a year ago. In most cases, the four BHC isomers were identified in soils and plants from rainfed fields. Only traces of β- and δ-BHC were present in irrigated fields. Among the four isomers, β-BHC was present in higher amounts in soils and plants (Table 9). In the grain, 3 ppb α- and γ-BHC were present while only traces of the β and δ isomers were detected.

Plant pathology

An analysis of physiological races involved in a blast outbreak on many rice varieties in the field showed that there are many races in the same field at the same time and that varieties with low incidence are resistant to most races of the fungus, while varieties with high incidence are susceptible to most races. This agrees with the theory put forth earlier that varieties with broad spectrum resistance may bring about stable resistance. □ Distinct differences in reactions to sheath blight were observed in three different testing methods. But none of the results completely agreed with those of the field tests. A preliminary experiment showed that when rice varieties of varied degrees of resistance are inoculated with isolates of the sheath blight fungus of variable virulence, the interaction is not distinctly differential. □ An improved inoculation clipper for bacterial blight inoculation was developed which allowed us to screen all new germ plasm bank entries and all breeding material in the field. Results of the second International Bacterial Blight Nursery showed that many IRRI breeding lines and IR20 and IR26 have a good level of resistance in most Asian countries. □ A virulent strain of *Xanthomonas oryzae* was identified from Isabela province, Philippines, which breaks down the resistance of IR20 and other varieties with similar resistance. Varieties BJ1 and DZ 192 and their progeny have shown resistance to the Isabela strain. □ The epidemiology of rice tungro disease was studied by the cage method and by surveying farmers' fields in Luzon. The relation of factors such as population and activity of *Nephotettix virescens*, availability of virus source, and susceptibility of rice varieties, to the percentage of infected seedlings was determined in the cage study. By continuous serial transfer of infective insects for 10 hours, we determined that an infective insect can inoculate no more than 30 seedlings per day. □ Tungro incidence was very low in Luzon in 1973 because of low populations of the insect vectors that may have resulted from lack of feeding materials from March to June before the wet-season crop. The monthly percentage of infective *N. virescens* moved parallel to the monthly incidence of the disease in the field.

BLAST

Qualitative and quantitative resistance to blast. In breeding for disease resistance, the main concern is whether resistant varieties will maintain their resistance for a long time. Our concept of blast resistance is that 1) the fungus is very variable, it produces many races, and no variety is resistant to all races, 2) the degree of resistance depends upon the spectrum of resistance to the races, 3) the resistance to blast is "vertical," but varieties with a very broad spectrum of resistance maintain their resistance because the pathogenic races change into many races to which the varieties are resistant, giving, in effect, "horizontal" resistance.

A severe outbreak of blast occurred on an upland rice variety trial at IRRI in 1973. Most of the varieties or lines were infected but the disease intensity varied. Some had only a few lesions while others had numerous lesions and the leaves were killed. Qualitatively, they were all susceptible but, quantitatively, they differed greatly. We took advantage of the opportunity to test our concept.

Three lines were selected; one had few lesions, another had an intermediate number of lesions, and the third had many lesions. The lesions on 100 tillers of each variety were counted and 200 lesions selected at random were isolated. So far 46 of the isolates have been inoculated on the three lines and, to identify races, on the 12 differential varieties. The results are shown in Table 1.

Although we have not yet completed our inoculations, the results show that many races of the fungus occur in the field at the same time and that the line having the fewest lesions has a broad spectrum of resistance. The lines that had higher disease incidence were resistant to only a few races. In other words, the line that had a broad spectrum of resistance maintained its level of resistance.

Table 1. Qualitative and quantitative resistance to blast—number of lesions on three selected lines in the field and pathogenicity of 11 races from 46 isolates inoculated.

Designation	Lesions in field (no./tiller)	Pathogenic races (no.)	Pathogenic isolates (no.)	Lesions from 46 isolates (no./10 seedlings)
IR442-2-58	72.8	9	37	26.0
IR2031-421	36.4	5	24	14.0
IR1514A-E666	2.9	1	1	1.0

New races. Ten new Philippine races were identified during the year. Their reactions to the 12 Philippine differential varieties are shown in Table 2. Based on the eight international differentials, the isolates were classified into four races: IA-124, IA-127, IA-128, I I, according to the standardized international race numbers.

The 10 new races were found among a total of 11 races identified from 46 inoculations made with isolates from a blast-infected upland plot. Khao-teh-haeng 17, a very susceptible variety, was resistant to nine of the 10 new races and Co 25, a usually resistant variety, was susceptible to nine of the 10 new races. This further illustrates the great variability of the fungus.

Random development of races. Using 12 Philippine differential varieties, 4,096 races are theoretically possible. So far only 229 have been identified. The theoretical frequency distribution and the distribution of these identified races, based upon the number of differential varieties infected by each, are shown in figure 1. The distribution of the identified races also resembles a normal curve. When more races are identified, the two curves may resemble each other more closely. This might indicate that the races develop very much at random.

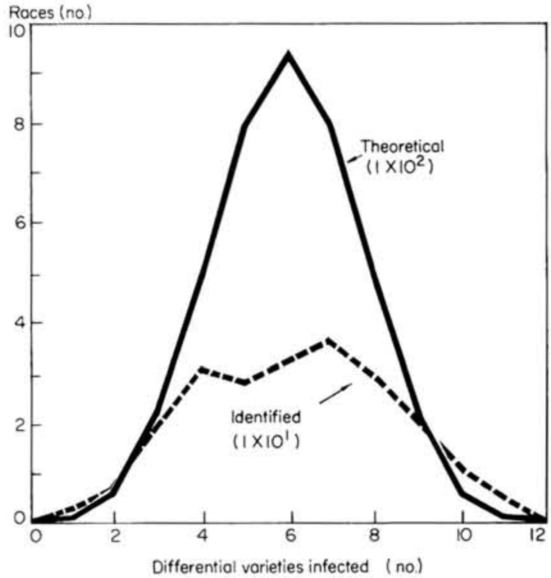
SHEATH BLIGHT

Perfect stage in upland rice. For the first time in the Philippines, the basidial stage of the sheath blight fungus was found on upland rice in a farmer's field in Batangas province. We believe that it may commonly occur in other upland rice fields. The disease may become more important in upland rice than in lowland rice.

Variability of single-basidiospore cultures. Forty of the 180 single-basidiospore cultures obtained from a field isolate, R57, were selected to study the variability in cultural morphology, temperature response, and pathogenicity. Great variations were observed in mycelial characteristics, such as color, configuration, and growth rate. The sclerotia formed also varied greatly in number and size, and whether they were solitary or aggregated.

The optimum temperature for mycelial growth varied with isolates, from 24 to 32°C. Optimal temperature for sclerotial production also varied widely, from 16 to 32°C (fig. 2). A wide range of differences in pathogenicity was also observed when the 40 isolates were inoculated onto five rice varieties. These results show the heterozygous nature of the fungus and great variation in field isolates is to be expected.

Isolate-variety interaction. Thirteen rice varieties, ranging from resistant to susceptible, were inoculated with 24 isolates of varying virulence to determine whether the interactions are differential or nondifferential. Three methods of inoculation were used: the detached-flag-leaf method, leaf-sheath inoculation (the second and third leaf sheath of standing plants inoculated), and adult-stage inoculation (entire hills inoculated at flowering stage). The detached-leaf method did not give consistent results and the experiment on adult-plant inoculation was destroyed by brown planthoppers. The results of leaf-sheath inoculation showed that the variation in virulence among the 24 isolates was great in certain isolate-variety combinations, but it was not as great when averaged for 13 varieties (fig. 3). The 13 varieties differed greatly in resistance or susceptibility to the average of the 24 isolates (fig. 4). In general, resistant varieties were more resistant to all isolates and susceptible varieties more susceptible to all isolates. The virulent isolates caused longer diseased areas on the sheath than the less virulent isolates to all varieties (fig. 5). Some variations exist but the interactions are not distinctly differential.



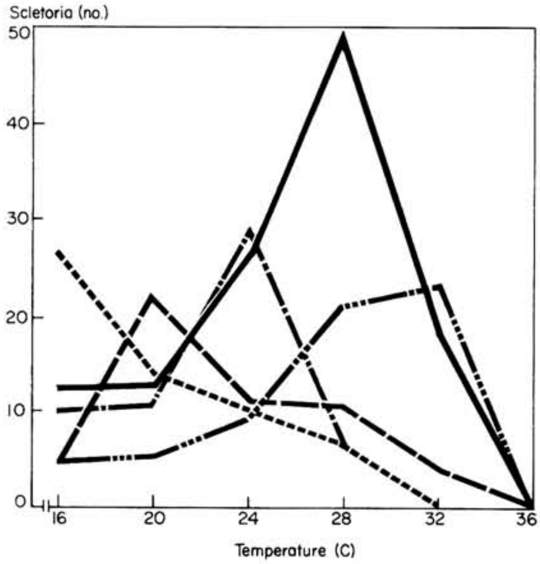
1. Distribution of 229 Philippine races of *P. oryzae* based upon number of the 12 differentials infected compared with the theoretically possible number of races.

Methods of inoculation. Two-week-old fungus cultures on rice grains (grain soaked in water for 24 hours and autoclaved) were found more convenient and useful as inocula for all types of inoculation than straw culture used previously.

Table 2. Reaction of 12 Philippine differential varieties to the 10 new races of *Pyricularia oryzae*.

Philippine differential variety	Reaction[a] on differential varieties									
	P220	*P221*	*P222*	*P223*	*P224*	*P225*	*P226*	*P227*	*P228*	*P229*
Kataktara DA2	●	●	●	●	●	●	●	●	●	●
CI 5309	●	●	●	●	●	●	●	●	●	●
Chokoto	●	●	●	●	●	●	●	●	●	●
Co 25	S	S	S	S	●	S	S	S	S	S
Wagwag	●	●	●	●	●	●	●	●	●	●
Pai-kan-tao	●	●	●	●	●	●	●	●	●	●
Peta	●	S	S	●	S	S	S	●	S	S
Raminad Str. 3	●	●	●	●	●	●	●	●	S	●
Taichung T.C.W.C.	●	●	S	S	●	S	●	S	S	●
Lacrosse	●	S	S	●	●	●	●	S	S	S
Sha-tiao-tsao(s)	●	●	●	●	●	●	●	●	●	●
Khao-teh-haeng 17	●	●	●	●	●	●	●	●	●	S

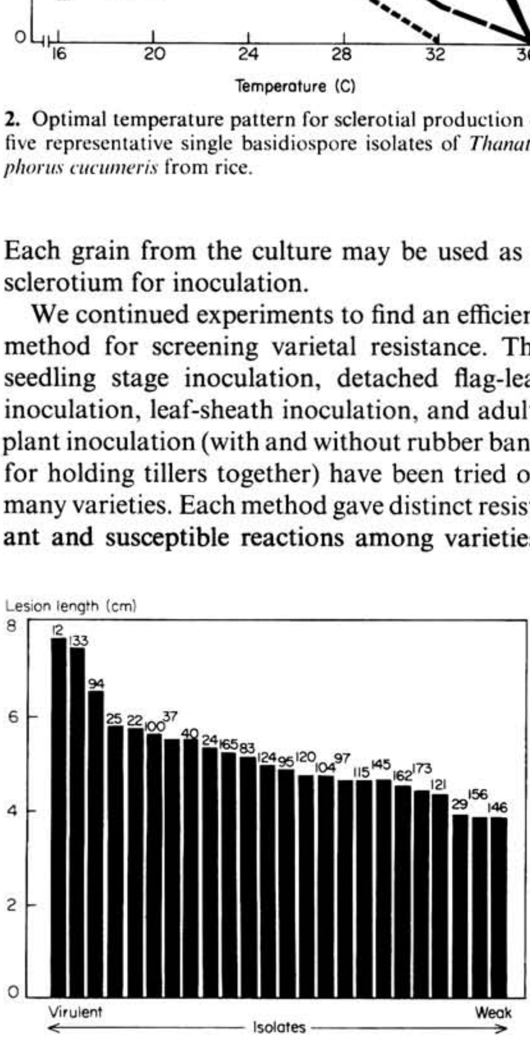
[a]● = resistant, S = susceptible.



2. Optimal temperature pattern for sclerotial production of five representative single basidiospore isolates of *Thanatephorus cucumeris* from rice.

Each grain from the culture may be used as a sclerotium for inoculation.

We continued experiments to find an efficient method for screening varietal resistance. The seedling stage inoculation, detached flag-leaf inoculation, leaf-sheath inoculation, and adult-plant inoculation (with and without rubber band for holding tillers together) have been tried on many varieties. Each method gave distinct resistant and susceptible reactions among varieties,



3. Virulence of single basidiospore isolates of *T. cucumeris* —average length of lesions on leaf sheaths of 13 varieties produced by 24 isolates.

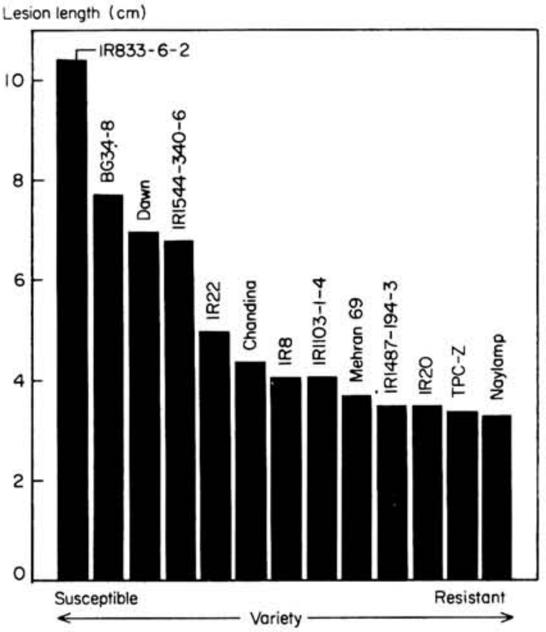
but the results did not always completely agree with each other. There were always some varieties which were found resistant by one method, and susceptible by the other. Since the disease is most important at the adult stage, adult-stage inoculation still must be used. No simpler method is completely reliable. Because the disease development is affected by climatic as well as by nutritional factors and because no highly resistant or immune varieties have been found, it is difficult to standardize the screening method. A known resistant and a susceptible variety should be included in each experiment for comparison. Inoculation experiments during the dry and wet season showed that the disease developed as well in the dry season as in the wet season, so screening for resistance may be carried out in both the dry and the wet seasons.

Varietal resistance. The screening for resistance to sheath blight of 140 varieties from the Assam collection, of 295 from the international blast nursery, and of 207 from the hybridization block was repeated twice this year at the adult stage. In addition, 197 lines of replicated yield trials, 157 lines of the observational yield trial, and 134 lines of IR2061 were tested in the wet season. About 10 percent of the 1,100 entries tested were moderately resistant, 40 percent moderately susceptible, and the rest susceptible. Among the high-yielding varieties, Pelita I/1, Bahagia, and Mehran 69 are moderately resistant; IR5, IR8, IR20, IR22, Ratna, and Nilo are moderately susceptible; and Chandina, Nahda, RD-2, and Tongil are susceptible. Of 134 IR2061 lines tested, 3 percent were resistant or moderately resistant, 28 percent moderately susceptible, and the rest susceptible.

Our general impression of varietal resistance to sheath blight is that while many varieties are susceptible, a considerable number are either resistant or moderately resistant and serious damage may not occur on them.

IMPROVING SOURCES OF RESISTANCE TO DISEASES

Under a severe outbreak of brown planthopper and grassy stunt during the wet season, eight hybrid lines from two crosses showed a high level of resistance to both. One line is from IR8[3]



4. Varietal resistance to sheath blight--average length of lesions on leaf sheaths produced by 24 single basidiospore isolates of *T. cucumeris* on 13 varieties.

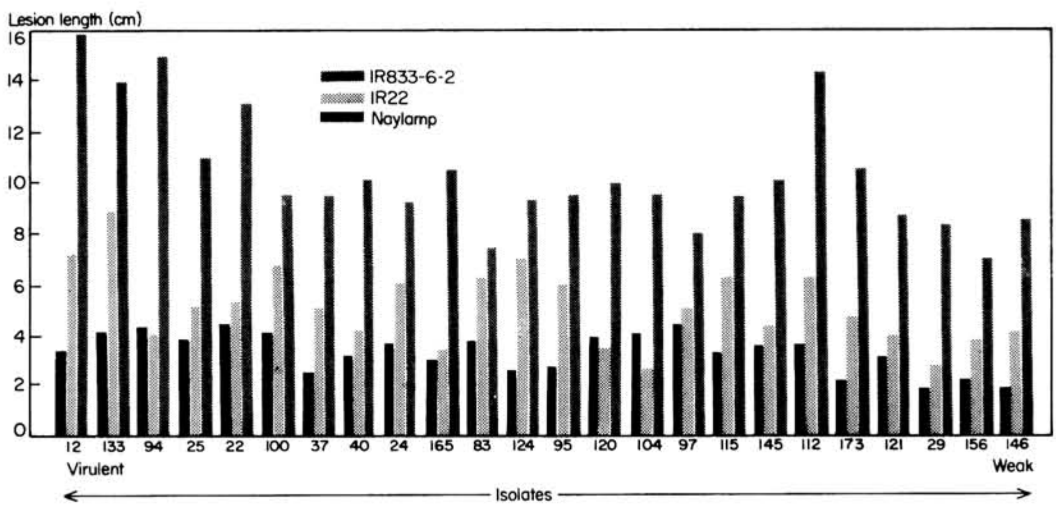
brown planthopper (fig. 6). When confirmed, these eight lines may be used as new sources of resistance to grassy stunt, in addition to *Oryza nivara*. All the parents were not considered resistant to grassy stunt.

Many hybrid lines have been developed to carry resistance to two or more diseases from many crosses. About 60 lines from the cross IR3265 (IR841//Mudgo/IR8///IR8^4/*O. nivara)* and 10 lines from the cross IR3268 (IR841// Mudgo/IR8///IR24^4/*O. nivara*) were resistant to both grassy stunt and tungro as well as to brown planthopper and green leafhopper. They were, however, moderately resistant to blast and moderately susceptible to bacterial blight in general; some lines were more resistant than the others. They have good plant type and grain shape, are lodging resistant, and yield well based upon preliminary estimates.

///IR8/Carreon//IR8/Tetep, which was intended to increase the spectrum of resistance to blast. The seven other lines are from IR24//Zenith/ Malagkit Sungsong, which was intended to increase the resistance to bacterial blight. None of the 42 plants (hills) of each of these lines were infected by grassy stunt nor damaged by the

BACTERIAL BLIGHT

Inoculation technique. An inoculation clipper has been designed to inoculate rice plants with *Xanthomonas oryzae*. Small grass trimmers, available in local markets in many Asian countries, have been modified so that a bacterial suspension automatically drips on the blade from a 200-ml plastic bottle during cutting (fig. 7). More than 3,000 plants per hour can be clip-inoculated by one person with approxi-

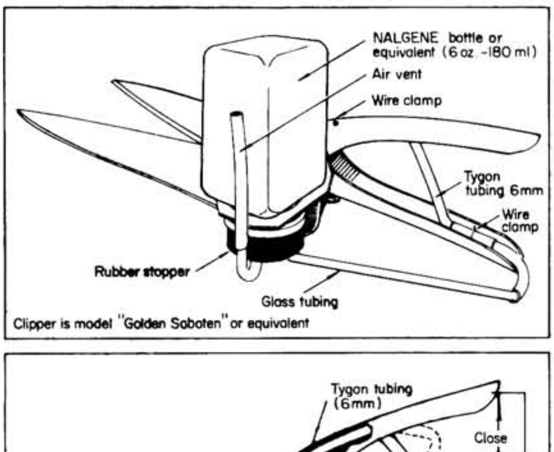


5. Reactions of three varieties (resistant: Naylamp, intermediate: IR22, and susceptible: IR833-6-2) to 24 sheath blight fungus isolates.

6. A plot of resistant plants from IR24//Zenith/Malagkit Sungsong, resistant to both grassy stunt and brown planthopper, surrounded by severely damaged plants in the field.

mately 200 ml of the bacterial suspension. This is three times more efficient than using a scissors which must be redipped into the suspension after inoculating every five plants (1972 Annual Report).

The inoculation clipper works best with a suspension of artificially cultured bacteria. A leaf extract suspension generally results in good infection but sometimes infection frequency is poor. The reason for the low infection frequency when leaf extract is used is not clearly understood. The number of escapes is minimized if the population of *X. orzyae* is above 10^9 cells/ml, however. New lesions must be used in preparing the suspension and limited amounts of clean water used to suspend the bacteria. Inoculations should not be made in the field during rain or when plants are severely infected with bacterial leaf streak.

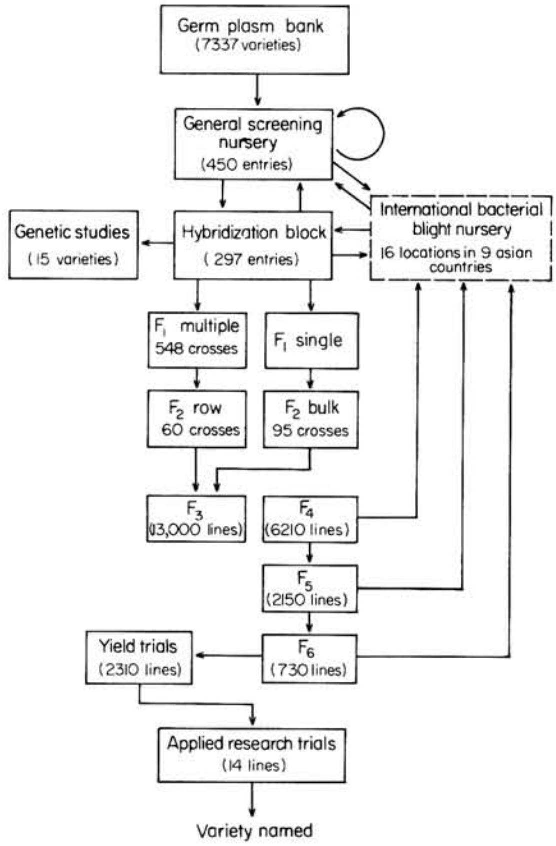


7. Bacterial blight inoculation clipper.

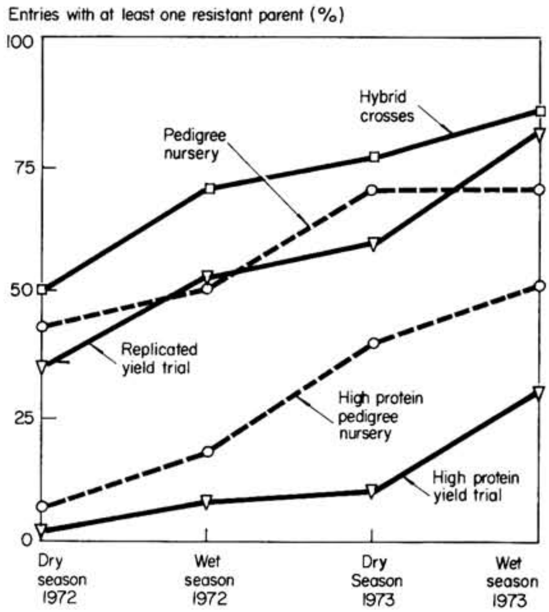
Varietal screening system. A more systematic approach has been developed to screen new germ plasm and breeding material for bacterial blight resistance (fig. 8). The inoculation clipper has helped develop the comprehensive screening system because large numbers of plants can be efficiently inoculated and scored in breeders' field plots. Each season all new accessions in the germ plasm bank are screened in the seed-increase plots. Resistant varieties are then advanced to the general screening trial where they are grown in single hills and screened both artificially by clipping and naturally by creating epidemic conditions. Varieties of diverse origins in the general screening test which show resistant reactions in two successive seasons are then placed in the hybridization block where crosses are made to study their gene action and to incorporate the resistant genes into the dwarf breeding material. The best varieties are promoted to the International Bacterial Blight Nursery for testing in nine Asian countries.

All breeding lines and varieties which have one parent resistant to bacterial blight are systematically screened from the F_1 and F_2 generations through all generations in the pedigree nursery and in all yield trials. Heavy disease pressure applied in the screening for the F_1 generation of multiple crosses and F_2 and F_3 generations of all crosses allows most breeding lines to become homozygous resistant to bacterial blight by the time they reach the F_4 generation. This eliminates a large number of undesirable lines before they are carried to advanced generations and allows larger volumes of breeding populations to be grown.

By systematically screening all relevant breeding material, complete records can be kept to gauge progress made in breeding for disease resistance (fig. 9). Rapid progress has been made at IRRI during the past several years because



8. Systematic screening for bacterial blight resistance. Number screened during 1973 in ( ).



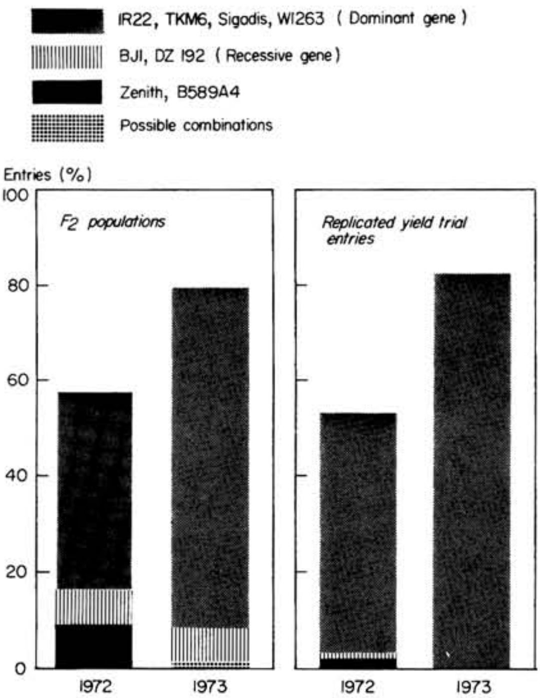
9. Percentage of breeding lines with resistance to bacterial blight, and hybrid crosses made with resistant parents.

many crosses have been made with at least one resistant parent and rigid selection has been made of progeny material. Thus the number of resistant breeding lines in the pedigree nurseries and advanced yield trials has increased rapidly.

Correlation continues to be high between disease scores from plants clip-inoculated and those exposed to natural infection. Only progeny lines from Zenith, Malagkit Sungsong, and B589A4 failed to show high correlation. Progenies from these varieties are screened by first clip-inoculating them, then blasting them 10 days later with a high-volume sprayer at 3,500 kg/sq m. The air blast, which simulates a typhoon, damages the leaves and natural spread of the disease results.

From studies currently under way at IRRI there appear to be at least three distinct sources of bacterial blight resistance. Most varieties (IR22, TKM 6, Sigadis, Syntha, and W1263) have dominant genes which appear to be at the same locus. Another group (BJ1 and DZ 192) have a recessive gene for resistance, but it is not yet known whether this gene is at the same locus. Progeny from a third group (Zenith, B589A4, and Malagkit Sungsong) seem to have an intermediate level of resistance, but the gene action is not yet clearly understood.

Although the gene action for bacterial blight resistance has not been determined for all varieties, it is possible to use the three groups to classify the current status of the IRRI breeding material. Most breeding lines in the breeding program have TKM 6, Sigadis, and IR22 as the source of bacterial blight resistance (fig. 10). During earlier years varieties such as Zenith and B589A4 were used to a limited extent as source of resistance, but because their resistance is only intermediate they are now being used less frequently. Since only BJ1 and DZ 192 have shown resistance to the Isabela strain of the bacterium from the Philippines, they are now being used more frequently in crosses. We hope that through a systematic crossing program, the various genes which give resistance to bacterial blight can be frequently used in the breeding material so that they are present in an equal



10. Source of bacterial blight resistance in early generation (F_2 populations) and advanced generations (replicated yield trial) of IRRI breeding material during wet seasons of 1972 and 1973.

proportion of advanced breeding material and future varieties. Crosses are also being made to combine the various genes into a single genetic background.

International bacterial blight nursery. IRRI coordinated the first and the second international bacterial blight nursery. The first nursery was conducted in 1972 in 15 locations in nine countries and the second in 18 locations in the same countries during 1973. Results from both years showed that several IRRI breeding lines and varieties with TKM 6 (IR20, IR26, IR1514A-E589, IR2061-464) and Sigadis (IR1487-194, IR1529-680) as the source of resistance had a good level of resistance in most countries. The broadest level of resistance, however, was expressed by BJ1 progeny lines from India.

Although these lines were resistant in most locations there was a definite indication that *X. oryzae* isolates in South Asia (Bangladesh and India) were more virulent than those from Southeast Asia (Indonesia, Malaysia, Philippines, and Thailand). Those from East Asia (Taiwan and Korea) appeared to be the least virulent.

New sources of resistance. During the year over 7,000 new germ plasm bank entries were screened for the first time. Of these 219 showed moderate to good resistance to bacterial blight and are now being rigorously screened several times to confirm their disease reaction.

Nearly 100 varieties which were first screened in 1972 continued to show good resistance to the Philippine isolates in 1973 (Table 3). Some varieties in this group may have distinct sources of resistance since they originated from several different Asian and African countries.

Virulence of Philippine isolates of ***X. oryzae.*** The virulence of 100 isolates of *X. oryzae* from four Philippine islands was evaluated. One isolate, Pxo 95, from Cauayan, Isabela, was highly virulent when tested on eight resistant test varieties (Table 4). It broke down the resistance of varieties which have a dominant gene for resistance (IR20, IR22, IR1529, and Pelita I/1). RP 291-7, RP 633(C), IR1545-339, and IR3264, which have recessive genes for resistance, remained resistant to the isolate.

A survey was made of the main rice-growing areas of southern Isabela Province, Philippines, to determine the distribution of the virulent strain. Diseased leaf specimens were systematically collected at 28 locations along the main roads. Inoculations of leaf extract and pure cultures of the bacterium from each specimen were made on IR20, RP291-7, IR1545-339, and IR8. Leaf extract bacterium and pure cultures from all locations were highly virulent on IR8, those from eight locations were intermediate to highly virulent on IR20, while none were highly virulent on RP291-7 or IR1545-339. All single-colony subisolates, collected from IR20 leaves inoculated with the strongly and weakly virulent strains, had the same virulence level as the original isolate inoculated to the leaves.

These results indicate that the "Isabela strain" is quite distinct and stable and that it is currently distributed in several areas of Southern Isabela. Observations made in farmers' fields, however, indicate that although the strain is capable of causing moderate to severe disease on IR20, it generally does not cause as much disease on IR20 as on susceptible varieties like IR8 and IR24.

Table 3. New varieties from the germ plasm bank with resistance to bacterial blight in the Philippines.

Designation	IRRI acc. no.	Origin
Arabi	14734	U.A.R.
ARC 6003	12174	India
ARC 6009	12293	India
ARC 7260	12346	India
ARC 7327	12368	India
ARC 7328	12369	India
ARC 10516	12495	India
Bageri	16193	Nepal
Bangaluwa	16263	Nepal
Bathkiriel	15212	Sri Lanka
Bitti Seke	15119	Ivory Coast
Blakka Tere Sakka	14787	Surinam
BW-196	15781	Sri Lanka
C 1345	15103	Madagascar
Chinsurah Boro I	11483	Japan
Dahanala	1502	Sri Lanka
Devasari	16173	Nepal
Doua H	15095	Zaire
Dudhi	16256	Nepal
Gaman	15121	Ivory Coast
Gukhue Saier	16195	Nepal
Halsudu Neenati	15599	Sri Lanka
Halsuduwee	15723	Sri Lanka
Heenati	15679	Sri Lanka
Item	14652	Indonesia
Japan Heenati C	15604	Sri Lanka
Japan Wee	15605	Sri Lanka
Jedish I	15179	Sri Lanka
Joseph Moyer	14909	Liberia
Kabre	14771	Ghana
Kahamalawee	15540	Sri Lanka
Kalu Alwee	15593	Sri Lanka
Kalu Illankayan	15586	Sri Lanka
Kalu Mudukiriyal	15221	Sri Lanka
Kalubalawee	15184	Sri Lanka
Karuppan	15508	Sri Lanka
Karuppu Seenadhi	15713	Sri Lanka
Katuwee	15589	Sri Lanka
Kirikunda	15558	Sri Lanka
Ku 43-1	14989	Thailand
Ku 43-2	14990	Thailand
Ku 68	15011	Thailand
Ku 71	15014	Thailand
Ku 78	15020	Thailand
Ku 83	15024	Thailand
Ku 115	15046	Thailand
Ku 131	15050	Thailand
Ku 279	15061	Thailand
Lal Ahu	16121	Nepal
Lal Sar	16185	Nepal
Lalaka Dadur	16255	Nepal
Madhukar	14781	India
Malalwariyan	15203	Sri Lanka
Mango	14749	Ghana
Marossourni	15084	Ivory Coast
Maturi	16187	Nepal
Mond-Ba	15813	Senegal
Murunga Balawee	15725	Sri Lanka
Murungawee	15498	Sri Lanka
Nakhi	16254	Nepal
No. 20	15606	Sri Lanka
OS 42	15176	Zaire
Patchaiperumal	15681	Sri Lanka
Perum Karuppan	15513	Sri Lanka
Race	15706	Sri Lanka
Rathu Balawee	15232	Sri Lanka
Rathu Heenati	15609	Sri Lanka
Rathkunda	15548	Sri Lanka
Redie Anaisa	14796	Surinam
Rerm Bilash	16273	Nepal
RT 1077	15093	Zaire
RT 1077-111a	15094	Zaire
1095	15107	Zaire
Sajani	16177	Nepal
Samanis	14797	Surinam
Sapin	15145	Ivory Coast
Sokan Dhan	16250	Nepal
Sudu Heenati	15749	Sri Lanka
Sudumalawee	15218	Sri Lanka
Sudumalawee	15248	Sri Lanka
Suduru Samba	14354	Sri Lanka
Suduwee	15580	Sri Lanka
Tally	16146	Nepal
Taothabi (M-163)	13146	India
Vella Kayan	15219	Sri Lanka
Wanni Dhanala	15721	Sri Lanka
Wanni Dasanala	15249	Sri Lanka
10-B	14827	Liberia
12-C	14870	Liberia
29-E	14876	Liberia
62-18	15097	Ivory Coast
62-77	15098	Ivory Coast
62-595	15177	Ivory Coast
63-105	15178	Ivory Coast
63-170	15114	Ivory Coast

Thus the threat of this strain may be relatively minor because it does not epidemiologically cause as much disease on IR20 and other similar resistant varieties as on susceptible varieties. We will, however, watch to see whether the virulent strain continues to spread and whether it does cause more severe disease outbreaks.

Virulence variability among Asian isolates of *X. oryzae*. To obtain further information on the interaction between rice varieties and bacterial isolates, the virulence of 51 isolates from various Southeast Asian countries was tested on 32 varieties. Thirty-day-old seedlings grown under carefully controlled greenhouse conditions were clip-inoculated with bacterial suspension adjusted to 0.4 optical density at 620 nm (about 10^8 viable cells/ml).

Among the tall varieties tested, BJ1, Chinsurah Boro II, Hashikalmi, Hom thong, Semora Mangga, and UCP-28 were highly resistant to

Table 4. Reaction of differential varieties and selections to Isabela and IRRI isolates of *Xanthomonas oryzae*.

Variety or selection	Parents[a]	Isolate from	
		Isabela	IRRI
	Dominant genes for resistance		
IR20	IR262/*TKM 6*	MS	R
IR22	IR8/Tadukan	MS	R
IR1529-680	*Sigadis*^{2}/TN1//IR24	MS	R
Pelita I/1	IR5/*Syntha*	MS	R
	Recessive genes for resistance		
IR1545-339	IR24/*DZ 192*	R	R
RP291-7	IR8/*BJ1*	R	R
RP633(C)	IR8/BJ1//*IR 22*	MR	R
IR3264	*BJ1*/O. nivara//IR773	R	R

[a]Variety name in italics is source of resistance.

most isolates (Table 5). Among the dwarf varieties, IR20, IR1514A-E666, IR1514-339, Ratna, and RP633(C) showed broad spectrum resistance. They were susceptible only to a few highly virulent isolates from South Asia. Varieties such as B589A4, Zenith, Lacrosse × Zenith-Nira, Laka, and others which were earlier considered moderately resistant were found to be susceptible to many of the isolates.

In some instances we found progenies to be more resistant than their resistant parents. For example, RP291-7 (IR8/BJ1) had a higher degree of resistance than BJ1, IR1545-339 (IR24/DZ 192) higher than DZ 192, and Ratna (TKM 6/IR8) and IR20 (IR262/TKM 6) higher than their resistant parent, TKM 6. This suggests the additive gene action in these varieties.

The isolates of *X. oryzae* exhibited wide variation in virulence. Pxo 46-1 from Isabela in the Philippines, H100 and H100S from India, PA3 from Bangladesh, PAxo 1 and PAxo 2 from Pakistan, were highly virulent and gave a susceptible reaction in several resistant varieties. H100S, a streptomycin-resistant clone of H100, was more virulent than the parent isolate. However, with Pxo 10, a weakly virulent isolate, the streptomycin-resistant clone (Pxo 10S) was less virulent than the parent isolate. Isolates like KD, Pxo 46-1, H100, PA3, PAxo 2, and PAxo 1, which were reported earlier as highly pathogenic, maintained their virulence even after long storage and many serial subcultures.

The study also confirms earlier findings that the interaction of the host and *X. oryzae* is generally not differential; resistant varieties are more resistant to all isolates, and weak isolates never attack severely the resistant varieties. We observed, however, a few cases in which some differential reaction among the resistant varieties and virulent isolates was evident. For instance, BJ1 was susceptible to H100 and resistant to PA3, whereas Nagkayat was resistant to H100 but susceptible to PA3. Also, BJ1 was susceptible to PAxo 2 and resistant to PA3, but IR20 was moderately resistant to PAxo 2 and susceptible to PA3. Varieties like BJ1 and Semora Mangga exhibited similar susceptibility patterns to those of H100, H100S, PAxo 1, and PAxo 2. Chinsurah Boro II and Hashikalmi also

Table 5. Susceptibility pattern of selected varieties resistant to 12 virulent isolates of *Xanthomonas oryzae*.

Variety	Avg suscept-ibility[a]	Mean lesion length (cm)											
		H100S	PAxo2	H100	PA3	C16	H14	Pxo46-1	Pxo 35	Ind 7-3	KD	B20-6	Vn-17
BJ1	2.7	18	24	13	3	2	3	3	2	4	2	1	1
Semora Mangga	2.8	21	15	12	4	2	4	3	1	2	1	2	2
Hashikalmi	3.1	19	19	17	11	3	3	1	4	3	1	2	3
Chinsurah Boro II	4.0	22	25	21	12	3	5	3	3	6	1	3	1
UCP-28	5.0	23	19	19	23	9	9	2	5	3	2	3	4
DZ 192	6.7	30	31	27	27	17	13	8	5	5	4	4	6
Remadja	5.4	21	9	18	17	8	4	11	7	13	1	5	9
Sigadis	6.8	23	10	19	24	8	7	21	6	16	2	6	10
TKM 6	6.0	16	10	15	18	14	5	12	3	5	13	12	5
M. Sungsong	7.4	15	18	8	14	13	7	24	15	11	22	7	10
Nagkayat	8.6	18	23	5	21	19	6	23	14	6	27	11	7
Wase Aikoku	5.7	17	15	4	12	9	9	8	10	8	16	6	4
Chukei	8.0	11	22	7	21	3	6	6	11	11	19	12	9
Hom thong	4.7	23	24	21	2	6	9	6	21	2	1	3	23

[a]Avg of reaction for 51 isolates.

showed similar reaction patterns to the above isolates but in addition, they were susceptible to PA3. DZ 192 had a similar susceptibility pattern to that of Chinsurah Boro II and Hashikalmi but in addition to the previously reported isolates, it was also susceptible to H14 and CL6. Varieties like Malagkit Sungsong, Nagkayat, and Wase Aikoku exhibited some degree of resistance to H100, but no variety was resistant to H100S (Table 5).

Physiological and biochemical variability in *X. oryzae*. In recent years, deviations from Ishiyama's original description have appeared with regard to several physiological and biochemical characteristics of *X. oryzae*. We studied these properties of 40 isolates of *X. oryzae* collected from various countries to find out whether distinct biochemical types exist and also to correlate pathogenicity with bacteriological properties. We found neither distinct biochemical types in *X. oryzae* nor correlation between pathogenicity and amounts of enzyme activities of various isolates. All isolates readily produced ammonia and hydrogen sulfide but not indole, hydrolysed gelatin but not casein or starch, reduced methylene blue but not nitrates, and they did not acidify milk or yield positive reaction in the methyl red test or acetoin production even after 2 weeks. All the isolates produced acid in various degrees from D(−)arabinose, D(−) galactose, D(+)glucose, D(−)fructose, D(+) mannose, and cellobiose, but few produced acid from D(+)xylose and sucrose and none produced acid from L(+)arabinose, L(+)rhamnose, D(−)ribose, L(−)sorbose, maltose, lactose, cellulose, starch, dextrin, inulin, glycogen, and sugar alcohols like sorbitol, mannitol, dulcitol, and glycerol. We also noticed growth inhibition. Organic acids of tricarboxylic acid cycle were readily utilized and glucose was not fermented. The *X. oryzae* isolates exhibited cellulase (Cx) activity, pectolytic activity and lipase activity, produced phospatase but not sulphatase and utilized uric acid but not urea. Among the isolates, Pxo 10, a weakly pathogenic isolate, showed strong gelatin liquefaction.

Differentiation of *X. translucens* **f. sp.** *oryzicola* **and** *X. oryzae*. Attempts were made to differentiate *X. translucens* f. sp. *oryzicola* and *X. oryzae* by specific enzymatic tests. Forty isolates of *X. oryzae* and 16 isolates of *X. translucens* f. sp. *oryzicola* were evaluated by standard bacteriological procedures (Table 6). Both the leaf streak and blight pathogens produced catalase, lipase, and hydrolysed aesculin but they yielded negative reaction for arginine hydrolase and decarboxylase, asparagine hydrolase, cytochrome oxidase, and urease. The isolates of leaf streak differed distinctly from blight isolates in producing phenylalanine deaminase 1 day after inoculation, and tyrosinase and β-glucosidase 4 days after inoculation. This provides another way to differentiate the two organisms in culture. Decolorization of lipid droplets, the browning of lesion and restriction of its development in the course of pathogenesis in leaf streak, suggests the possible role of the above three enzymes in host-parasite interaction.

Table 6. Some biochemical characteristics[a] of *Xanthomonas translucens* f. sp. *oryzicola* (bacterial leaf streak) and *Xanthomonas oryzae*. (bacterial blight).

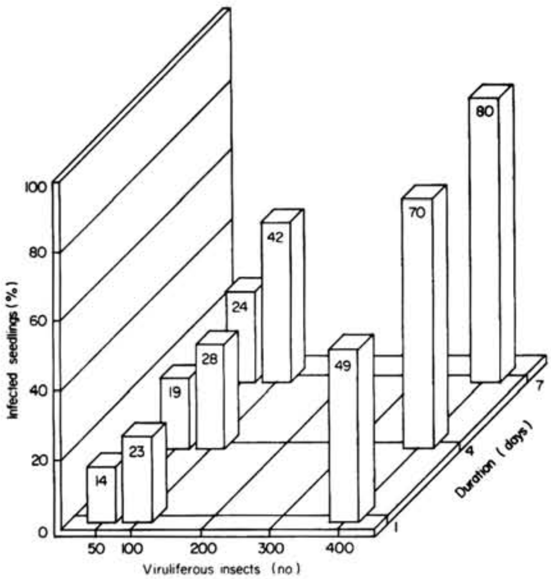
Test	*translucens* f. sp. *oryzicola*	*X. oryzae*
Aesculin hydrolysis	+	+
Catalase	+	+
Lipase	+	+
β-glucosidase	+	−
Phenylalanine deaminase	+	−
Tyrosinase	+	−
Arginine decarboxylase	−	−
Arginine hydrolase	−	−
Asparagine hydrolase	−	−
Cytochrome oxidase	−	−
Urease	−	−

[a]+ = positive, − = negative.

EPIDEMIOLOGY OF TUNGRO

Study of the epidemiology of rice tungro disease has been continued by using the cage method (1972 Annual Report) and by periodic collection and observation in farmers' fields in Luzon. The cage studies are experimental and emphasize influences on the percentage of infected seedlings. Studies in farmers' fields are statistical and focused on population of insect vectors, disease incidence, and stage of plant growth.

In cage studies, 152,400 seedlings and 88,200 insects of *Nephotettix virescens* were used to



11. Effect of number and duration of caged viruliferous *Nephotettix virescens* on the percentage of 31,273 seedlings (Taichung Native 1) infected by tungro.

determine the effect of factors such as number of insects, duration of insects confined in the cage, amount of virus source in the cage, and varieties on the percentage of infected seedlings. In addition, more than 25,000 seedlings were used to study the quality of virus source and the rate at which insects infect seedlings. Each experiment was conducted at least four times.

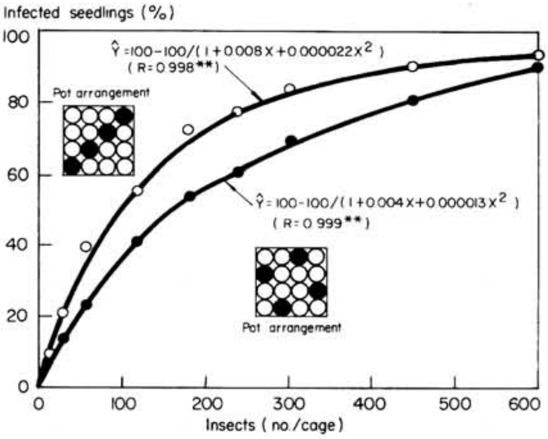
Viruliferous insects and infection. Confining viruliferoûs insects (insects which have been allowed to feed on diseased plants) on seedlings is a method of inoculating seedlings with a virus that is transmitted by the insect. The seedlings will become infected unless the insects are not infective (some insects may not have acquired the virus or may not be able to transmit the virus). But the number or the percentage of infected seedlings depends upon several factors such as number of insects per seedling, how long the insects are confined on the seedlings, movement of the insect, location at which the insects are released, and the direction of sunlight. To determine the quantitative variation due to number of insects and duration of confinement, we confined different numbers of viruliferous insects in cages containing 400 seedlings in 16 pots per cage for different number of days. Of over 31,000 seedlings tested, 35 percent became infected.

The more viruliferous insects there were in the cage and the longer the insects were confined in the cage, the greater the percentage of infected seedlings was (fig. 11). But increasing the number of insects did not increase the percentage of infected seedlings at the same rate as prolonging the duration. The rate was 0.38% infected seedlings per insect for the first 50 insects, 0.24% for the second 50 insects, and 0.12% for 101 to 400 insects. Thus, the rate decreased gradually as the number of insects in the cage or the number of insects per seedling increased. On the other hand, the confinement of the insects in the cage was rather steady except for the first day. The rate was 28.5% infected seedlings for the first day, 3.40% for the second to the fourth day, and 3.23% for the fifth to the seventh day.

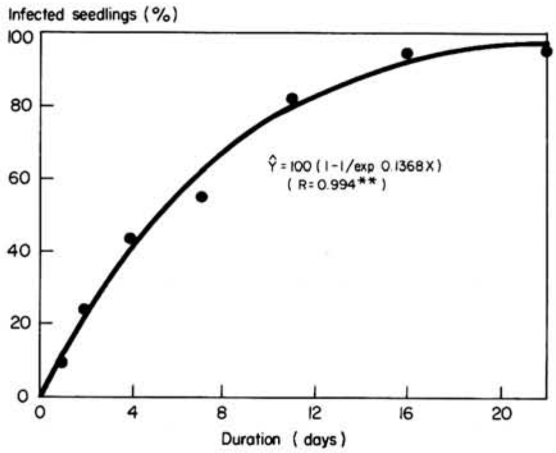
Because the percentage of infected seedlings did not increase at a constant rate, the relative importance of the number of insects and the duration of confinement of the insects varied. But, overall, one additional day of confinement was equivalent to about 25.5 additional viruliferous insects per cage or about 0.06 insect per seedling in increasing the percentage of infected seedlings.

The point at which the viruliferous insects were released into a cage affected the percentage of infected seedlings slightly. The insects introduced at the center of the cage gave 35 percent infected seedlings while those introduced at the corner gave 32 percent. The distribution of infected seedlings in the cage was strikingly different, however. When the insects were released at the center of the cage, the infected seedlings were more evenly distributed in the cage. When the insects were released at a corner of the cage, the percentage of infected seedlings per pot decreased with increasing distance from the point where the insects were released.

The direction of sunlight at the time the viruliferous insects were released into the cage did not affect the percentage of infected seedlings. But the infected seedlings were more evenly distributed when the insects were released at the side of the cage facing the sun than when they were released at the opposite side.



12. Effect of number of adult *Nephotettix virescens* in cage of 16 pots containing four pots of diseased plants in two arrangements on the percentage of tungro-infected seedlings (Taichung Native 1) after 7 days (closed circles indicate position of virus source in each arrangement: 10,000 seedlings tested in each arrangement).



13. Effect of duration of 180 adults of *Nephotettix virescens* confined in the cage of 16 pots containing four pots of diseased plants on the percentage of 7,467 seedlings (Taichung Native 1) infected by tungro.

Number of insects and infection. The transmission of the virus depends upon the insect vectors because the virus itself cannot move or spread from one plant to another in any other way. Consequently, the population of the insects is a major factor in the spread of the disease. Since the tungro virus does not persist in the vectors, the infective insects become noninfective after a time. The insects must reacquire the virus from diseased plants to become reinfective. Hence, the availability of virus source in a field is a major factor affecting the spread of the disease. Furthermore, the duration and activity of the insects in a field also affect the spread of the disease. These factors interact. To study the effect of the number of insects on the percentage of infected seedlings, we confined 0 to 600 insects in a cage containing 12 pots of 25 seedlings each and four pots of diseased plants for 7 days.

The percentage of infected seedlings increased as the number of insects increased (fig. 12) but not at a constant rate. In general, the fewer the insects, the higher the rate of infection per insect but the highest rate per insect was obtained with 15 to 30 insects. Over 180 insects per cage or 0.6 insect per seedling are required to get more than 60 percent infected seedlings in the cage within 7 days.

The arrangement of virus source in a cage affected the percentage of infected seedlings. Comparatively speaking, when pots of diseased plants were placed at the second position of each of the four outside rows (fig. 12), the percentage of infected seedlings should be slightly higher than with the virus sources placed diagonally in the cage. But, using over 10,000 seedlings for each arrangement, we obtained reverse results: 42 percent infected seedlings from the former and 52 percent from the latter. The reason could be the differential mortality of the insects because we used different colonies of insects for the experiments. The mortality of the insects at the end of the experiment was 37 percent for virus source arranged diagonally in the cage and 62 percent for the virus source arranged at the side rows. This illustrates the effect of mortality on the efficiency of transmission, and its independence of the number of insects.

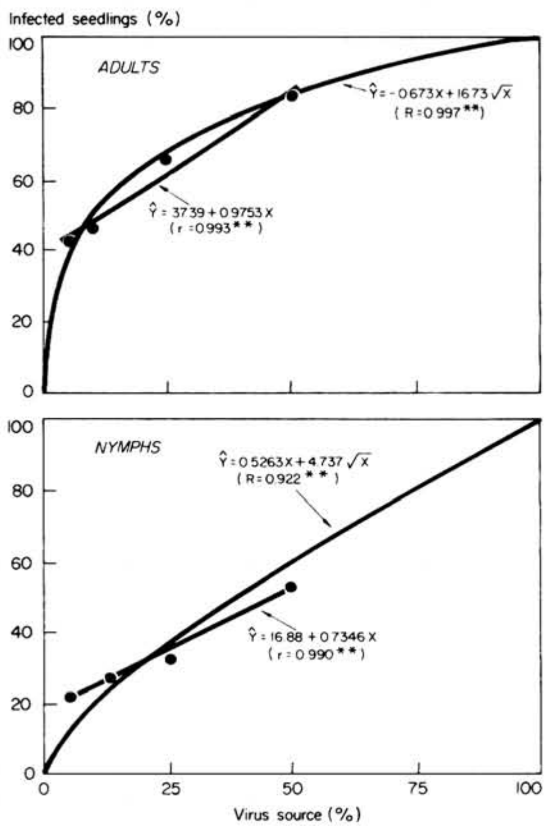
Duration and infection. How long insects are in a field affects the spread of the disease. We confined 180 *N. virescens* adults for 1 to 22 days in a cage containing 300 seedlings in 12 pots and four pots of diseased plants that were placed at the second position of each of the four outside rows. We used nearly 7,500 seedlings; 55 percent became infected.

The percentage of infected seedlings rose, the longer the insects were in the cage (fig. 13). The increase, however, was not proportional to the duration. The highest rate obtained was 15.6 percent infected seedlings per day from 1 to 2 days, although the equation indicated that the highest rate was 13 percent per day from 0 to 1 day. The rate decreased with time.

The results also show that the insects can complete the transmission of the disease within a day. The insects used for experiment were originally virus free and some seedlings were infected within 1 day after the insects were confined.

Virus source and infection. Since the tungro virus does not persist in the insect vectors, the quality, quantity, and location of the virus source (diseased plants) in a field affect the spread of the disease.

Quality of virus source. Not all diseased plants are equally good sources of the virus for the insect (1972 Annual Report). The quality of the



14. Effect of amount of virus source (percentage of pots of diseased plants in the cage of 16 pots) on the percentage of tungro-infected seedlings of Taichung Native 1 (180 *Nephotettix virescens* caged for 7 days) (4,373 seedlings for adults, 3,940 seedlings for nymphs).

virus source refers to the percentage of insects becoming infective after acquisition feeding on diseased plants of different kinds. In a study with over 4,100 insects, 22% were infective after feeding on diseased C4-63G plants; on IR20, 23% were infective; on IR22, 81% were infective; and on Taichung Native 1, 84% were infective. Consequently, IR22 and Taichung Native 1 are better virus sources than C4-63G and IR20.

Subsequent to inoculation, if *N. virescens* fed on a diseased plant, the plant became a better virus source for other *N. virescens* than diseased plants of the same age at the same number of days after inoculation but without subsequent insect feeding. The reason is not clear. In tests with nearly 1,500 insects, 80 percent became infective after an acquisition feeding on diseased plants of Taichung Native 1 that had been previously fed on by insects for 7 days, while only 73 percent of nearly 1,500 insects became infective after they had an acquisition feeding on diseased plants that had never been exposed to insects after inoculation.

Nitrogen level in culture solution did not alter the quality of virus source. Allowing about 3,900 insects an acquisition feeding on diseased plants growing in culture solutions with 5, 10, 50, 100, or 300 ppm N from 2 to 18 weeks after inoculation gave a range of only 85.2 to 86.2 percent infective insects, indicating practically no difference among the treatments.

Quantity of virus source. To determine the effect of the quantity of the virus source on the percentage of infected seedlings, we confined 180 insects in a cage for 7 days. Since the cage accommodates only 16 pots, we placed 1, 2, 4, and 8 pots of diseased plants together with, respectively, 375 seedlings in 15 pots, 350 seedlings in 14 pots, 300 seedlings in 12 pots, and 200 seedlings in eight pots. When adult insects were used for the experiment, 57 percent of 4,400 seedlings became infected, and when nymphs were used, 31 percent of 3,900 seedlings became infected.

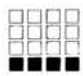
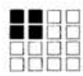
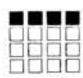
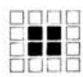
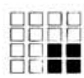
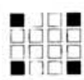
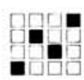
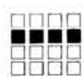
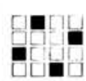
The more pots of diseased plants in the cage, the greater the percentage of infected seedlings was, regardless of the growth stage of the insects used for the experiment (fig. 14). Within the range of the tested amount of virus source, 6 to 50 percent (one to eight pots of diseased plants in a cage of 16 pots), the percentage of infected seedlings seemed to be proportional to the amount of the virus source (with adult insects, the average rate was 0.98% for each 1% increase in number of pots of diseased plants in the cage, while with nymphs the rate was 0.73% for each 1% increase in diseased pots). In figure 14, curves have been drawn through two theoretical points, zero percent infection and 100 percent infection, in addition to the points experimentally obtained. Zero infection would occur if no disease source were placed in the cage; 100 percent infection would occur if all the plants placed in the cage were infected. The curves thus drawn show that the proportion of infected seedlings does not have a straight-line relationship to the amount of virus source in the cage.

Location of virus source. The effect of location of virus source on the spread of the disease is obvious because if the diseased plants are beyond the distance that can be reached by the insects, the diseased plants could not contribute to the spread of the disease. Due to the limited size of the cage, we studied the location of virus source by placing four pots of diseased plants in various arrangements in a cage with 300 test seedlings in 12 pots and 180 adult *N. virescens* for 7 days. Of 1,820 ways to arrange four pots in a cage of 16 pots, we tested only 10 arrangements. Over 11,000 seedlings were used and 44 percent became infected.

Depending on the arrangement, 29 to 58 percent of the seedlings in the cage became infected (Table 7). The difference in percentage of infected seedlings seemed to be affected by differences in source of light in relation to the location of virus source in the cage as well as to the distance between pots of virus source and pots of test seedlings. For instance, the difference in percentage of infected seedlings between arrangements 1 and 3 (Table 7) was due to the direction of light source in relation to the location of virus source: the diseased plants placed in the bright side of the cage gave a higher percentage of infected seedlings. The difference between arrangements 3 and 9 was apparently due to the number of pots of seedlings adjacent to the pots of diseased plants (Table 7). The more pots of seedlings adjacent to the pots of diseased plants, the higher the total infected seedlings.

Neither the amount of virus source nor the location of the virus source could restrict the distribution of infected seedlings to a certain portion of the cage. Although the infected seedlings were scattered in the cage, the percentages of infected seedlings in different portions of the cage were different. The pots adjacent to the diseased plants generally had higher percentages of infected seedlings than other pots regardless of stages of the insects confined in the cage. For

Table 7. Infected seedlings of Taichung Native 1 in cages with different arrangements of virus source and 180 adults of *Nephotettix virescens* for 7 days.

Arrangement no.	Location of pots of diseased plants in cage[a]	Seedlings tested (no.)	Tungro-infected seedlings (%)	Variance[b]
1		1110	28.8	11.7
2		1120	41.3	11.9
3		1122	41.4	17.6
4		1126	41.7	5.8
5		1111	42.1	6.3
6		1138	46.3	2.3
7		1141	47.2	4.5
8		1138	47.9	4.3
9		1142	49.2	12.0
10		1119	57.6	1.5

[a]Light source was from the top in the drawings. [b]After converting to a total of 100 percent.

instance, with adult insects, when one pot of diseased plants was placed in the cage, 60 percent of 1,400 seedlings in the eight pots adjacent to the diseased plants became infected, while only 40 percent of 1,200 seedlings in the remaining seven pots in the cage became infected. When nymphs were used, 22 percent of 1,400 seedlings in pots adjacent to the diseased plants became infected compared with 12 percent of 1,200 seedlings for the rest of the pots in the cage.

When four pots of diseased plants were arranged diagonally in the cage (arrangement 7 in Table 7), 58 percent of 12,500 seedlings of Taichung Native 1 became infected. The six pots adjacent to the pots of diseased plants had 64 percent infected seedlings, the four pots that were the next closer to the virus source had 56 percent infected seedlings, and the two pots farthest from the virus source had 47 percent. The differences were statistically significant.

When four pots of diseased plants were placed at the second position of each of the four outside rows (arrangement 10 in Table 7), 56 percent of 24,500 seedlings of Taichung Native 1 became infected. The four pots in the center of the cage had 58 percent infected seedlings and the other eight pots in the cage had 53 percent. Of the latter eight pots, the four pots at the corners of the cage had 52 percent infected seedlings while the other four had 57 percent.

Results with other rice varieties were similar. Forty-four percent of over 48,000 seedlings of rice varieties and lines, including Taichung Native 1, became infected. Seedlings in pots in the center of the cage had 47 percent infection, seedlings in pots at the corners of the cage had 40 percent infection, and test seedlings in the other pots had 44 percent infection.

The pots at the corners of the cage had the lowest percentage of infected seedlings probably because the pots were adjacent to only one pot of diseased plants and half of them were away from the light source: the two pots nearer the light source had 44 percent infected seedlings while the other two pots had only 35 percent.

Virus source versus number of insects. In experiments discussed above we confined 180 insects in a cage to study the effect of amount of virus source on the percentage of infected seedlings. That means the number of insects per test seedling varied because the more pots of diseased plants in the cage, the fewer the test seedlings. Consequently, there was 0.48 insect per test seedling with one pot of diseased plants in the cage, 0.51 with two pots, 0.6 with four pots, and 0.9 with eight pots.

So to study the effect of amount of virus source at a constant number of insects per seedling (0.6), we confined 225 insects in a cage with one pot of diseased plants, 210 insects with two pots of diseased plants, 180 insects with four pots of diseased plants, and 120 insects with eight pots of diseased plants. With adult insects confined in the cage for 7 days, 71 percent of 4,190 seedlings became infected, while with nymphs, 21 percent of 4,400 seedlings became infected.

The percentage of infected seedlings obtained with adult insects was not raised by increasing the number of pots of diseased plants from 4 to 8 (Table 8). Hence, once the amount of virus source reaches a certain level, the number of insects in the cage is more important in increasing the percentage of infected seedlings. On the other hand, when nymphs were used for the experiment, raising the amount of diseased plants from two to four pots in the cage balanced the decrease in number of insects from 210 to 180, as shown by the unchanged percentage of infected seedlings. But further increasing the diseased plants from four to eight pots increased the percentage of infected seedlings, although the number of nymphs was reduced from 180 to 120 in the cage. Consequently, the maximum levels of virus source for highest percentage of infection by adults and nymphs may not be identical. With nymphs, the amount of virus source may be more important in the spread of the disease than the number of insects. With more diseased plants, the distance between them and the test seedlings in the cage is shorter, so it may be easier for the nymphs, which cannot fly, to spread the disease.

Infection by adults and nymphs. Although nymphs of *N. virescens* can transmit the tungro virus regardless of their stage of development, they have at least two physical and physiological defects in spreading the disease compared with adults. Nymphs cannot fly, so the distance they can traverse to reach a diseased plant to acquire the virus or to reach a healthy plant to introduce the virus is shorter than the distance that an adult can traverse. Within its range, the nymph should take longer to traverse a given distance than the adult. Hence, the nymph should move between diseased and healthy plants less frequently than the adult per unit time. Furthermore, the longer the time after acquisition feeding, the lower the infectivity of the insects, so the nymphs should tend to be less infective by the time they reach another plant. But when the distance between the insect and the plant is shorter than the distance of one jump of the nymph, the difference in spread of the disease between the nymph and the adult will be small.

The other defect of the nymph in spreading the disease is that during molting the insect is practically inactive, so it cannot spread the disease. In addition, molting ends the infectivity of the insect. The insect only becomes infective again after another acquisition feeding on diseased plants. On the other hand, the adult cannot spread the disease during mating, and the female cannot spread it while laying eggs.

As shown in figure 14, the adults gave a much higher percentage of infected seedlings than the nymphs (although the experiments were not made on the same dates). The adults also had a higher percentage of infected seedlings per 1 percent of diseased plants than the nymphs. In 10 tests with the same treatments made on the same dates, nymphs infected 8 to 34 percent (average: 20%) of 10,800 seedlings while adults infected 33 to 84 percent (average: 63%). Consequently, the adults were about three times more efficient in spreading the disease than the nymphs.

Number of seedlings per pot and infection. The activity of the insects in spreading the disease may vary with the total number of insects within a given area. For instance, when several insects are feeding on a leaf and one of them moves out or another one moves in, that may induce the others to move. Frequency of movement should affect the spread of the disease. When few insects are in an area, the movement of insects is less disturbing and that could also affect the spread of the disease. We therefore attempted to

Table 8. Effect of number of *Nephotettix virescens* and amount of tungro virus source on percentage of infected seedlings of Taichung Native 1 in a cage containing 16 pots.

Pots of diseased plants	Insects (no./cage)	Infected seedlings (%)	
		Adults	Nymphs
1	225	59	13
2	210	73	20
4	180	79	20
8	120	76	29

determine if differences in the total numbers of insects in a cage, maintaining a fixed ratio of insects to seedlings, causes any difference in disease spread.

We used 1 to 25 seedlings per pot and 12 pots per cage with four pots of diseased plants. The number of diseased plants in a pot was matched to the number of test seedlings per pot. We used 0.6 insect per seedling for all treatments, giving 8 to 180 insects per cage, depending on number of seedlings per pot. Since the number of seedlings per cage for one and two seedlings per pot was too small for reliable results, we used two extra cages for these two treatments. We used about 2,100 seedlings and 56 percent became infected. With 1, 2, 5, 10, and 25 seedlings per pot, 35, 44, 50, 66, and 57 percent of the seedlings, respectively, became infected. Thus the percentage of infected seedlings was related to the number of insects in the cage. The percentage of infected seedlings increased as number of insects per cage increased up to 72 in a cage with 120 seedlings (10 seedlings/pot). Further increase resulted in a slightly lower percentage of infected seedlings.

Watering seedlings and infection. Since inducing the insects to move from one plant to another would increase the spread of the disease, any agent, artificial or natural, that induces the insects to move should increase the percentage of infected seedlings in the cage. It is, however, difficult to standardize and to maintain the movement of the insects. Sometimes, we obtained variable results among the replications of the treatments tested by the cage method. One possible cause of the variation is watering the pots which may disturb the insects, inducing them to move. To determine the effect of watering the seedlings on the percentage of infected seedlings, a set of pots were submerged in a tank so the seedlings needed no watering for 7 days. Another set of pots received watering as usual. With the adult insects in the cage, 62 percent of 3,800 seedlings with watering became infected while without watering, 51 percent of 3,500 seedlings became infected. With nymphs in the cage, 27 percent of 3,700 seedlings with watering became infected, and without water 11 percent of 3,500 seedlings became infected. Therefore, watering increased the percentage of infected seedlings regardless of the stages of the insects in the cage and watering had greater effect on increasing the percentage of seedlings infected by nymphs than on increasing the percentage of seedlings infected by adults.

Infected seedlings per insect per day. A viruliferous insect cannot inoculate a seedling instantaneously. Previously, we reported that 7 minutes was the shortest duration of proven inoculation feeding obtained at the IRRI. In that experiment we exposed 42 seedlings to individual viruliferous insects for 1 to 7 minutes. We also reported that within a certain time range, the longer the inoculation feeding period, the higher the percentage of infected seedlings. Thus shortening the inoculation feeding period would result in a lower percentage of infected seedlings, but a greater number of seedlings that could be inoculated by an insect in the given time period.

To determine the maximum possible number of seedlings an insect can infect in 10 hours, viruliferous insects were transferred individually and serially to seedlings at intervals of 5, 10, 15, 30, and 60 minutes during 1 day from 0800 to 1800 hours. Ten thousand seedlings were exposed to 257 viruliferous insects. Only 118 infective insects lived through the 10 hours. They infected 460 out of 5,114 seedlings. The other 4,886 seedlings died before symptoms developed, or were exposed to non-infective insects, or were inoculated by insects that died before the 10-hour testing period was completed.

The percentage of infected seedlings varied among individual insects regardless of the length of inoculation feeding period. However, the maximum, minimum, and average percentages of infected seedlings increased, the longer the inoculation feeding period was (Table 9). The number of infected seedlings per insect in the 10-hour period also increased as the inoculation feeding period increased up to 30 minutes. Increasing the feeding period to 60 minutes resulted in a lower rate of infected seedlings, however. Hence, the highest rate of infected seedlings was obtained from insects that were transferred to seedlings at 30-minute intervals.

The number of seedlings that can be inoculated by an insect in a 24-hour day can be calculated assuming that the infectivity of the insects during the first 10-hour period stays unchanged for the rest of the day. The minimum number of infected seedlings per insect per day was 2.4 to 2.6 (fig. 15). The theoretical minimum should be 2.4 regardless of length of inoculation feeding period because one infected seedling in the 10-hour period is the minimum number possible, otherwise the insect cannot be considered infective. The deviation of obtained figures from the theoretical was due to the mortality of the seedlings.

For transfer intervals of 5 to 60 minutes the maximum number of infected seedlings per insect per day ranged from 15.6 to 30.3 (fig. 15). Thus at most, an infective *N. virescens* can infect only about 30 seedlings a day. And

Table 9. Effect of inoculation feeding period of viruliferous *Nephotettix virescens* on percentage and number of tungro-infected seedlings of Taichung Native 1 in a period of 10 hours.

Inoculation feeding period (min)	Infective insects (no.)	Seedlings exposed (no./insect)	Total seedlings exposed (no.)	Infected seedlings (%)			Infected seedlings (no. • insect^{-1} • 10h^{-1})
				Max	Avg	Min	
5	21	120	2415	5	2	1	2.2
10	17	60	984	19	7	2	4.2
15	26	40	986	31	12	3	4.4
30	23	20	441	63	24	5	4.7
60	31	10	288	90	41	10	3.8

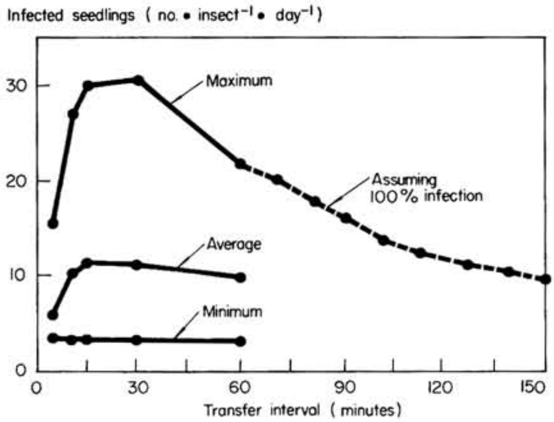
transferring every 30 minutes gives the highest number of infected seedlings per insect per day. But the difference in number of infected seedlings among transfer intervals of 10, 15, and 30 minutes was not striking. Prolonging the transfer interval would increase the percentage of infected seedlings but reduce the number of seedlings that can be inoculated by an insect in a day. Even assuming 100 percent infection, when the transfer interval is longer than 60 minutes, the number of infected seedlings per insect per day decreases gradually with increasing time between two transfers because the possible number of seedlings that can be inoculated by an insect in a day decreases (fig. 15).

The average number of infected seedlings per insect per day was 5.8 at the transfer interval of 5 minutes and 9.7 to 11.5 at the transfer intervals of 10 to 60 minutes. Hence, except for the transfer interval of 5 minutes, an infective insect can infect an average of only 10 to 12 seedlings with tungro in a day.

Determining the minimum time required by an infective insect to transmit the tungro virus to a seedling is difficult because the percentage of infected seedlings decreases as the length of inoculation feeding period declines. The only direct evidence that demonstrates positive transmission is infected seedlings. We exposed 4,800 seedlings to 71 viruliferous insects at 5-minute intervals. Excluding 197 seedlings that died before symptoms developed, 95 seedlings or 2.1 percent became infected from 41 insects. The number of infected seedlings per insect varied from one to seven. Thus, the shortest proven inoculation feeding period of tungro-infective *N. virescens* is 5 minutes.

This experiment also showed that transferring *N. virescens* from seedling to seedling with an aspirator damages the insect. Insects transferred at 5-minute intervals had 44% mortality; those transferred at 10-minute intervals had 26% mortality; at 15-minute intervals, 13% mortality; at 30-minute intervals, 9% mortality; and at 60-minute intervals, 5% mortality. Thus the more frequent the transfer, the higher the mortality of the insect is.

Varieties and infection. Susceptibility of a rice variety affects the spread or the incidence of the disease. To determine the variation in percentage of infected seedlings among rice varieties in the cage, we confined 180 adults in a cage with four pots of diseased plants of Taichung Native 1 and 300 seedlings of a test variety in 12 pots. Of over 11,000 seedlings, 37 percent became infected. With IR24, 17% of the seedlings became infected; with IR8, 23%; with IR5, 24%; with C4-63G, 27%; with IR20, 43%; with IR22, 62%; and with Taichung Native 1, 86%.

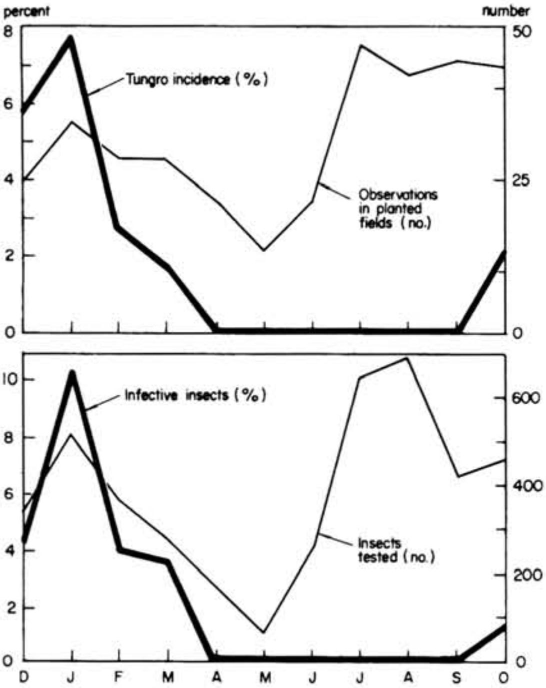


15. Calculated number of tungro-infected seedlings of Taichung Native 1 by an infective *Nephotettix virescens* having different transfer intervals in a 24-hour day (assuming that the infectivity of the insects in the first 10-hour period remains unchanged for the rest of the day).

We similarly tested seven IRRI lines and IR26. Except for IR2061-213-2 which had five replications, the test had six replications. We tested 12,300 seedlings and 32 percent became infected. These lines were also tested by the mass screening method with six replications—41 percent of 3,400 seedlings became infected. Regardless of method of testing IR1514A-E597-2, IR1541-76-3, IR2061-213-2, and IR2061-464-4 had low percentages of infected seedlings while IR1561-228-3 had the highest (Table 10). In general, the mass screening method gave a higher percentage of infected seedlings than did the cage method. These results illustrate the effect of varietal differences in susceptibility on the percentage of infected seedlings.

TUNGRO VECTORS AT THE IRRI FARM

Collecting insect vectors of rice tungro virus was continued in 1973. Collections were made every Tuesday evening from 1700 hours to 2 hours



16. Incidence of rice tungro disease and percentage of infective *Nephotettix virescens* in the survey sites.

after sunset except the collection scheduled for October 30, which was made on the following day. We collected 13,300 adults of *N. virescens*, 8,700 adults of *N. nigropictus*, and 1,900 adults of *Recilia dorsalis*. The largest number of insects in a single light trap was 5,700 *N. virescens*, 3,600 *N. nigropictus*, and 700 *R. dorsalis* on August 28. Less than 20 insects were trapped on 3 days in January, 1 day in April, 2 days in May, 1 day in June, 2 days in July, 1 day in September, 3 days in October, and 3 days in December. No insects were trapped on five of those days.

A portion of the trapped insects were tested for infectivity by daily serial transfers for 3 days. Of 1,640 insects of *N. virescens*, 1,380 insects of *N. nigropictus*, and 550 insects of *R. dorsalis*, less than 2 percent of any species was infective.

TUNGRO IN LUZON

The epidemiology of rice tungro disease has been studied not only by the cage method but also by periodic collection and observation in farmers' fields in Central Luzon and Laguna province. In December 1972, 11 fields were selected for the study. We increased the number of fields in the survey as our proficiency in collecting insects and testing their infectivity improved so that by October 1973, 26 fields were being surveyed. Two of the fields were in Laguna province, 10 in Bulacan, 3 in Nueva Ecija, 5 in Pampanga, and 6 in Tarlac.

Table 10. Tungro-infected seedlings of rice lines as tested by two methods.

Line	Infected seedlings[a] (%)	
	Cage method	Mass screening method
IR1541-76-3	20 a	26 a
IR2061-213-2[b]	24	26 a
IR1514A-E597-2	25 ab	19 a
IR2061-464-4	27 ab	26 a
IR26	30 abc	45 b
IR1529-680-3-2	32 bc	52 b
IR442-2-58	37 c	65 c
IR1561-228-2	58 d	84 c

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Not included in statistical analysis because it had one replicate less than the other lines.

The method for the study was simple. We visited the fields once every other week, bringing seedlings of Taichung Native 1 with us in test tubes. At each field we first made 10 sweeps and placed the collected insects in a nylon bag to be grouped by species and counted on the following day. Then, if possible, 40 extra insects were collected from the field. They were immediately placed in the test tubes (one per test tube) unless, due to morning dew or rain, they were wet. If wet insects had been transferred immediately into the test tubes, the mortality would have been high, so instead we placed them in a nylon bag and transferred them to the test tubes 10 to 20 minutes later, by which time they were dry.

The number of insects collected from 10 sweeps was used to indicate the population level in the field and the infectivity of the insects placed in the test tubes was used to indicate the percentage of infective insects in the field.

Over 400 field observations were made from December 1972 to October 1973. Forty-three observations were on seedbeds, 142 on rice plants in the vegetative stage, 101 on the rice plants in the reproductive stage, 60 on regenerated rice stubble, and 60 on idle or plowed fields. In March, April, May, June, and July, 3, 32, 67, 33, and 4 percent of the fields respectively, were

Table 11. Average population of tungro vectors, proportion of infective *N. virescens*, and incidence of tungro, by variety in survey fields, Luzon, Philippines, December, 1972 to October, 1973.

Variety	Survey fields planted (%)	Insects (no./10 sweeps)			Infective *N. virescens* (%)	Tungro incidence (%)
		N. virescens	*N. nigropictus*	*R. dorsalis*		
Bencer	4.3	8	5	0.6	23.8	24.5
C4-63G	9.0	37	19	0.8	1.3	0.1
Intan	0.3	25	12	0.0	23.5	60.0
IR5	2.6	49	4	0.6	3.9	0
"IR12"	2.6	9	8	1.9	0	0
IR20	73.1	18	6	0.3	0.6	0.4
IR22	0.6	0	0	0.0	—	45.0
Other varieties	7.5	2	2	0.1	0	0

idle. The increase in the percentage of idle fields from March to May and the decrease from May to July was related to the dry-season period in Central Luzon in 1973. IR20 occupied three-fourths of the fields observed (Table 11).

Incidence of tungro disease. From December 1972 to October 1973, the average incidence of tungro disease was very low, 1.8 percent of 346 observations. There was no tungro disease in the field from April to September (fig. 16). The average incidence of the disease was highest in Tarlac (Table 12). Among the rice varieties, the incidence was highest on Intan (one observation) and IR22 (Table 11).

Some regenerated growth from rice stubble showed the symptoms of tungro disease. Most diseased stubble was diseased before harvest. The average incidence was 30% in January, 3% in February, 1% in March, and 0% in other months. The average was 1 percent.

Number of insect vectors. In 260 collections of 10 sweeps each, from December 1972 to October 1973, 4,806 *N. virescens*, 1,176 *N. nigropictus*, and 110 *R. dorsalis* were collected. The highest number of tungro vectors per collection was 453 for *N. virescens* in San Ildefonso, Bulacan, on September 18, 1973, and 203 for *N. nigropictus* and 9 for *R. dorsalis* in different fields in Gapan, Nueva Ecija, on December 12, 1972. Although the insects were usually present in the fields, the number of the insects was not constant throughout the period. There seemed to have been two peaks for *N. virescens*, one in January and one in September (fig. 17). The monthly average number of *N. nigropictus* varied from 3 to 17.

The population of insects was not identical in the five provinces. The average number of *N. virescens* per 10 sweeps was highest in Bulacan, *N. nigropictus* was highest in Nueva Ecija and Bulacan, and *R. dorsalis* was highest in Nueva Ecija (Table 12).

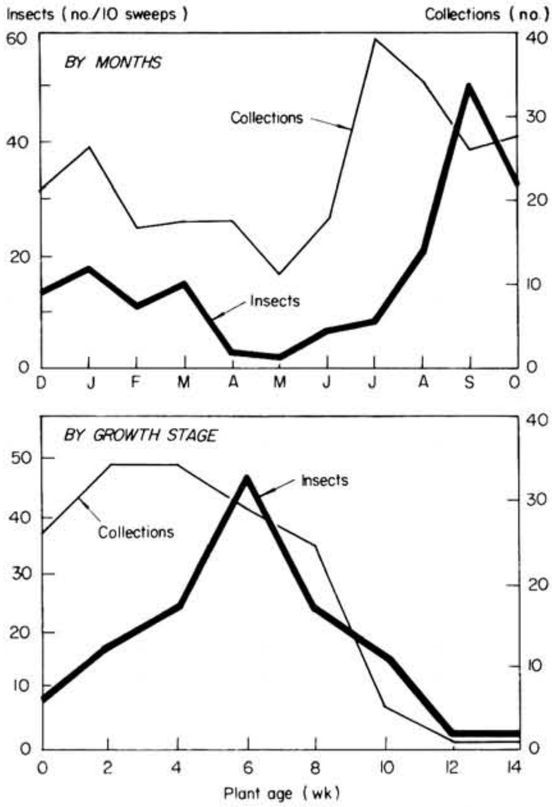
The number of collected insects also varied among rice varieties. The number of *N. virescens* was highest on IR5, *N. nigropictus* was highest on C4-63G, and *R. dorsalis* was highest on "IR12" (Table 11). The changes in number of *N. virescens* collected from IR20 at different stages of plant growth after transplanting followed a similar trend to changes in number of insects collected from all rice varieties in the survey sites (fig. 17).

In 42 collections in seedbeds, we gathered 908 *N. virescens*, an average of 22 insects per seedbed per collection. The insects were present in seedbeds during all months, except January and February, when we did not collect in seedbeds.

The insects were present on the regenerated growth of rice stubble after harvesting. In 58 collections from stubble, 177 *N. virescens*, 188 *N. nigropictus*, and 11 *R. dorsalis* were gathered. In general, regeneration of stubble was poor

Table 12. Average population of tungro vectors, number of infective *Nephotettix virescens*, and incidence of tungro in survey fields in five provinces, Luzon, Philippines, December, 1972 to October, 1973.

Province	Insects (no./10 sweeps)			Infective *N. virescens* (%)	Tungro incidence (%)
	N. virescens	*N. nigropictus*	*R. dorsalis*		
Bulacan	31	9	0.5	0.8	0.6
Laguna	4	4	0.6	0.8	0.1
Nueva Ecija	18	9	0.7	2.0	2.1
Pampanga	11	6	0.1	0.4	0.0
Tarlac	9	4	0.3	8.0	6.6



17. Number of *Nephotettix virescens* collected from rice plants in the survey sites (December 1972 to October 1973).

because of lack of water particularly from April to June.

Insect population and availability of food. Climatic conditions undoubtedly affect the population of the insect vectors in the field directly and indirectly. One of the indirect effects is "availability of insect food." That is, the amount of rice plants in the field depends on the climatic conditions, particularly in areas without irrigation in the tropics. Our survey provided evidence that "availability of insect food" has a critical effect on the population of the vectors in the field. A total of 3,700 *N. virescens* were found in 163 collections made from fields with rice plants, from transplanting to maturity at 2-week intervals (fig. 17). Regardless of the month of transplanting, the number of the insect increased with increasing age of rice plants from 0 to 6 weeks after transplanting. Thereafter, it decreased, although we were able to make only a few collections after flowering of the rice crop because of farmers' restrictions. If the population of the insect was directly related to the month, the number of insects would not follow the age of rice plants. Hence, the population increased with increasing vegetation (the rice plant), that is, with increase in insect food in the field.

On the other hand, the population of the insect is limited by the absence of insect food. In 99 insect collections made in Bulacan province, 3,100 *N. virescens* were collected (fig. 18). The population of the insect was low from March to June. The percentage of fields with rice plants during this period was also low due to lack of water. Although it is difficult to conclude that the low population of the insect in the field was caused by the direct effect of climatic conditions or lack of food for the insect, the indirect effect of climatic conditions, in our 9 years in Los Baños, there has been no difficulty in rearing *N. virescens* from March to June as long as the insects were provided with sufficient food plants. Hence, the climatic conditions of the period were less likely to be the direct limiting factors of the insect population than was the insect's food.

Infective insects. Infectivity ranged from 2.4 percent for 4,170 tested insects of *N. virescens*, to 0.1 percent for 2,120 *N. nigropictus*, to zero for 63 *R. dorsalis*. Based on infectivity as well as number of insects collected in the survey sites, *N. virescens* should be considered the major vector of tungro.

Infective insects of *N. virescens* were not distributed evenly throughout the period (fig. 16). From April to September 1973, none of 2,200 insects tested were infective. The percentage of infective insects seemed related to the incidence of tungro disease in the field (fig. 16). On a monthly basis whenever there was the disease there were infective insects, but with some exceptions. None of 94 insects from five collections from three survey sites with tungro disease were infective. And one of 25 insects from one collection in a site without the disease was infective (Table 13).

The proportion of infective insects of *N. virescens* was highest in Tarlac, and on varieties Bencer and Intan (Tables 11 and 12).

Infective insects were present in one seedbed. Four out of 31 insects collected from the seedbed were infective. The other 536 insects from 35 collections were non-infective. Infective insects were also present in regenerated rice stubble. Out of 145 insects collected from stubble with the disease, 31 were infective. And nine insects out of 35 collected from stubble without symptoms of the disease were infective (Table 13).

SCREENING FOR TUNGRO RESISTANCE

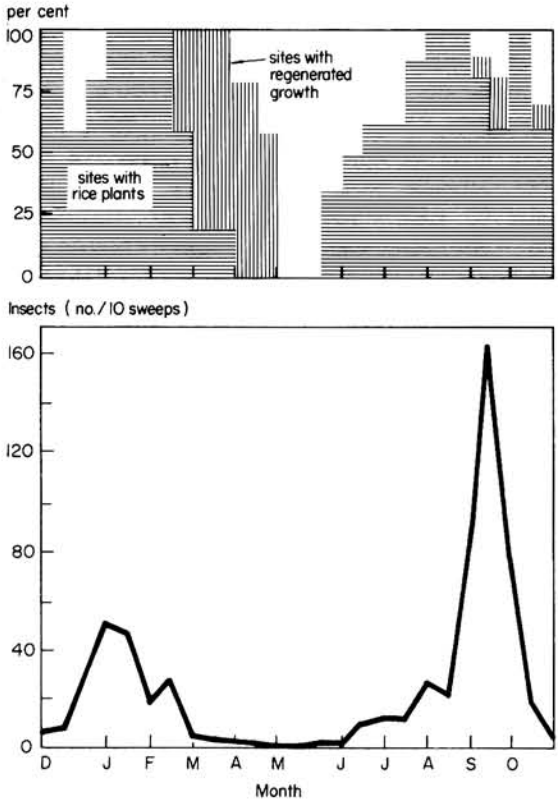
Screening for varietal resistance to tungro by the improved mass screening method (1972 Annual Report) has been continued. A total of 11,777 entries involving about 326,000 seedlings (3% for agronomy department, 26% for plant pathology department, 33% for plant breeding department, 3% for Philippine Atomic Research Center, 7% for University of the Philippines at Los Baños College of Agriculture, and 18% for experimental purposes) were tested in 1973. The entries included 1,171 varieties and selections. Of them 38 showed less than 30% infected seedlings (Table 14); 915, more than 61%; and the rest, 31 to 60%.

Taichung Native 1 and IR22 were compared for susceptibility by testing about 10,000 seedlings by the mass screening method. No significant difference in percentage of infected seedlings between the two varieties was found.

GRASSY STUNT

Screening for resistance. In continued mass screening for varietal resistance to grassy stunt, 5,738 entries involving about 133,000 seedlings (57% for plant pathology department and 43% for plant breeding department) were tested in 1973. None of the tested varieties were resistant, but 19 selections from the crosses IR1704, IR1721, IR1924, IR2031, IR2035, IR2037, IR2042, IR2061, IR2146, IR3265, and IR3273 were resistant. All of them have *Oryza nivara* in their parentage.

Outbreak in Laguna, Philippines. Grassy stunt, which is only transmitted by the brown planthopper (*Nilaparvata lugens*), has been a minor disease of the rice plant because it rarely occurred in farmers' fields in the past although it was a problem on farms on which rice was intensively cultivated. An outbreak of the disease occurred



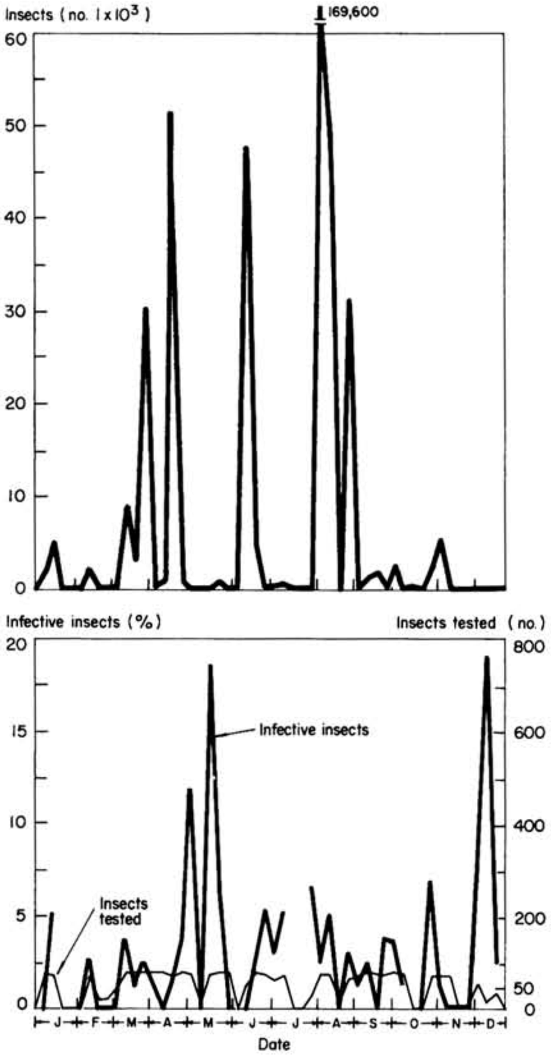
18. Number of *Nephotettix virescens* in the survey sites and percent of survey sites with rice plants and regenerated stubble in Bulacan.

in Laguna, Philippines in 1973. Based on a survey of the disease made in August, the disease was distributed widely in Laguna (Table 15). One-third of the 977 hectares of rice fields observed had diseased plants. The infected varieties were

Table 13. Infective *Nephotettix virescens* collected in the survey with and without tungro disease (December 1972 to October 1973).

Tungro disease	Sites (no.)	Collections (no.)	Insects	
			Tested (no.)	Infective (%)
Present	6	10	271	21
Present	3	5	94	0
Present	1	1	0	—
Absent	1	1	25	4
Absent[a]	1	1	31	13
Absent	25	168	3132	0
Present[b]	3	3	145	21
Present[b]	1	1	2	0
Absent[b]	2	2	53	17
Absent[b]	13	40	418	0

[a]Seedbed. [b]Regenerated rice stubble.



19. Number and percentage of grassy stunt infective insects of *Nilaparvata lugens* collected weekly by light trap in IRRI farm from 0500 hours to 2 hours after sunset (1973).

Table 14. Rice varieties and selections showing less than 30 percent tungro infected seedlings after being tested by the mass screening method. IRRI, 1973.

Designation	Tests (no.)	Seedlings Inoculated (no.)	Seedlings Infected (%)
ARC 6064	7	205	10
ARC 6104	4	70	26
ARC 6561	6	125	14
ARC 7104	2	59	25
Barah	4	95	22
Bengawan	4	110	28
C556-1	5	97	28
Gendjah melati	7	191	21
Habigonj DW#8	10	199	16
Intan	4	97	28
IR1487-194-5-3-2	8	228	29
-372-4	14	387	27
IR1514A-E597	4	98	28
-E597-2	20	531	19
IR1529-667-2-3	4	120	27
IR1541-76-3-65	20	504	27
-102-3	5	44	26
IR1702-158-3	4	116	24
IR1813-694-2	4	110	25
IR1818-1-19-2-2	4	98	28
IR1909-1-3-3	4	97	28
IR2031-114-2	4	110	26
IR2037-1-3	4	81	28
IR2049-104-2	4	111	27
-120-2	4	113	24
IR2061-125-12	5	118	25
-125-37	5	91	24
-213	5	135	26
-213-2	16	385	26
-281	5	135	27
-464-2	9	222	27
-464-4	21	499	28
Kataribhog	4	100	26
Ku 52	6	147	25
Mala	6	139	23
N 22	4	101	18
Pankhari 203	6	133	6
Remadja	4	119	24

C4-63G, Dague, IR5, "IR12," IR20, IR24, "IR253," "IR1561," Malagkit Sungsong, a selection of PARC, and unknown varieties. The outbreak of the disease was the result of an unusually high population of brown planthoppers in Laguna. About 6 percent of the survey area was severely damaged by the insect.

At the IRRI farm, we started collecting insect vectors by light trap in August 1972. In 1973, the light trap collection was made every Tuesday evening except that the collection scheduled for October 30 was made on the following day. The number of insects caught by the light trap may not reflect the actual population of the insects in the field because the light method has at least two defects. First, the light never catches the nymphs or the brachypterous form (with short or abbreviated wings) because they are unable to fly there. Second, climatic conditions affect the number of insects caught by the light trap although the exact conditions that prevent the migration of the insects to the light is unclear. Hence, catching few insects in the light trap may not reliably indicate a low population of the insect in the field. We observed the field occasion-

Table 15. Area of rice plants infected with grassy stunt, Laguna, Philippines August 15 to 16, 1973.

Town	Area	
	Observed (ha)	With grassy stunt (%)
Bay	120	51
Biñan	18	100
Cabuyao	20	66
Calamba	65	75
Los Baños	45	79
Mabitac	50	60
Pila	100	45
San Pablo	100	15
Santa Maria	25	72
Santa Rosa	40	65
Siniloan	100	12
14 other towns	294	0
Total	977	33

ally on the day following the light trap collection, and sometimes we found many insects in the field although few were caught by the light trap 12 hours earlier. But catching a large number of insects by the light trap should indicate a large population of the insect in the field as well as movement of the insect in the field. If this assumption is correct, the population of brown planthopper during 1973 was high even in March (fig. 19). The largest number of insects caught by light trap was 169,000 on August 7. In 1972, it was 25,300 on October 17.

Only 20 to 40 percent of brown planthoppers are active transmitters (1968 Annual Report) when the insects are allowed acquisition feeding on diseased plants and the insects are tested by daily serial transfer until their death. Hence, under natural conditions, the proportion of infective insects can not be extremely high. Of insects caught by the light trap in 1973, 0 to 19 percent were infective (fig. 19), with an average of 3.4 percent. From March to December, about three out of four collections contained infective insects, indicating the high frequency of infective insects in the field resulting from the outbreak of grassy stunt at the IRRI farm.

Plant breeding

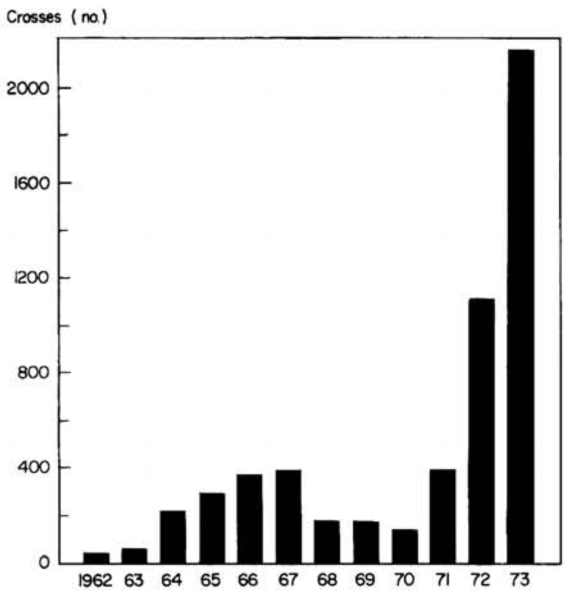
We named and released a new variety, IR26, for general cultivation. It is the first variety resistant to brown planthoppers to be named by the Institute. IR26 is also resistant to green leafhoppers and tungro, and bacterial blight diseases, and moderately resistant to stem borers, blast, and grassy stunt. Six IRRI lines were named as varieties in other countries. Several promising breeding lines with multiple resistance to all the major diseases and insects were evaluated in replicated yield trials. Four promising selections, IR2035-290-2, IR2061-214-3, IR2071-88, and IR2151-957-5, are being evaluated in large scale trials. ☐ A number of improved lines were identified which have two percent higher protein than does IR8 or IR20. Breeding work was accelerated on tolerance to problem soils and cool temperatures. The first International Rice Yield Nursery was distributed to 16 countries. ☐ Progress was made in incorporating the drought resistance and early maturity of upland varieties into plants with more tillers and shorter height. We developed a mass screening technique for evaluating breeding materials for resistance to drought. ☐ More than 2,500 seed samples of indigenous rices were collected for our germ plasm collection from four Southeast Asian countries in collaboration with national agencies. ☐ Brown planthopper resistant progenies were obtained from the cross of TKM 6 and other susceptible varieties. Genetic studies revealed that TKM 6 is homozygous for *Bph 1*, the gene for brown planthopper resistance, as well as for *I-Bph 1* which inhibits *Bph 1*.

BREEDING PROGRAM

The crossing program was further expanded during 1973 (fig. 1). More than 2,000 crosses were made, half of them either topcrosses (F_1 hybrid × line or variety) or doublecrosses (F_1 hybrid × F_1 hybrid).

We consider the capability for high-volume crossing essential to our breeding operations for several reasons. It increases the chances for desirable recombinations because it expands the volume of hybrid material and perpetuates heterozygosity through multiple crossing. Second, it facilitates diversification, which is basic to any breeding program that meets the challenges of nature and of changing agronomic practices. Finally, high-volume crossing allows breeders to discard entire crosses which lack good "combining ability" because many other crosses made for the same objective will be available.

Crossing is time consuming and laborious. The most tedious and limiting factor of the total operation is emasculation, or extracting the anthers from the florets. By the conventional method with fine forceps, an average technician can emasculate 300 florets in the first hour of work but efficiency soon drops off and he can emasculate fewer than 200 florets in the third hour.



1. Number of crosses in the IRRI breeding program.

We experimented with a vacuum extraction system for removing the anthers and found it much more efficient. With vacuum extraction, the average technician can emasculate about 500 florets during the first hour and about 350 during the third hour. Our overall average with vacuum extraction has been about 425 florets per man-hour, compared with about 250 per man-hour with forceps. The extractor consists of disposable capillary pipettes connected to a vacuum source by tygon tubing (fig. 2).

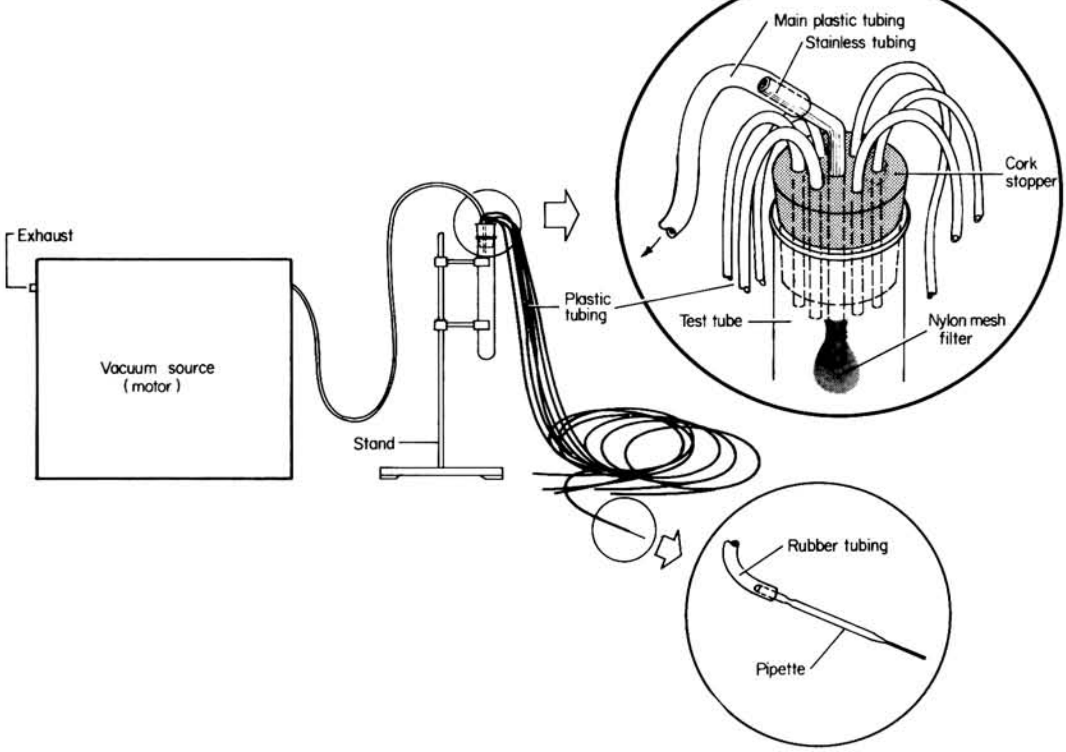
We grew 221 F_2 populations during 1973, a considerable increase over previous years. A total of 30,937 pedigree nursery rows were grown, most without any insecticide protection because they were resistant to brown planthoppers and grassy stunt disease. We evaluated more than 1,000 lines in replicated yield trials.

New variety. IRRI named its sixth variety, IR26, in October. IR26 (the experimental line IR1541-102-7) originated from a cross of IR24 and TKM 6 made in 1969. IR26 has clear, medium-long, slender grains which are comparable to those of IR20 in size and shape, but are more translucent (fig. 3). The amylose content of IR26 is from 26 to 29 percent, and its milling recovery is excellent.

IR26 is the first IRRI variety which is resistant to brown planthoppers. It is also resistant to green leafhoppers and moderately resistant to stem borers. It is resistant to bacterial blight and tungro diseases and moderately resistant to blast and grassy stunt. IR26 is the only IRRI variety with some resistance to grassy stunt (fig. 4). It is particularly suited to areas where the brown planthopper is a problem (Philippines, Vietnam, Indonesia, India, Sri Lanka, and Bangladesh) as well as to areas with grassy stunt (Philippines, Vietnam, and Indonesia).

IR26 is insensitive to photoperiod and matures in 125 days. It has high tillering ability and is moderately resistant to lodging. Its yield potential is slightly better than that of IR20. Soil chemists have found IR26 resistant to iron toxicity and moderately resistant to injuries caused by alkali, salt, and reduction products.

International cooperation. We continued to cooperate with breeding programs throughout the world and to coordinate the first International Rice Yield Nursery (1972 Annual Report).

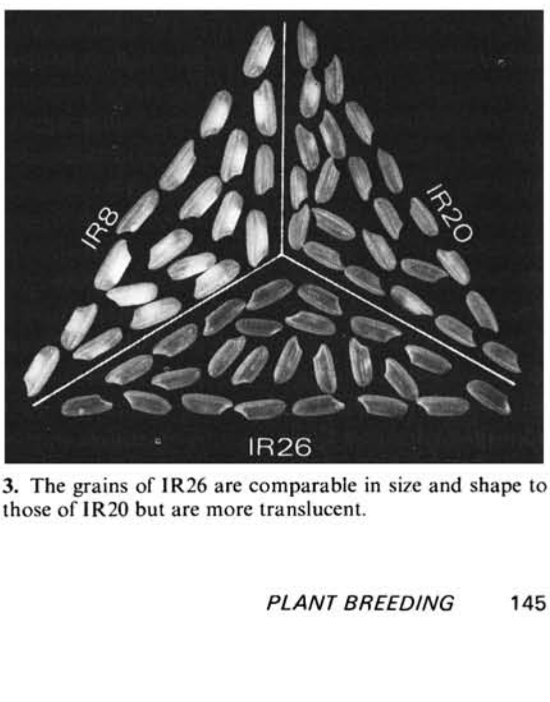


2. Diagram of the vacuum emasculator. The number of vacuum tubes depends on the size of the motor.

The IRYN was distributed to 17 countries this year. The nursery will be planted in two seasons and at several locations within many countries. We anticipate about 80 percent return of data after 18 months. The data will be summarized and distributed to all cooperators.

We will organize an international observational nursery in 1974 to test sets of better breeding lines of varietal potential. Some lines will come from disease and insect nurseries, while others will be nominated by the national breeding programs. The nursery will consist of about 400 lines. Each entry will be planted on non-replicated observational plots in several locations in each country under varying environmental conditions. To expose the entries to disease and insect pressures, they will be given only minimal insecticide protection. This nursery will provide basic information to cooperating programs on disease and insect resistance and on adaptability to varied environmental conditions. It will also facilitate the exchange of breeding material and provide breeders an opportunity to compare their best lines with the best lines of other programs.

We continued to exchange breeding materials with other programs. We sent 7,618 seed packages of breeding lines to research workers in 45 countries. These lines are being tested for



3. The grains of IR26 are comparable in size and shape to those of IR20 but are more translucent.

4. Under field conditions, IR26 is more resistant to grassy stunt than most other varieties and selections.

adaptability to local conditions; some have been named as varieties. A total of 25 breeding lines developed at IRRI have been released as commercial varieties by other countries, six this year (Table 1). In Nepal, IR400-29-9, an early maturing line adapted to the Terai region, was named Parwanipur 1. IR789-59-3, a waxy line, was named Masria in Malaysia. Two long-grain selections from IR1052 and IR1055 were named variety "R" and variety "S" in Guyana. Vietnam named IR1529-680-3 as TN 73-1. IR1529-680-3 is a high-yielding selection with sturdy stems and excellent grain quality which is resistant to blast, bacterial blight, and green leafhoppers. It matures in 130 days. Vietnam also named IR1561-228-3, an early maturing selection with long, slender grains and high yield potential, as TN 73-2. IR1561-228-3 is resistant to blast, bacterial blight, brown planthoppers, and stem borers. A reselection of IR24 was named Chianung Sen 8 in Taiwan. Because of its low amylose, Chianung Sen 8 is expected to be popular with local consumers.

Table 1. IRRI lines named as varieties in other countries in 1973.

Name	IRRI line	Cross[a]	Country where named
Parwanipur 1	IR400-29-9-73	Peta⁴/TN1	Nepal
Masria	IR789-59-3-1	IR8/Muey Nahng 62M	Malaysia
Variety "R"	IR1052	BG 79/IR8	Guyana
Variety "S"	IR1055	BG 79//Peta⁴/TN1	Guyana
TN 73-1	IR1529-680-3-2	Sigadis²/TN1//IR24	Vietnam
TN 73-2	IR1561-228-3-3	IR8/Tadukan//TKM6²/TN1	Vietnam

[a]New system of designating crosses: / = first cross; // = second cross; /// = third cross.

Plant type. Although the dwarf plant type represented by IR8 (100 cm high) has proved successful for lowland irrigated production, IR5 (120 cm high) has been more popular for rainfed lowland conditions in several countries. Farmers in Malaysia and Indonesia, for example, prefer varieties of intermediate height. This has led us to modify our breeding objectives for plant height. We have made a large number of crosses with IR5 and C4-63 and are selecting progenies of intermediate height. We are evaluating fixed lines from IR2053 that are intermediate in height, have intermediate amylose content and are resistant to blast, bacterial blight, tungro, and green leafhoppers. We are combining other desirable plant characters, such as high tillering ability, erect leaves, and sturdy stems with intermediate height. Our major emphasis, however, continues to be on developing short-statured varieties.

Growth duration. Although most of our breeding lines have medium growth duration (120 to 130 days), we are also developing early maturing varieties. Several early maturing selections such as IR747B2-6, IR579-48-1, IR833-6-2, IR1561-228-3, and IR1712-217-2, have yielded comparably to IR8 and IR20. Because they lack disease and insect resistance, however, none of them have been named as varieties. We are now evaluating other early maturing selections with

Table 2. Agronomic characteristics and grain yields of early maturing selections. IRRI, 1973 wet season.

Designation	Cross	Maturity (days)	Tillers (no.)	Height (cm)	Yield (t/ha)
IR747B2-6	TKM 6^2/TN1	101	14	83	2.4
IR833-6-2	IR262-43/Gam Pai	107	11	90	1.2
IR1561-228-3	IR8/Tadukan//TKM 6^2/TN1	111	16	91	4.5
IR1712-217-2	IR747B2-6/IR665-40	107	16	91	4.3
IR2061-214-3	IR833-6///IR1561-149//$IR24^4$/ *O. nivara*	105	12	107	4.6
-464-2		111	11	115	4.5
-465-1		107	12	105	3.3
IR8[a] (check)	Peta/Dee-geo-woo-gen	—	—	—	—
IR20 (check)	$Peta^3$/TN1//TKM 6	130	11	91	1.0

[a]Destroyed by grassy stunt.

good yield potential and with resistance to major diseases and insects (Table 2). Examples include several selections of IR2061 which mature in about 105 days, have good grain quality, and are resistant to blast, bacterial blight, tungro, grassy stunt, green leafhoppers, and brown planthoppers (Table 3). During the wet season, selections of IR2061 outyielded all other early maturing selections. Damage due to brown planthoppers and grassy stunt virus lowered the yields of IR8 and IR20 checks, but not of the resistant IR2061 lines.

We made a large number of crosses with photoperiod-sensitive rices to develop disease- and insect-resistant varieties with sensitivity to photoperiod. Such varieties are needed in large river-deltas of Vietnam, Thailand, Burma, Bangladesh, and India. We also identified several photoperiod-sensitive lines from several crosses, such as IR2070, IR2071, and IR2151, which involve photoperiod-sensitive lines from *Oryza nivara* backcrosses.

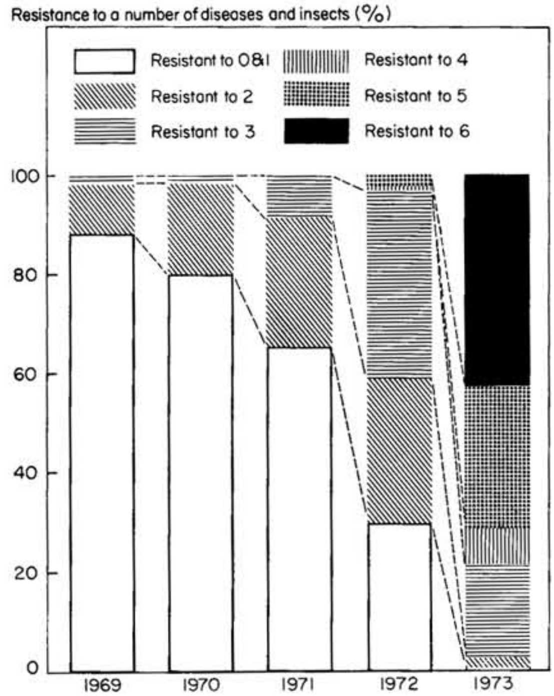
Grain quality. Several promising lines with intermediate amylose content from crosses of BPI 121-407 are resistant to blast, bacterial blight, and green leafhoppers, but are susceptible to tungro, grassy stunt, and brown planthoppers. We made a large number of crosses with these lines to develop varieties with intermediate amylose content and multiple disease and insect resistance. We also added several other sources of intermediate amylose to the crossing program.

Several glutinous lines which are resistant to all the major diseases and insects are being evaluated. One is IR2061-464-4, an early maturing glutinous line which is resistant to blast, bacterial blight, tungro, grassy stunt, green leafhoppers, and brown planthoppers (Table 3). Another, IR2061-255, has high yield potential and multiple disease and insect resistance.

To develop aromatic varieties, we made several crosses using IR841-85, an improved-plant-type aromatic line from the cross of Khao Dawk Mali and IR262. Several aromatic lines from Basmati crosses are being evaluated for yield.

Disease and insect resistance. Pedigree and yield trial nurseries were screened for resistance to blast, bacterial blight, tungro, grassy stunt, green leafhoppers, and brown planthoppers. Selected entries were also screened for resistance to stem borers. We made considerable progress in combining resistance to these major diseases and insects into a desirable agronomic background. The number of entries with multiple resistance in the replicated yield trials has greatly increased. All have resistance to more than three diseases and insects; several have resistance to four or five. This year, for the first time, several selections resistant to all the major diseases and insects were entered into yield trials (fig. 5). Table 3 lists some improved-plant-type selections which are either being used extensively as parents in the hybridization program or being evaluated in coordinated trials as varietal possibilities. Selections with multiple disease and insect resistance have been obtained from IR2035, IR2039, IR2061, IR2070, IR2071, and IR2151 (Table 3).

Tungro. Tungro incidence in the Philippines declined greatly this year. Our screening nurseries at cooperating stations of the Bureau of Plant



5. Changes in proportion of entries in annual replicated yield trials with multiple resistance to important diseases and insects (blast, bacterial blight, tungro, grassy stunt, brown planthoppers, and green leafhoppers). Each year's trial consisted of about 185 entries.

Industry in Maligaya, Pili, and Iloilo had no tungro infection during the dry season. A moderate level of infection occurred in the wet-season screening nursery at Maligaya. Most of the selections were classified as susceptible, moderately resistant, or resistant. In the wet season, a tungro nursery of 3,204 selections from 12 crosses was planted at Cauayan, Isabela, where a moderate level of tungro infection occurred in farmers' fields. In the tungro nursery, infection was moderate and most of the lines could be classified as resistant or susceptible. Selections from IR2070 and IR2071 were the most resistant.

A serious outbreak of tungro occurred in South Sulawesi, Indonesia, where we tested a large number of breeding lines in cooperation with Indonesian scientists. The first of three nurseries grown there consisted of 472 F_5 lines from IR2031, IR2034, IR2035, and IR2039. The second consisted of 371 lines from IR2061, IR2070, IR2071, IR2074, and IR2076. Lines of IR2061, IR2070, and IR2071 looked outstanding for resistance. The third nursery consisted of 223 lines from IR2031, IR2034, IR2035, IR2039, IR2053, IR2151, IR2152, and IR2153. Resistant lines from these crosses were identified. We also tested some of the parental sources of resistance to tungro virus, such as Pankhari 203, PTB 18, Gam Pai, Malagkit Songsong, H 8, Hashikalmi, Latisail Aman, BG11-11, W 1263, and some dwarf lines derived from them. All the varieties and selections resistant in the Philippines were also resistant in Indonesia.

The field testing program, begun in 1971, has expedited breeding for tungro resistance. Many lines have been screened under heavy virus pressures. Resistant entries in the replicated yield trials increased from 6 percent in the 1972 wet season to 53 percent in the 1973 wet season (fig. 6). Similarly, 68 percent of the crosses made in the 1973 wet season had at least one tungro-resistant parent.

Grassy stunt. We made rapid progress in combining the gene for grassy stunt resistance from *O. nivara* with resistance to other diseases and insects. We developed a field screening technique which facilitated the screening of large amounts of segregating material. A field is planted to a variety susceptible to both grassy stunt and brown planthoppers, such as IR24, without insecticidal protection. Because brown planthoppers and grassy stunt naturally occur in the area, the susceptible variety is exposed to both the virus and the vector. When the plants are 60 to 90 days old and have large populations of first-instar nymphs of the brown planthopper, the test materials are planted on wet beds prepared in the middle of the field. As the seedlings emerge, they are exposed to high populations of insects which are viruliferous. They move to the young seedlings and inoculate them with grassy stunt. Sometimes insects move from the old plants to young seedlings rapidly because the old plants become hopperburned. At other times, the insects must be manually transferred by cutting the old plants and shaking them over the test seedlings.

Twenty-five-day-old seedlings from these seedbeds are transplanted into regular nurseries. Resistant, segregating, and susceptible lines show clear-cut differences (fig. 7).

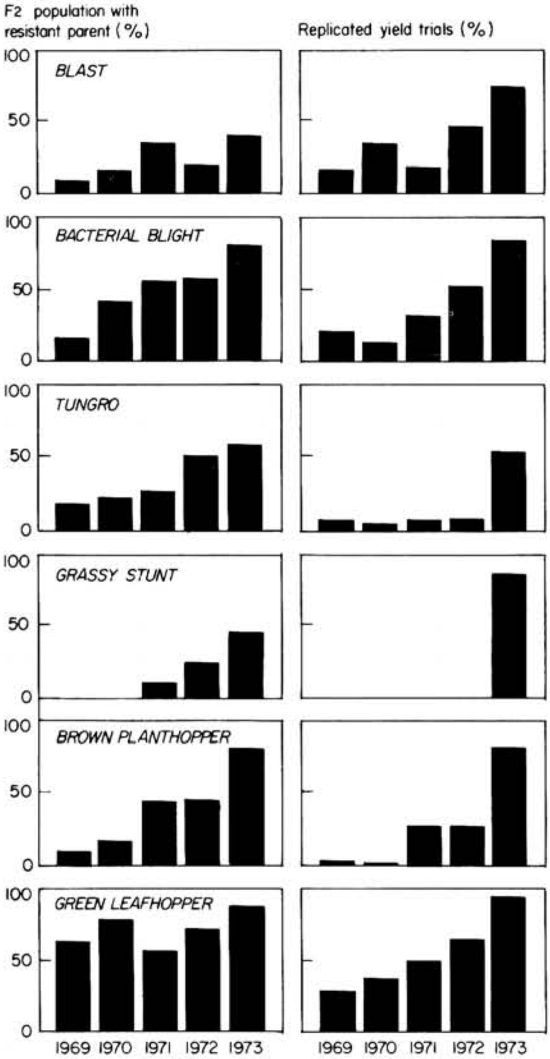
Two of the four pedigree nurseries were screened in this manner. All the lines came from crosses in which at least one parent was resistant to grassy stunt. Promising grassy stunt resistant lines with multiple resistance to other diseases and insects were identified from IR2031, IR2034, IR2035, IR2039, IR2061, IR2070, IR2071, IR2151, IR2152, and IR2153 (Table 3). Lines resistant to grassy stunt were entered in the replicated yield trials for the first time in the dry season. In the wet season, 86 percent of the entries were resistant (fig. 6). Similarly, the proportion of F_2 populations which had at least one grassy stunt resistant parent rose from 10 percent in 1971 to 44 percent this year.

O. nivara is the only source of grassy stunt resistance currently available. But some breeding lines have considerable field tolerance which they inherited from different parental sources.

Table 3. Data on disease and insect resistance of promising breeding lines.

Line	Cross	Resistance[a] to						
		Blast	Bacterial blight	Tungro	Grassy stunt	Green leafhoppers	Brown planthoppers	Stem borers
IR747B2-6[b]	TKM 6^2/TN1	MR	R	S	S	S	R	MR
IR833-6-2[c]	IR262-43/Gam Pai 15	R	S	R	S	R	S	S
IR1364-37-3	$Peta^3$/TN1//HR 21	S	S	R	MR	R	S	S
IR1416-131-5	$Peta^4$/TN1//Tetep	R	MR	S	S	S	S	MR
IR1514A-E597-2	IR20/TKM 6	MR	R	R	S	R	R	MR
IR1529-680-3	$Sigadis^2$/TN1//IR24	R	R	MS	S	R	S	S
IR1539-823-1[d]	IR24//Mudgo/IR8	MR	MR	S	S	R	R	S
IR1544-340-6	IR24/Tetep	R	S	S	S	MR	R	S
IR1545-339-2	IR24/DZ 192	MR	R	S	S	R	S	S
IR1561-228-3[b]	IR579-48/IR747B2-6	MR	R	S	S	S	R	MR
IR1614-389-1	IR22//Mudgo/IR8	S	R	S	S	R	R	S
IR1628-632-1	IR24/IR1154-243	MR	S	S	S	R	R	S
IR1702-158-3[e]	IR24/PTB 18	MR	S	R	S	R	R	MR
IR1704-3-2-3[e]	$IR24^2$/*O. nivara*	R	S	S	R	R	S	—
IR1712-217-2[b]	IR747B2-6/IR665-40	M	R	S	S	R	R	—
IR1721-11-6	$IR24^3$/*O. nivara*	R	S	S	R	R	S	MR
IR1818-1-19	$IR24^3$/*O. nivara*//IR400-28/Tetep	R	S	S	R	R	S	—
IR1820-52-2	IR1539-60//IR400-28/Tetep	R	S	S	S	R	R	—
IR2031-238-5[f]	$IR24^3$/*O. nivara*//IR400-28/Tetep///IR1330-3-2	R	R	S	R	R	R	—
-354-1[f]	"	MR	R	S	R	R	R	—
-724-2[f]	"	R	R	S	R	R	R	—
IR2034-238-1	IR1539-60/IR1364-37//$IR24^4$/*O. nivara*	R	S	R	R	R	R	—
-289-1	"	MR	S	R	R	R	R	—
IR2035-290-2	IR400-28/Tetep//IR1364-37///IR1539-260//$IR24^3$/*O. nivara*	R	MR	R	R	R	R	—
IR2039-269-1	IR1330-5-3-3/IR1737	MR	R	R	R	R	R	—
IR2042-101-2	IR1561-228//$IR24^3$/*O. nivara*	R	R	S	R	R	R	MR
IR2049-104-2[g]	IR24//Mudgo/IR8///BPI 121-407	S	S	S	S	R	R	—
IR2053-375-1[h]	IR400-28/Tetep//IR22/C4-63	R	R	R	S	S	R	—
-522-2	"	R	R	R	S	S	R	—
IR2055-219-1[g]	BPI 121-407//IR1416-131/IR22	R	R	S	S	S	R	—
IR2061-214-3[b]	IR833-6-2///IR1561-149//$IR24^4$/*O. nivara*	R	R	R	R	R	R	MR
-464-4[c]	"	R	R	R	R	R	R	MR
IR2070-24	$IR20^2$/*O. nivara*//CR 94-13	R	R	R	R	R	R	—
IR2071-88	IR1561-228//$IR24^4$/*O. nivara*///CR 94-13	R	R	R	R	R	R	—
IR2151-957-5[e]	IR26//$IR20^2$/*O. nivara*	R	R	R	R	R	R	—

[a]R = resistant; MR = moderately resistant; S = susceptible. [b]Early. [c]Early, waxy. [d]Upland potential. [e]High protein. [f]R to sheath blight. [g]Intermediate amylose. [h]Intermediate height.



6. Changes in proportion of F_2 populations and entries in replicated yield trials with resistance to important insects and diseases.

7. Resistant selections such as IR2061-443-3 are not infected with grassy stunt under heavy disease pressures, while susceptible varieties such as IR20 become infected.

Presumably they have different minor genes for resistance. We began a breeding program to combine these minor genes from different sources to develop varieties with horizontal resistance to grassy stunt.

Blast. In our crossing program, we emphasized the use of breeding lines which inherited their blast resistance from Tetep and Carreon. Many blast-resistant lines from *O. nivara* crosses continued to show high levels of resistance. Resistance inherited from Gam Pai has held out well in many lines. Breeding for blast resistance has not progressed as fast as has breeding for other diseases and insects, mainly because of rapid shifts in fungus races. Many selections which are resistant in one season are susceptible in another. Many which have Dawn as a source of resistance were resistant for several seasons, but became susceptible in the 1972 wet season. Seventy-three percent of the entries in replicated yield trials in the 1973 wet season were resistant to blast (fig. 6). Some blast-resistant selections with resistance to other diseases and insects are shown in Table 3.

Bacterial blight. We made rapid progress in developing varieties resistant to bacterial blight. Eighty-two percent of the entries in the replicated yield trials during the wet season were resistant; 79 percent of the F_2 populations had at least one resistant parent (fig. 6). We are using two different sources of resistance. When the resistance is conditioned by a dominant gene, such as in TKM 6, Sigadis, or Tadukan, we start screening F_1 populations obtained from topcrosses or double crosses. We have made an increasing number of crosses with BJ 1 and DZ 192 which have a recessive gene for resistance. Some of the promising selections with blight resistance are listed in Table 3.

Brown planthoppers. A large proportion of the entries in the replicated yield trial during the wet season were resistant to brown planthoppers (fig. 6). Similarly, 78 percent of the F_2 populations grown during that season had at least one parent resistant to brown planthoppers. F_2 populations and pedigree nurseries from crosses involving brown planthopper and grassy stunt resistance were grown with minimal insecticide protection and screened for resistance to this insect during both the dry and wet seasons. Diazinon controls the predators but not the brown planthoppers, so it is used to control other insect pests in the F_2 and pedigree nurseries. Only resistant plants were selected for the next generation. We are incorporating the dominant as well as the recessive genes for brown planthopper resistance into our breeding materials. Promising lines with brown planthopper resistance are listed in Table 3.

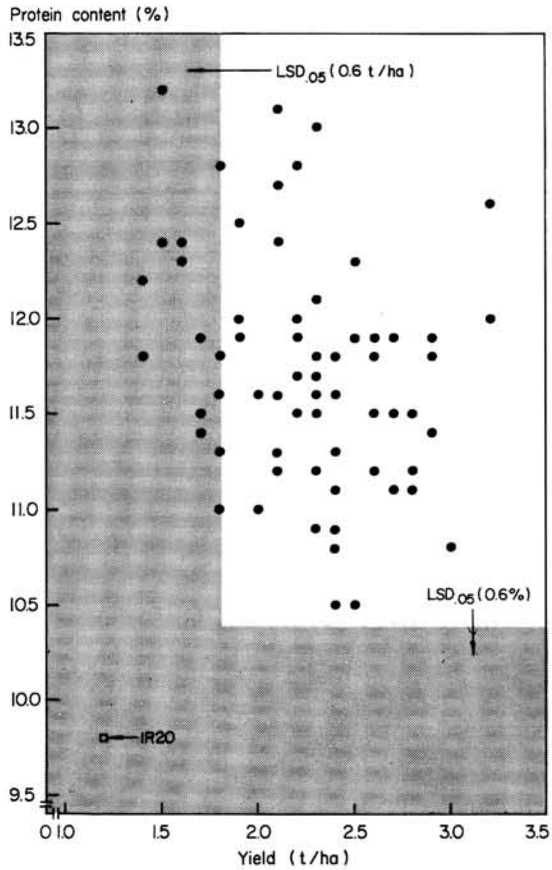
Green leafhoppers. Most of our breeding lines are resistant to green leafhoppers (fig. 6). Most of the advanced lines have the *Glh 3* gene for resistance but we have made a large number of crosses with lines which are homozygous resistant for *Glh 1* and *Glh 2*. Promising selections with green leafhopper resistance are listed in Table 3.

Protein content. We identified several promising breeding lines this year. Data for two seasons are available on some of these materials (Table 4); other lines were first identified during the wet season (Table 5). In the dry season we evaluated 138 lines in the high-protein yield trials and discarded 86. In the wet season we evaluated 286 lines and discarded 178.

Several years ago, IRRI agronomists identified IR480-5-9 as a line which probably had a high level of protein. This has been confirmed and it is now being used as a high-protein check in our trials. IR480-5-9 has been released for commercial production in Fiji but not in other countries because it is susceptible to some major diseases and insects. Crosses were made about 2 years ago to remedy that problem. Improved lines are now available with protein content and yield potential comparable to those of IR480-5-9 and with resistance to blast, bacterial blight, green leafhoppers, and brown planthoppers (Table 5). These lines are susceptible to tungro and grassy stunt virus diseases but many crosses have been made to incorporate resistance.

The variety PTB 18 and an accession from *Oryza nivara*, both from India, were identified as possible sources of genes for high protein content, because several high-protein breeding lines have one of these cultivars as a common parent. Lines of PTB 18, the most promising of which is IR1702-158-3 (Table 4), are resistant to tungro, green leafhoppers, and brown planthoppers. *Oryza nivara* is the only known source of a major gene for resistance to grassy stunt; it also transmits blast resistance.

Many crosses were made this year, from which we should be able to identify varieties with relatively complete spectrums of pest resistance and 20 to 25 percent higher levels of protein. But many crosses involving *Oryza nivara* and PTB 18 have already reached advanced stages in the disease and insect programs. We may be able to identify high-protein lines with varietal potential from these crosses almost immediately. The performance of 69 F_5 lines from IR2151 (IR24/TKM 6// IR20^3/*O. nivara*) during the wet season is a good example (fig. 8). All 69 lines had significantly higher protein content and most yielded significantly higher than did the IR20 check. The results may be questionable, how-



8. Performance of several F_5 lines of IR2151 compared with IR20 (IRRI, 1973 wet season; average of 4 replications).

Table 4. Brown rice protein, grain yield, and disease and insect reactions of some varieties and breeding lines in replicated trials. IRRI, 1973.

Designation	Cross	Dry season				Wet season				Resistance to					
		Protein		Yield		Protein		Yield							
		%	Index[a]	t/ha	Index[a]	%	Index[b]	t/ha	Index[b]	Blast	Bacterial blight	Tungro	Grassy stunt	Brown planthopper	Green leafhopper
BRJ1-13-B-55	IR8/DA 31	9.2	128	4.8	77	9.4	103	2.8	96	S	MS	—	S	S	S
IR160-45-1	Nahng Mon S4/TN1	8.8	122	5.9	95	9.7	106	2.2	76	MS	S	S	S	S	S
IR480-5-7	Nahng Mon S4^2/TN1	8.9	124	5.1	82	10.0	110	3.3	114	R	S	—	MR	S	S
IR1103-15-8	IR8/Chowsung	9.4	130	5.0	81	11.2	123	1.1	38	MS	MS	S	S	S	S
IR1163-153-2	IR8^2/BP1 76	8.4	117	5.2	84	9.3	102	3.6	124	MR	S	MS	MS	S	R
IR1253-10-1	IR8/T. 141	8.8	122	5.5	89	9.5	104	2.6	90	MS	S	—	S	S	R
IR1514A-E562-2	IR20/TKM 6	8.1	112	6.7	108	9.5	104	4.0	138	MR	R	R	S	R	R
IR1550-16-2	Nahng Mon S4/TN1//DV 133	8.2	114	5.8	94	9.5	104	1.9	65	MS	MR	—	S	S	S
IR1552-80-2	Nahng Mon S4/TN1//Crosa 2	9.0	125	6.2	100	10.5	115	2.6	90	MR	S	—	S	S	S
IR1702-158-3	IR24/PTB 18	8.6	119	6.3	102	10.7	118	3.5	121	MS	S	R	MR	R	R
IR1704-3-2	IR24^2/*O. nivara*	8.6	119	6.3	102	10.0	110	3.3	114	R	S	—	R	S	R
IR1712-238-3	TKM6^2/TN1///IR8//Peta^5/Belle Patna	8.8	122	5.5	89	10.2	112	2.4	83	MR	R	MS	MS	R	R
IR2044-409	IR480-5-9/L4 (1915)-12	8.8	122	6.4	103	9.3	102	2.4	83	MS	S	—	S	S	S
-766	"	8.3	115	6.5	105	9.5	104	2.9	100	MR	S	—	MR	S	S
IR442-2-58	Peta^2/TN1//Leb Mue Nahng	7.8	108	5.4	87	10.1	111	2.1	72	S	S	MR	S	S	R
IR480-5-9 (check)	Nahng Mon S4^2/TN1	8.9	124	5.4	88	10.3	113	3.1	107	R	S	S	MR	S	S
IR8 (check)	Peta/Dee-geo-woo-gen	7.2	100	6.2	100	8.6	94	1.8	62	S	S	S	S	S	R
IR20 (check)	Peta^3/TN1//TKM 6	—	—	—	—	9.1	100	2.9	100	MR	R	MR	S	S	R
CV (%)		5.1	—	8.4	—	5.9	—	14.6	—	—	—	—	—	—	—
LSD (.05)		0.5	—	0.6	—	0.5	—	0.4	—	—	—	—	—	—	—

[a]Percent of IR8. [b]Percent of IR20.

Table 5. Brown rice protein, grain yield, and disease and insect reactions of some promising varieties and breeding lines in replicated trials. IRRI, 1973 wet season.

Designation	Cross	Protein		Yield		Resistance to					
		%	Index[a]	t/ha	Index[a]	Blast	Bacterial blight	Tungro	Grassy stunt	Brown planthopper	Green leafhopper
Rajeswari (India)		9.5	104	3.7	127	MS	S	—	MR	S	S
IR26	IR24/TKM 6	8.9	98	4.9	169	MR	R	MR	MR	R	R
IR789-63-1	IR8/Muey Nahng 62M	10.2	112	3.3	114	S	S	—	MR	S	S
IR887-15-2	IR8^2/Muey Nahng 62M	9.8	108	3.2	110	S	S	—	MR	S	R
IR1702-74-3	IR24/PTB 18	10.5	115	2.7	93	MR	S	R	MR	R	R
IR1857-1	IR8^3/*O. nivara*///IR841//Mudgo/IR8	9.8	108	3.8	131	MR	S	—	R	R	R
IR1917-1-15	IR20^3/*O. nivara*	10.0	110	3.4	117	MR	R	MR	R	S	R
-3-19	"	10.2	112	2.9	100	MR	R	MR	R	S	R
IR1924-30-2	*O. nivara*/IR773^4	9.4	103	3.8	131	MR	S	—	R	S	S
IR2003-P7-7	IR1103-15/IR480-5-9///IR22//Mudgo/IR8	9.8	108	3.8	131	R	R	—	MR	R	R
-P16-7	"	11.0	121	2.9	100	MR	R	—	S	R	R
IR2006-P12-12	IR1103-15/IR1163-124///IR22//Mudgo/IR8	9.8	108	3.7	128	MS	R	—	MR	R	R
IR2014-P111-6	IR1103-49/IR1103-15///IR22//Mudgo/IR8	10.6	116	3.1	107	MS	R	—	MS	R	R
-P136-10	"	10.1	111	3.5	120	MR	R	—	MS	R	R
IR2016-P7-4	IR1103-49/IR480-5-9///IR22//Mudgo/IR8	11.1	122	3.1	107	MS	R	—	S	R	R
IR2018-P43-2	IR1103-49/IR1163-96///IR22//Mudgo/IR8	10.2	112	3.0	103	MR	R	—	MR	R	R
IR2044-71-6	IR480-5-9/L4 (1915)-12	9.8	108	2.9	100	MR	S	—	MR	S	R
IR2145-20-4	*O. nivara*/IR773^4	9.6	105	4.7	162	R	S	S	R	S	S
IR480-5-9 (check)	Nahng Mon S4^2/TN1	10.3	113	3.1	107	R	S	S	MR	S	S
IR8 (check)	Peta/Dee-geo-woo-gen	8.6	94	1.8	62	S	S	S	S	S	R
IR20 (check)	Peta^3/TN1//Leb Mue Nahng	9.1	100	2.9	100	MR	R	MR	S	S	R
CV (%)		5.9	—	14.6	—	—	—	—	—	—	—
LSD (.05)		0.5	—	0.4	—	—	—	—	—	—	—

[a]Percent of IR20.

ever, because of several factors. Yields were low because of long, cloudy periods, as well as typhoon damage. Nitrogen topdressing was also applied. The lines carry potential resistance to blast, bacterial blight, tungro, grassy stunt, green leafhoppers, and brown planthoppers, and probably carry moderate resistance to stem borers. Although many more of them may be discarded as they are more thoroughly evaluated we hope to identify a few which combine high protein with the necessary resistance.

In exploring different breeding methods for improving protein content, we are giving particular attention to reinforcing or concentrating genetic factors for high-protein content in a single genotype. We intercrossed our four best high-protein breeding lines with our best disease- and insect-resistant line in all possible combinations (excluding reciprocals) to give a total of 10 single-cross F_1 hybrids. We then intercrossed these F_1 hybrids in all possible combinations (again excluding reciprocals) to make a total of 45 double-cross F_1 populations. We originally intended to subject these populations to selection pressures, emphasizing disease and insect resistance and agronomic characteristics. Plants finally selected would have been evaluated for protein content and the best ones intercrossed, using the ratoon crop. The procedure would then have been repeated with the new hybrid population. But this was undesirable because it did not allow new germ plasm to be introduced. Also, environment influences the protein content of individual plants, and attempts to control it through replication by vegetative propagation were only marginally successful.

We finally adopted the following scheme of long-cycle recurrent selection. Initially, the 45 double-cross F_1 populations were rogued of plants that were undesirable in disease and insect resistance and agronomic characters. The remaining plants were randomly used as pollen parents on females chosen on the basis of previous performance in the high-protein yield trials. We plan to repeat the procedure with the new set of segregating F_1 populations. The pollen parents during each cycle will enter the pedigree system. We expect lines selected from them to eventually surface in the high-protein yield trials. We will select some of these as female parents in the system, thus completing the cycle. Only the best performing lines in the high-protein yield trials will be used as females, however, regardless of their origins. This permits the involvement of new genetic sources of protein content, disease and insect resistance, and other desirable characters.

Cold tolerance. Because we are located in an area of low elevation and low latitude, we have not been able to develop germ plasm suitable for areas where cold temperatures may affect the rice crop. Rice improvement programs in these areas have not been able to use our tropical germ plasm because it cannot be grown, even for crossing purposes, except in greenhouses.

Considering this, we are largely confining our efforts to collecting the commonly grown varieties from such areas, crossing them with our most promising materials from the standpoint of agronomic characters (especially earliness) and disease and insect resistance, and distributing seed of the first segregating generation to cooperating breeders in the areas concerned. Table 6 lists some of the materials that were crossed in 1973.

We tried to grow some of these materials and segregating materials in La Trinidad, Benguet, a high-elevation area of the Philippines. But the area was apparently too high and too cold. Except for a few japonicas, such as Tainan 3, the materials were mostly sterile. But vegetative development was excellent in some cases. We have now relocated to the Tublay Valley, Benguet, which we consider more representative of high-elevation areas in the tropics.

Problem soils. Using greenhouse techniques, the soil chemists have identified varieties that are resistant or tolerant to problem soils. We have incorporated these materials into the crossing program and have recently expanded joint efforts with the soil chemists to screen segregating material.

We are initially concentrating on the problem of salinity. We have made an extensive number of crosses to combine quality factors, yielding ability, and broad-spectrum disease and insect resistance with the salinity resistance of varieties such as Pokkali, CAS 209, and SR 26B. The F_1

hybrids were grown during the wet season; we plan to begin screening F_2 populations during the 1974 dry season.

Deep-water varieties. We are cooperating with scientists in Thailand and other countries who are interested in improving deep-water or floating varieties. Our objectives are twofold. First, we think it would be beneficial to incorporate some degree of elongation capacity into our short- and intermediate-statured germ plasm. Short-statured, high-yielding varieties which are able to elongate could be grown in many areas where water control is poor because they would have some flood tolerance. Second, scientists in deep-water areas would like to improve the floating varieties, especially in disease and insect resistance and eating quality. We do not know whether yielding ability in floating types can be improved by adjusting the plant architecture, but we feel that the possibility should not be ignored.

We decided to begin the breeding work by forming and distributing a deep-water composite. Fifty-five crosses were made in the wet season. Eleven conventional lines which are superior in eating quality, disease and insect resistance, and other desirable factors were used as females. They were crossed to five floating types recommended by breeders from deep-water areas. F_2 seed of these crosses will be distributed to interested breeders who may bulk it into a composite or handle it as they choose.

Upland-lowland crosses. Critical comparisons of upland and lowland varieties have indicated that desirable characteristics from both variety groups should be combined to improve upland rices. We initiated such a breeding program with, as major breeding objectives, an efficient plant type for upland culture, wide adaptability, and responsiveness to nitrogen. Other desired features include resistance to drought, potential for tillering, resistance to the major diseases and insects, early maturity, tolerance to problem soils, and preferred panicle and grain features. Combinations of the desired characters are often found in one of the two variety groups: drought resistance and tall height in upland varieties; low-but-stable yields and good filling of grain under water stress in upland types; and resistance to virus diseases and to their insect vectors in lowland varieties. In the progenies of the initial upland-lowland crosses, we noted the prevalence of some of the above character associations, such as drought resistance and intermediate-to-tall plant height. So we hope to increase the frequency of genetic recombination by bringing together many diverse rice types in modified hybridization schemes.

Table 6. Some varieties and lines collected from cold tolerance areas for crossing at IRRI.

Designation	Origin
China 1039	Kashmir
China 1039 mutant (dwarf)	Kashmir
JP 5	Pakistan
Kulu	Australia
Madaw	Kashmir
Raja Imut	Indonesia
Remei	Japan
Sough	Kashmir
Sug	Kashmir
Tainan 3	Taiwan
YR6-100-9	Australia
AC-71	H. Pradesh
AS-11	H. Pradesh
AS-46	H. Pradesh
Jiddah Mango	Indonesia
K42-55B	Kashmir
K 71	"
K 78-13	"
K 78-28	"
K 85-1	"
K 85-2	"
K 113	"
K 116	"
K 152	"
KH 6605	"
KH 746	"
KH 974	"
KH 6119	"
KH 7019	"
KN-1h-36	Indonesia
KN-1h-214	"
KN-1h-361	"

We widened our search for promising parents among diverse upland and lowland types. During the dry season we tested for drought resistance 700 traditional upland varieties and 603 semidwarf lines from lowland breeding nurseries. In the wet season we planted two replications of the promising rices at two different dates in yield trials on well-drained clay loam soils. We also included in an observational trial 102 traditional upland varieties recently received from West Africa and tropical Asia, 424 breeding lines from the International Institute for Tropical Agriculture (IITA), Nigeria, and 77 breeding lines from our upland breeding nurseries. We frequently visited upland plots of other IRRI researchers at two sites, searching for promising parents.

Among the traditional upland varieties in the observational yield trials, KU 70-1, TD 47, R54, Malokoro S1, and Jedish 1 were resistant to both drought and bacterial blight. Among the semidwarfs, the lines IR790-28-1, IR1529-680-3, and IR2035-170-2 showed good vegetative vigor in upland soil when there was no severe moisture stress. In the dry season test, two lines, IR2035-170-2 and IR2039-7-3, showed intermediate levels of drought resistance (the highest we have yet found in semidwarfs).

We began by making single crosses between drought-resistant, tall and early upland types from Africa which are low in tillering and susceptible to pests, and drought-susceptible, short- or intermediate-statured lowland types which are high in tillering and resistant to pests. In 1973, we added some promising F_7 lines from our upland nurseries as parents.

We selected and crossed many F_1 hybrids in various combinations to bring together most of the desirable features in double crosses.

At the 1973 international rice research conference, breeders from major upland rice countries in Africa, Asia, and South America asked the institute to make composite crosses from some of the principal or promising varieties grown in each geographic area. We received and crossed a number of parents. We will furnish F_1 or F_2 seeds of such composite crosses to breeders outside the Philippines.

During the year we made a total of 181 single crosses, 48 three-way crosses, and 210 double crosses.

Progeny testing in upland fields. We made most progeny selections in our F_2 populations under upland conditions in the wet season. Several three-way crosses, however, were planted under simulated upland culture in the dry season.

During the wet season 54 F_2 populations—about 90,000 plants—were planted in rows spaced 25 cm apart by dibbling seeds in the rows and thinning the young seedlings to 5 cm apart. But immediately after seeding in June, a few light showers were followed by a dry period; the heavy soil caked and only two-thirds of the plants survived. Damage by the sorghum shoot-fly after emergence destroyed another 5 percent of the seedlings. More plants were lost in several heavy waves of brown planthoppers.

More distinct segregation occurred in tall upland × semidwarf lowland crosses than in intermediate-statured upland × intermediate lowland or intermediate-statured upland × semidwarf lowland crosses. We noted in the F_2 plants obvious associations between the following characters: 1) tall stature and vigor of vegetative growth; 2) high tillering and severe symptoms of internal water stress (extreme and sustained leaf rolling); 3) tall stature, long panicles, and good filling of grain; 4) tall stature and lodging susceptibility; and 5) grain shattering and predominant lowland parentage. Full genetic recombination seemed to be restricted in the F_2 populations of single crosses.

In the pedigree nursery of F_5 lines, we often observed distinct differences between progenies of the same 3-way crosses that had been selected in the preceding generation under different moisture regimes. Lines that we selected from upland nurseries tended to be tall, low tillering, light green in leaf color, long in panicle length, and early in maturity. Those taken from lowland plots tended to be intermediate in height, high tillering, dark green, rather leafy, later in maturity, and short in panicle length. The preceding generation was selected for intermediate stature, medium tillering, and good growth vigor. But the morpho-agronomic features of F_5 lines appeared to be influenced by the water regime under which the F_4 plants were grown. This suggests that the effect of cultural systems on the products of selection should be studied.

During the wet season both leaf and neck blast occurred in epidemic proportions, offering good opportunities to select for blast resistance. We inoculated all of the progenies with a composite culture of the bacterial blight pathogen by the leaf clipping method and selected the agronomically desirable plants from those which were resistant or moderately resistant.

At the end of the wet season only 414 F_2 plants were saved. The extremely few desirable progenies indicated the limits of genetic recombination from single crosses of diverse parents. Breeders should involve many hybrid derivatives in further cycles of crosses and selections.

Mass screening for drought resistance. We planted diverse rices in an upland field during previous dry seasons and supplemented these plantings with frequent surface watering to simulate rainfall under upland conditions during the wet season. Our findings have convinced us that such simulated upland culture is not suitable for general agronomic evaluation, even though previous tests have shown that drought symptoms in dry seasons seem identical to those observed under prolonged drought in wet seasons.

We planted 705 traditional upland varieties, 100 traditional lowland varieties which were reputed to be drought resistant, and 603 semidwarf breeding lines from the lowland breeding nursery in 5-m rows spaced 25 cm apart. We irrigated the plots about once a week, but withheld water during three growth stages to observe water-stress symptoms. The first drought period began about 30 days after seeding. Water was withheld until the susceptible check varieties (such as TN1) showed drought symptoms such as extreme leaf folding, drying of leaf tips, and, sometimes, miniaturized new leaves. The dry spells usually lasted for 2 weeks or longer. After recording the reactions of the plants, we watered the field a few times and waited for the next drought period, at panicle initiation stage. The third stress period was during flowering and grain ripening of the traditional upland varieties. These drought-resistant upland types exserted panicles inspite of the earlier stresses. On the other hand, water stress affected semidwarfs so much that few of them produced panicles at the end of the drought test period (6 months after seeding).

We rated varietal differences in drought resistance among all the rice types planted by several criteria. A sign of drought susceptibility for plants at the tillering stage is early rolling of leaves at mid-day, which remain rolled until the next morning. Resistant varieties, after a longer stress period, roll gently and unfold at night. The proportion of lower leaves which die after the stress period indicates the extent of stress damage. After severe stress, the production of darker, shorter, and narrower leaves is another distinct sign of drought susceptibility. At the reproductive stage, common signs are delayed heading, incomplete panicle exsertion, deformed rachises, aborted terminal spikelets, low panicle fertility, and light grains.

Table 7. Ranking of varieties and selections according to their levels of resistance to drought in field tests, IRRI, 1973 dry season.

Rating	Upland	Lowland
Resistant	OS4, M1-48, 63-83, Sankok	Dular
Moderately resistant	OS6, E425, Agbede, Azmil, Rikuto Norin 21, Hirayama, Palawan, Kinandang Puti, Khao Lo, Moroberekan	Peta, Carreon, IR5, Bluebonnet 50
Intermediate	BPI-9-33, C22-51, DB1, DB4, Miltex, Tapol	IR8, IR24, IR305-4-20, IR442-2-58, IR841-67-1, IR1529-680-3, C12, Pelita I/1, 81B-25
Moderately susceptible	Jappeni Tunkungo, Iguape Cateto	IR20, IR22, IR577-24-1, IR1541-76-3, MTU 17, C4-63, Mala
Susceptible	NARB, Sintianne Diofor	IR747B2-6-3, TN1, IR532-1-218, IR790-28-1, IR1514A-E666

Table 7 gives drought resistance ratings of major varieties and test lines in the dry season field tests. The outstanding drought resistance of OS4, M1-48, and Dular supported our observations of their resistance in the wet seasons of previous years. We also found from both dry- and wet-season tests that TN1, IR20, and IR747B2-6-3 were susceptible.

Previously, we used the proportion of yield reduction of a variety when planted under upland conditions, compared with its yields when planted under lowland conditions, as an indicator of drought resistance during the wet season, when drought cannot be artificially controlled. This year we found that the drought resistance ratings in the dry seasons correlated with the yield variations of nine well-tested varieties planted on two dates in the 1972 wet season. The relative reductions in yield between the June-20 seeding and the July-14 seeding (which was affected by stress) were positively correlated with varietal differences in the drought resistance ratings in the dry seasons (Table 8).

Table 8. Drought resistance ratings and comparisons of grain yields of nine varieties planted at two dates, IRRI, 1972 wet season.

Designation	Drought resistance rating	Yield (t/ha) June 20 planting	Yield (t/ha) July 14 planting	Yield percent (July 14:June 20 plantings)
M1-48	R	2.40	2.36	98
Palawan	MR	2.32	1.06[a]	46
Bluebonnet 50	MR	2.20	1.32	60
IR5	MR	3.89	2.51	65
IR8	I	2.74	1.82	66
C-12	I	2.93	1.58	54
C22-51	I	3.36	0.60[a]	18
IR661-1-170	MS	2.07	0.58	28
TN1	S	2.76	0.55	19

[a]Yield affected by sheath blight and bacterial blight.

We found a similar association between our drought resistance ratings and relative reductions in yield of several varieties and lines in the rice production upland trials in Central Luzon during the 1972 wet season. Then, drought affected yields in the late planting (1972 Annual Report).

The 603 promising semidwarf lines from the lowland breeding nursery varied from susceptible to intermediate in field resistance to drought. None were as resistant as IR5 or any of the drought-resistant upland varieties. But the varietal differences were sufficient to qualify the intermediate rices, such as IR8 and IR1529-680-3, as drought resistant under rainfed lowland culture. Test results from outside IRRI support such varietal differences in performance under water stress (1972 Annual Report).

Root systems and drought resistance. In simulated upland culture, we studied the root systems of two intermediately resistant semidwarf lines, two susceptible semidwarfs, five drought-resistant upland varieties, and IR8. Table 9 indicates that the differences in drought resistance among semidwarfs are associated with differences in root length, predominant root types, proportions of thick roots, and diameters of thick roots. The same association was previously found among tall or intermediate varieties (1971 Annual Report).

We compared the structural features of thick roots among the lowland and traditional upland varieties. Lowland varieties such as Peta had as many primary xylem (eight) as did the upland variety OS4. IR5 had five primary metaxylem elements in the central stele; the same number was found in the upland variety Palawan. We found no obvious histological differences in the roots of the two variety groups.

Evaluation of selections from upland nurseries. Progeny of the first single crosses made in 1970 continued to segregate distinctly for agronomic characters and spikelet fertility in pedigree lines through the F_5 and F_6 generations. Many of the 160 F_5 lines selected in the 1972 wet season, which were planted in seed-increase plots

Table 9. Root development of five upland varieties and five semidwarfs in simulated upland culture, sampled at 60 days after seeding, 1973 wet season.

Designation	Drought resistance	Roots: Predominant type[a]	Density[b]	Number	Modal length (mm)	Max. length (mm)	Avg. diameter (mm)	Max. diameter (mm)
Upland varieties								
Ginanta	MR	5-6	3-4	27	12	30	1.2	1.4
Kinandit	S	3-5	1-3	20	11	23	1.0	1.3
Kinaribo 2	S	2-4	1-2	16	12	22	0.8	1.1
KU 10	MR	4-5	1-2	18	11	26	1.2	1.4
OS4	R	4-6	2-4	28	13	36	1.3	2.0
Lowland lines								
IR2035-474-1	S	3-4	3-4	35	9	30	0.9	1.1
IR2039-71-1	S	3-4	3-4	40	13	24	0.9	1.2
IR8	I	3-4	3	46	9	25	1.0	1.2
IR2035-170-2	I	3-5	2-5	42	22	43	1.1	1.4
IR2039-7-3	I	5	5	67	12	51	1.1	1.3

[a]1 = very fine, 6 = very thick. [b]1 = very few, 5 = very dense.

Table 10. Agronomic traits, grain characteristics, and disease reactions of some promising selections from upland × lowland crosses grown in a non-replicated upland yield trial at Santo Tomas, and grain yields from a replicated lowland trial at IRRI, 1973 wet season.

Designation	Cross	Grain yield (t/ha)		Maturity (days)	Plant ht (cm)	Blast	Bacterial blight	Grain[c]		Amylose (%)
		Upland[a]	Lowland[b]					Length	Width	
IR1746-F5B-3	OS4/IR8	3.5	2.4	137	138	MR-R	MS	ML	I	24
-F5B-13	"	3.8	2.5	138	142	MS-R	MS	M	I	24
-226-1-1-2	"	3.8	2.5	119	131	MS-R	MS	M	MB	23
-226-1-1-3	"	4.4	2.8	127	150	R	S	M	B	23
-226-1-2-2	"	3.9	2.5	127	127	MS-MR	S	ML	MB	24
IR1749-F5B-12	OS4/IR22	3.0	2.5	123	121	Seg.	MS	ML	I	24
IR1750-F5B-3	E425/IR22	3.4	4.0	120	94	MS-S	R	ML	S	22
-F5B-5	"	4.0	2.5	118	93	MS	R/S	L	S	23
-F5B-10	"	3.7	2.6	128	145	S	MS	M	I	23
IR1754-F5B-16	E425/IR8	3.2	2.1	136	159	R	S	M	I	23
IR5	Peta/T. Rotan	4.2	4.2	150	110	MR	S	M	I	30
IR442-2-58	$Peta^2$/TN1//LMN	1.7	2.7	135	87	S	R	M	I	29
C22		3.8	2.8	135	148	MS-S	MS	M	S	26
M1-48		3.6	1.9	132	143	MR	R	ML	I	25
OS4		2.0	2.8	130	137	MR-R	S	ML	I	24

[a]At Santo Tomas. [b]At IRRI. [c]L = long; ML = medium long; I = intermediate; M = medium; MB = medium bold; B = bold; S = short.

at the end of that year, segregated for height, maturity, or both. Because some lines were partially sterile when they flowered in March, we did not collect enough seed to enter all lines in replicated yield trials in the wet season. But we sent enough seeds for 1-row observational trials to IITA in Nigeria and the Institut de Recherches Agronomiques Tropicales (IRAT), Ivory Coast. We planted another seed-increase field in May, which gave seeds for cooperative testing in the October planting season in Indonesia and Brazil.

We planted 26 lines for which we had seeds in a replicated yield trial at IRRI in late May under both upland and lowland cultures. A non-replicated upland trial was planted in mid-June. In cooperation with the agronomists, we planted a non-replicated yield trial during early June at Santo Tomas, Batangas, Philippines. The 77 lines with limited seed, or which segregated as F_6's, were entered in single-row observational trials at IRRI on two dates of seeding.

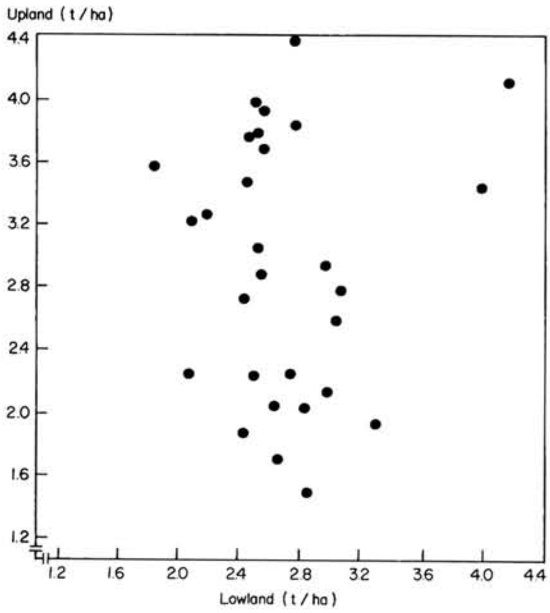
Plants in the replicated upland yield trial in a well-drained clay loam at IRRI grew well, although several susceptible entries were damaged by an outbreak of leaf blast at about 30 or 40 days after seeding. A buildup of brown planthoppers in September was followed by heavy incidence of grassy stunt, then by severe rat damage on ripening plants. The stands in the non-replicated trial became sparse and uneven shortly after seeding when the heavy soil caked. Sheath blight also limited the yields of susceptible lines. Harvests were so erratic that the yield data were not indicative of the yield potential of the F_7 lines.

Blast also developed on susceptible varieties at Santo Tomas. One upland selection, IR1746-226-1, yielded 4.4 t/ha, followed by IR5 which yielded 4.2 t/ha (Table 10). Four other selections yielded between 3.7 and 3.9 t/ha; these yields compared favorably with the improved Philippine upland variety C22 (3.8 t/ha). Two other traditional upland varieties, M1-48 and OS4, yielded 3.6 and 2.0 t/ha. IR442-2-58 yielded only 1.7 t/ha because it was susceptible to blast at the seedling stage.

We compared the heading dates of various entries with the rainfall data at Santo Tomas and found that a 3-week dry spell preceded panicle initiation of most of our selections and of M1-48. But IR5 probably benefited by the rains which came from the time of flowering to ripening.

We also compared the yields of varieties and lines in the upland trials at Santo Tomas with those in the lowland trial at IRRI (Table 10). We found no correlation between yield performances under the two water-and-soil regimes (fig. 9).

Progenies of African upland × semidwarf crosses yield higher than do the traditional upland types. These selections yielded as much



9. Relationship between grain yields of 29 varieties and lines in an upland experiment in SantoTomas and in a lowland experiment at IRRI, 1973 wet season. The simple correlation coefficient was nonsignificant.

as the high-tillering improved upland variety C22 and more than the traditional upland varieties OS4 and M1-48. Their intermediate amylose contents are equal to those of most traditional upland varieties. Higher levels of resistance to the major diseases and insects will be incorporated into the new upland selections.

RICE GERM PLASM BANK

During 1973, IRRI received 4,660 seed samples. The major donors were Bangladesh, 722 samples; Indonesia, 1,540; Khmer Republic, 769; Republic of Korea, 400; Laos, 351; South Vietnam, 226; and Thailand, 113. Most samples from Bangladesh, Indonesia, and the Khmer Republic were collected from farmers' fields through collaborative efforts of the concerned governments and IRRI. The IRRI field advisor on rice collection participated in collections in Bangladesh, Burma, Indonesia, and the Khmer Republic. We discussed with national leaders the prospects of further field collections in Laos, Thailand, and South Vietnam. We also assisted an American anthropologist in assembling 63 samples from the Mountain Province, Philippines.

We tried to collect special types reported to be resistant to salinity, tolerant to acid-sulfate soils, or resistant to drought. Through literature surveys, extensive correspondence, and field collections, we acquired 29 saline-resistant varieties, 100 acid-tolerant types, 20 floating varieties, 938 upland varieties, and 45 varieties grown at high elevations in Indonesia.

We responded to 96 foreign requests from 38 countries and sent abroad 9,777 seed packages. We received several large requests for special types such as saline- or drought-resistant accessions. We also supplied 7,016 seed packages in response to 63 requests from IRRI research departments.

We also supplied 422 seed packages of wild species and 34 genetic testers in response to 22 requests from 11 countries. The increasing requests depleted our seedstocks for most wild species.

During the year, we planted 8,417 plots for seed multiplication, description, or rejuvenation. We completed description of 700 accessions, and partly recorded another 4,900 accessions.

Because so many of the samples were collected recently by many field workers in diverse regions, we checked all incoming seed samples to see if they were duplicates of accessions already in the IRRI collection, or of other samples coming into the collection from the same country. The initial criteria in determining duplicate samples are the variety name (or its vernacular name), the country of origin, and the seed characteristics. By such comparisons, we found that 414 samples from Bangladesh, Indonesia, and the Khmer Republic are probably duplicates; we stored the seeds for critical study. Another 475 questionable samples from Indonesia were identified as duplicates after we planted them in the field side by side with samples with identical or similar names. One hundred and eighty breeding lines from South Korea and 600 pure lines from Bangladesh are being held in cold storage until we receive detailed information about their parentage. Another 832 samples are being temporarily stored because of limited field space for planting.

In this manner, we have been able to separate the duplicate samples and to accommodate the new samples in our seed-increase and characterization operations without straining our limited manpower and physical facilities. A total of 3,951 distinct new accessions were added to the collection during 1973.

GENETICS AND CYTOGENETICS

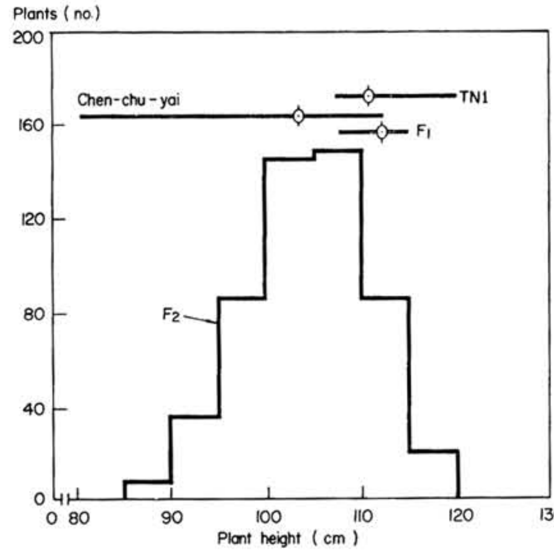
Allelic relationship between Chinese semidwarfs. During 1970 and 1971, we received from other countries three semidwarf varieties which originated from the China mainland: Cheng-chu-ai 11 and Chi-nan-ai from Sri Lanka, and Chen-chu-yai from Pakistan. These varieties are morphologically similar to Taiwan's semidwarfs, Dee-geo-woo-gen and Taichung Native 1, but they differ slightly in growth duration and in grain shape. We do not know their breeding histories.

We crossed each of the three semidwarfs with TN1. The F_1 and F_2 progenies, along with the parents, were grown in the wet season. Those crosses which involved Chen-chu-yai and Chi-nan-ai produced F_1 hybrids similar in height to both parents. Further, the range of F_2 segregation was within the limits of parental variation in each cross (fig. 10, 11). Therefore, Chen-chu-yai and Chi-nan-ai apparently have the same semidwarfing gene as TN1, although they may have different modifying genes for height.

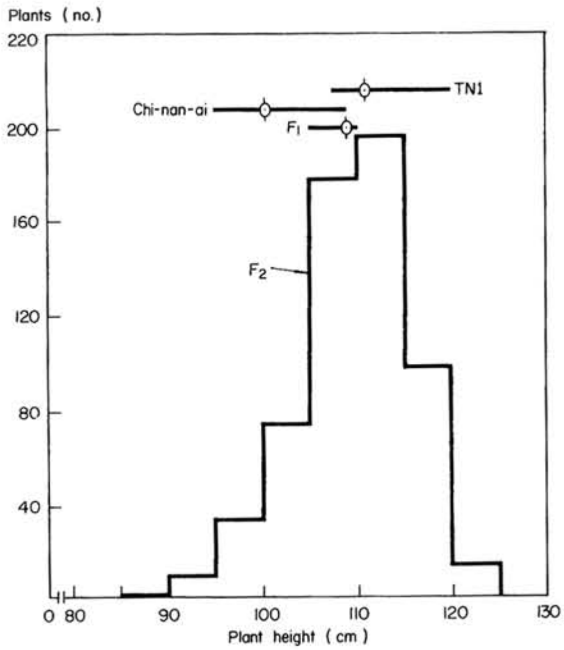
In the cross between Cheng-chu-ai 11 and TN1, the F_1 hybrids averaged 150 cm tall while both parents were slightly more than 100 cm. The F_2 population distinctly segregated in a range from 80 to 200 cm (fig. 12). Obviously, Cheng-chu-ai 11 and TN1 have different genes for semidwarfism. Further crosses are needed to determine if a major recessive gene controls the short stature of Cheng-chu-ai 11, as in TN1.

A new source of semidwarfism offers rice breeders the opportunity to diversify the genetic backgrounds in semidwarf breeding programs. Our studies have shown that the following semidwarfs share the same recessive dwarfing gene: Dee-geo-woo-gen, I-geo-tze, and Taichung Native 1 from Taiwan; Purbachi from the China mainland via Pakistan; and the C53-39 mutant from Burma. Studies in Taiwan indicate that three induced semidwarf mutants (KT 20-74, IKB 4-2, and SC 30-21) also carry the same gene. Seven short-statured varieties collected from Assam, India, were also reported to have the recessive gene.

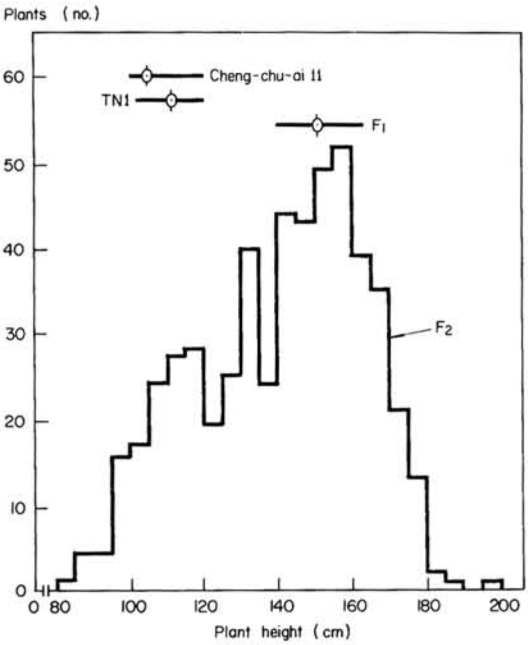
Inheritance of protein content. Protein analysis of individual F_2 grains of 12 crosses (1972



10. Segregation for plant height in F_2 population of Taichung Native 1/Chen-chu-yai.



11. Segregation for plant height in F_2 population of Taichung Native 1/ Chi-nan-ai.



12. Segregation for plant height in F_2 population of Taichung Native 1/Cheng-chu-ai 11.

Annual Report) indicated that low protein content was dominant to high protein content. Because the endosperm is of triploid tissue, its protein content can be affected by the two doses of alleles from the maternal parent or by the xenia of a set of alleles from the paternal parent. The protein content of F_2 plants, represented by that of F_3 grains sampled from each plant, would be a more reliable indicator of the mode of segregation in the F_2 generation.

We planted 12 crosses in the dry season: two combinations of high × high protein content, seven of high × low, and three of low × low. Each cross included 40 plants of each parent and about 500 F_2 plants. Protein content of each F_2 plant was determined from a bulk sample of ground brown rice randomly sampled from two or three of the five early heading panicles.

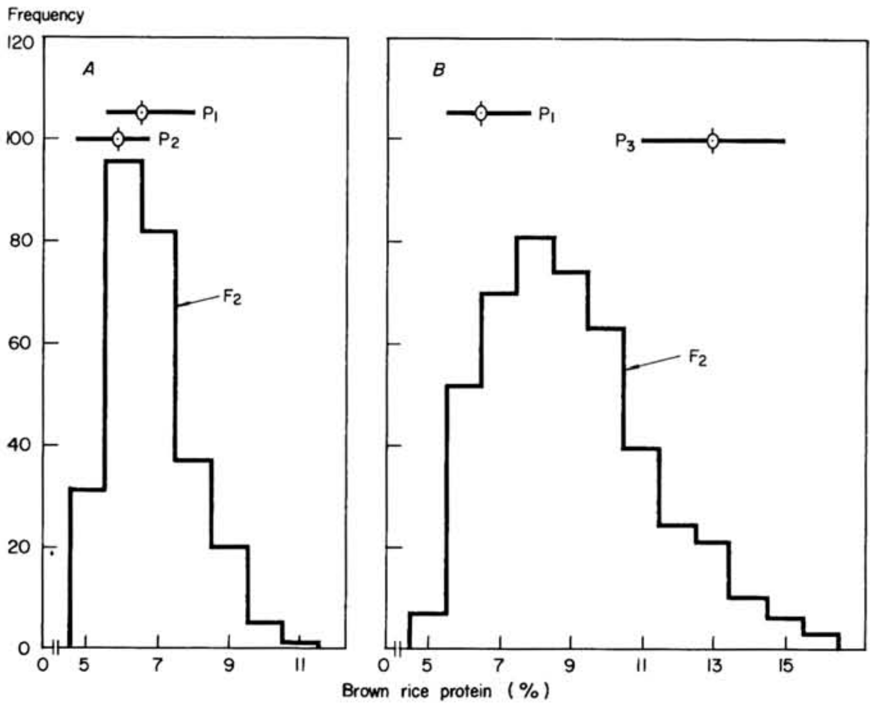
Ten of the 12 F_2 populations showed a significant or highly significant positive skewness in distribution, indicating an excess of low-protein plants.

Although some parents distinctly deviated from their previous ranking in protein content, only a few low-protein segregates were lower than the lower limits of the low-protein parents. But a few transgressive segregates with high protein were found in two high × high and three high × low cross combinations (fig. 13). None of the three low × low crosses produced high-protein plants.

The positive skewness of distributions of F_2 plants again confirmed our 1972 findings—that low protein is dominant to high protein content. The continuous nature of F_2 distribution indicated that many genes with additive effects are also operating. The combined action of additive and dominance gene effects may explain the predominance of low-protein segregates and a lack of transgressive segregates on the high end of distribution in low × low crosses. On the other hand, a few transgressively high-protein plants may appear as 1) products of gene interactions which include complementary gene action, 2) differential effects of environment on high-protein segregates, or 3) combined effects of the additive and recessive alleles for high protein. Through progeny testing, we can differentiate between the true-breeding nature of the additive-plus-recessive effects, and the unstable phenotypes with high protein due to gene interaction or environment, or both.

Affinity between *O. sativa* **and** *O. nivara*. In cooperation with cytogeneticists of the University of the Philippines at Los Baños, we began studying the genetic affinity between cultivars of *O. sativa* and a wild relative, *O. nivara*. We chose one strain of *O. nivara* (accession 101508) because unlike the other 80 strains it is resistant to grassy stunt.

Spikelet fertility was determined from F_1 hybrids of crosses between *O. nivara* and each of six cultivars: Dee-geo-woo-gen, Taichung Native 1, IR5, IR8, Mudgo, and TKM 6. The range in spikelet fertility of various F_1 hybrids varied from 40 to 83 percent. Because the *O. nivara* parent was partially sterile (54% fertility) and the six cultivars also varied in panicle fertility, we compared the F_1 fertility with that of the two parents in statistical tests. The mean fertility of six F_1 populations was different from that of either of the two parents involved in each of the six crosses, with one exception. In the reciprocal crosses of *O. nivara*/Mudgo, the F_1 plants did not differ from their respective male parents in spikelet fertility. Comparisons of pollen fertility of the same sets of crosses and parents would



13. Distribution of parents and F_2 plants (represented by F_3 grains) by brown rice protein content in (a) low × low cross and (b) low × high cross. P_1, IR1103-46-3; P_2, IR1093-148-3; P_3, IR1100-18-3.

indicate more reliably the genetic affinity between the two species.

Resistance to bacterial blight. We continued to study the genetics of resistance to bacterial blight. To determine the mode of inheritance and the allelic relationships of genes for resistance, we are investigating the varieties commonly used as sources of resistance in breeding programs. Two loci for resistance have been identified. BJ 1 and DZ 192 each seems to have a single recessive allelic gene for resistance. Sigadis, TKM 6, and IR22 each has a dominant allelic gene for resistance. The resistance of Zenith seems to be controlled by another locus.

Resistance to grassy stunt. On the basis of F_2 and backcross data, we earlier concluded that a dominant gene controls resistance to grassy stunt in *Oryza nivara*. This was verified by a study of an F_3 population. One plant from IR24^3/*O. nivara*, heterozygous for grassy stunt resistance, was selfed and an F_2 population was grown without being inoculated with grassy stunt. Of 376 F_3 lines tested for grassy stunt resistance, 89 were found homozygous resistant, 203 were segregating, and 84 were susceptible. These data agree with the 1:2:1 ratio expected on the basis of monogenic control of resistance. The dominant gene for grassy stunt resistance is designated as *Gs*.

A line resistant to grassy stunt from IR1737 (IR24^4/*O. nivara*) was crossed with a line resistant to brown planthoppers from IR1539 (IR24//Mudgo/IR8). Three hundred and seventy-four F_3 families from this cross were screened for resistance to grassy stunt and brown planthoppers. A two-way classification indicates that resistance to the virus and resistance to the vector are inherited independently of each other.

Table 11. F_3 lines of IR1539-525/IR1737 classified for their reactions to brown planthoppers and grassy stunt disease.[a,b]

Reaction to grassy stunt	Lines (no.)			
	Reaction to brown planthoppers			Total
	Resistant	Segregating	Susceptible	
Resistant	24	49	23	96
Segregating	53	74	45	172
Susceptible	20	61	25	106
Total	97	184	93	374

[a] X^2 for independence of two traits = 6.8^{ns} [b] X^2 for 1:2:1:2:4:2:1:2:1 = 10.0^{ns}

Table 12. Segregation for resistance to brown planthoppers in the F_2 generation of crosses between resistant and susceptible parents.

Cross	Seedlings (no.)			X^2	P
	Resistant	Susceptible	Total	3:1/1:3	3:1/1:3
TN1/IR747B2-6	1582	575	2157	3.06	0.1-0.05
IR1154-243/TN1	904	2802	3706	0.70	0.5-0.30
IR4-93/TN1	727	2090	2817	0.93	0.5-0.30

Table 13. Classification of F_3 families of crosses between resistant selections and TN1 for their reactions to brown planthoppers.

Cross	Families (no.)				X^2	P value
	Homozygous resistant	Segregating	Homozygous susceptible	Total	1:2:1	1:2:1
IR747B2-6/TN1	57	109	54	220	0.08	1.0-0.95
IR1154-243/TN1	53	108	59	220	0.39	0.9-0.70

The segregation data in Table 11 show the monogenic natures of the two traits. The proportion of resistant, segregating, and susceptible genotypes for each trait fit the expected 1:2:1 ratio.

Resistance to brown planthoppers. We investigated inheritance of resistance to brown planthoppers in three breeding lines: IR4-93, IR747-B2-6, and IR1154-243. IR4-93 inherited its resistance from H-105. Both parents of IR747B2-6, as well as those of IR1154-243, are susceptible. The F_1 plants of IR747B2-6/TN1 were resistant, indicating that resistance is dominant. But the F_1 plants of IR1154-243/TN1 and IR4-93/TN1 were susceptible, showing that resistance is recessive in these two selections. The F_2 data (Table 12) show that IR747B2-6 has a single dominant gene for resistance while a single recessive gene governs the resistance of IR1154-243 and IR4-93. These conclusions were confirmed by the study of F_3 families of the crosses IR747B2-6/TN1 and IR1154-243/TN1. The proportions of homozygous resistant, segregating, and susceptible families of both crosses fitted the 1:2:1 ratio expected for monogenic segregation (Table 13).

Table 14. Resistance to brown planthoppers in the F_2 generations of crosses between resistant lines.

Parent or hybrid	Plants (no.)			Dead seedlings (%)
	Live	Dead	Total	
IR747B2-6	597	34	631	5.89
IR1154-243	740	47	787	5.97
IR4-93	590	28	618	4.53
Mudgo	608	7	615	0.01
ASD 7	350	5	355	0.01
Mudgo/IR747B2-6	3971	61	4032	1.51
IR1154-243/IR747B2-6	3251	130	3381	3.85
IR4-93/IR747B2-6	4115	41	4156	0.99
IR1154-243/Mudgo	4842	21	4863	0.43
Mudgo/IR4-93	4355	56	4411	1.27
IR4-93/IR1154-243	3857	129	3986	3.24
IR1154-243/ASD 7	2704	17	2721	0.62

Information on allelic relationships of genes for resistance was obtained from the reactions of F_1, F_2, and F_3 progenies of crosses between these lines as well as of Mudgo, which has a dominant gene for resistance (*Bph 1*), and ASD 7, which has a recessive gene for resistance (*bph 2*). The F_1 progenies of all cross combinations among resistant parents were resistant; so were the reciprocal crosses. Because IR1154-243, IR4-93, and ASD 7 have recessive genes and the F_1 progenies of IR1154-243/IR4-93 and IR1154-243/ASD 7 are resistant, these three lines must have the same recessive gene for resistance. Table 14 shows data on F_2 segregations. A few seedlings died and were classified as susceptible in all F_2 populations. But fewer died than we expected on the basis of independent assortment of resistance genes. We cannot determine from these data whether the dead seedlings represented the susceptible class from the recombination of non-allelic genes, or if seedlings died because the gene for brown planthopper resistance in some individuals lacked penetrance. The latter seems more plausible because a similar proportion of seedlings of the resistant parents also died. So, the dominant genes for resistance in Mudgo and IR747B2-6 are apparently allelic. We confirmed this conclusion in a study of 219 F_3 lines of this cross, all of which were homozygous resistant (Table 15).

We found similar results from the study of F_2 and F_3 populations of other crosses between resistant varieties. All F_3 lines were homozygous resistant except one line of the IR1154-243/IR747B2-6 cross. This line must have resulted from a contaminant seed because the product of a rare recombination should be heterozygous. Thus we found no evidence of genetic recombination between the dominant genes for resistance in Mudgo and IR747B2-6 and the recessive genes for resistance in IR4-93, IR1154-243, and ASD 7.

Because IR747B2-6 originated from the cross of two susceptible varieties, TKM 6 and TN1, we repeated the cross and also crossed TKM 6 with several other susceptible varieties. The F_1 seedlings of all cross combinations were susceptible. But a few resistant seedlings from these cross combinations appeared in the F_2's (Table 16). In F_3 progeny tests, they proved to be heterozygous for resistance since they produced segregating progenies. Therefore, they must all have dominant genes for resistance. Although we have not made allele tests between these resistant progenies and IR747B2-6 or Mudgo, we suspect they all have the *Bph 1* gene. Because IR1154-243 was obtained from a cross of IR8 and Zenith, we repeated the cross and crossed Zenith with several other susceptible varieties. We are studying the F_2 and F_3 progenies.

The resistance in the progenies of TKM 6 crossed with other susceptible varieties could not have originated from complementary gene action since the resistance in IR747B2-6 is under monogenic control. It also seems improbable that resistance in these selections originated through mutation. The resistant seedlings appear in many crosses involving TKM 6 at frequencies too high for random mutational event. The logical explanation from the available data is that TKM 6 is homozygous for *Bph 1* as well as for a gene which inhibits *Bph 1*. Because F_1 seedlings from crosses of TKM 6 and other susceptible varieties (such as IR8 and TN1) were found susceptible, the inhibitor of *Bph 1* must be dominant. This dominant inhibitory gene is designated *I-Bph 1*. The genotype of TKM 6 thus would be *I-Bph 1 I-Bph 1*, *Bph 1 Bph 1* and that of TN1, *i-bph 1 i-bph 1*, *bph 1 bph 1*. Although an independent assortment of *I-Bph 1* and *Bph 1* from crosses of TKM 6 and other susceptible varieties such as TN1 should yield 18.75 percent resistant seedlings, the actual proportion is much lower. *I-Bph 1* and *Bph 1*, therefore, seem closely linked. Only recombinant gametes with *i-bph 1*, *Bph 1* alleles yield such resistant seedlings.

Table 15. Reactions to brown planthoppers of F_3 families of crosses between resistant varieties and selections.

Cross	Families (no.)		
	Homozygous resistant	Segregating	Homozygous susceptible
IR747B2-6/Mudgo	219	0	0
IR1154-243/ IR747B2-6	209	0	1
IR4-93/IR747B2-6	220	0	0
IR1154-243/Mudgo	220	0	0
Mudgo/IR4-93	220	0	0
IR4-93/IR1154-243	220	0	0
ASD 7/IR1154-243	217	0	0

Table 16. Reactions of F_2 seedlings from the crosses of TKM 6 and other varieties which are susceptible to brown planthoppers.

Cross	Seedlings (no.)		Resistant seedlings (%)
	Susceptible	Resistant	
TN1/TKM 6	4926	1	0.02
IR5/TKM 6	1672	3	0.18
IR8/TKM 6	1872	4	0.21
IR20/TKM 6	2111	0	0.00
IR22/TKM 6	1997	2	0.10
IR24/TKM 6	230	2	0.86

Agricultural engineering

The design for an axial flow multicrop thresher was finalized and manufacturers in several countries began production of the machine. ☐ The third prototype of an experimental stripper harvester neared completion. ☐ More than 3,000 IRRI 5-hp to 7-hp power tillers were manufactured in the Philippines during 1973. A wide range of implements is being adapted to the tractor to broaden its utility. ☐ Testing the prototype of a 8-hp to 14-hp diesel power tiller indicated the need for further development. ☐ Herbicide applicators designed to reduce chemical requirements and to increase precision of placement were tested. ☐ We undertook development of a simple, inexpensive moisture meter. ☐ Changes to reduce the cost of the 1-ton batch dryer were completed. ☐ Tests indicated significant potential for improved output of the Engleberg rice mill through minor design changes. ☐ Field surveys of large tractor operators indicate profitable use in contract land preparation, and large potential for expanding their use in other operations. ☐ The nature of grain losses in the fields showed that post-harvest systems should be improved to realize the full yield potential of the new rice technology.

MACHINE DESIGN AND TESTING

Axial-flow thresher. We tested the axial-flow thresher (fig. 1) extensively and improved the design. The 480-kg machine, now in production, is powered by a 7-hp engine and threshes 1 t/h of paddy with three operators.

Primary criteria for the final design were performance, reliability, cost of production, and simplicity of operation and maintenance. For longer life and more aggressive threshing action, we changed the wire-loop threshing cylinder to a pegtooth cylinder with bolts 1.1 cm in diameter as pegs. For increased capacity and longer life, we replaced the perforated sheetmetal concaves with a concave of steel rods and bars. The upper concave is hinged and independent of the cover for easy cleaning and access to the threshing cylinder. Separate cover and concave assemblies also make fabrication easier.

We increased the diameter of the grain auger from 7.6 cm to 10.2 cm, and increased the rotary screen area by 20 percent, to match the grain transfer and cleaning capacity to the threshing output. A sheetmetal trough was installed inside the rotary cleaner to eject straw pieces adhering to the rotary screen.

The single-belt drive system was replaced with independent belt drives to the key components. The life of the engine drive belt was increased by eliminating the small clutch idler and mounting the engine on a simple sliding frame. An over-center linkage moves the engine to engage or disengage the drive.

We designed a hitching and seat arrangement so that the thresher can be towed behind a power tiller while the operator sits on it.

1. Axial flow thresher with cover open and upper concave exposed.

An improved drafting system provides more lucid drawings and a new numbering system makes identification of parts easier. This will help manufacturers to estimate the costs and to build the thresher.

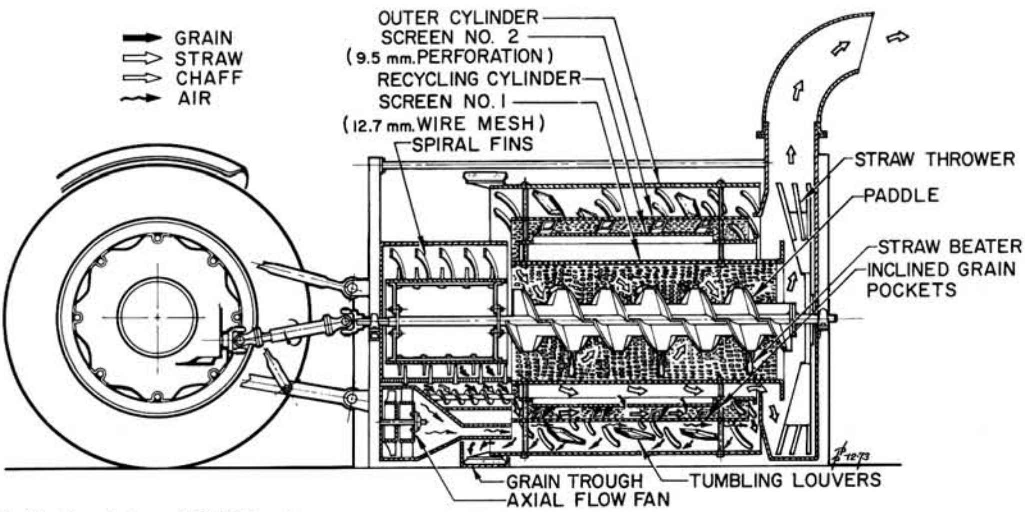
The thresher's ability to operate under adverse conditions has elicited praise from farmers. Limited trials with soybeans and sorghum indicate that the machine may also be used for other crops.

PTO thresher. We tested the second prototype of the PTO thresher (fig. 2) which has several desirable new features (1972 Annual Report). The feeding conveyor increased the rate and uniformity of feeding and was primarily responsible for the increased threshing output (2.5 t/ha) with dry paddy. Separation losses ranged from 1 to 3 percent. Cleaning efficiency, however, was not satisfactory at the higher output.

The concentric space between the outer cylinder and the No. 2 screen was increased to 15 cm by increasing the diameter of the outer cylinder. The number of grain-conveying louvers was increased from 64 to 96 and the tumbling louvers from 24 to 48. The airflow pattern was improved by widening the outlet of the tapered airduct. The inner cylinder was changed from perforated sheetmetal to a heavy wire mesh. Threshing and separation efficiencies were unchanged but cleaning efficiency was not significantly improved.

We examined the relationship of the conveying and tumbling louvers and altered them so that grain would be constantly tumbled and impurities would be suspended in the air. We are testing this arrangement.

Stripper harvester. The self-propelled stripper harvester does not sever the plant stems but uses "fingers" to strip the spikelets from the panicles. Data obtained from operating an experimental four-row stripper harvester (1972 Annual Report) were used to design a six-row prototype (fig. 3). The wide crop dividers required to accommodate the half-track system of the four-row unit significantly reduced the throat openings of the side intake mechanisms. Plants at the edge of the swath were deflected toward the center before entering the machine. This deflection hindered entry, leaving plants unthreshed



2. Sectional view of PTO thresher.

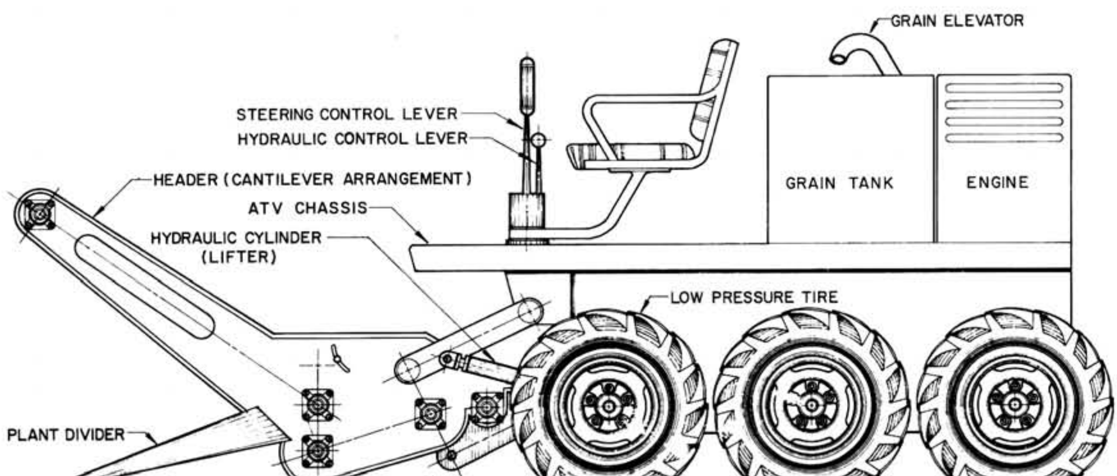
at the swath edge. The six-row width permitted the design of a six-wheel all-terrain vehicle (ATV) power unit which is narrower than the swath width. This allows the use of narrow crop dividers to simplify plant entry into the machine.

The power unit uses a 19-hp aircooled engine. The wheels on the right side of the machine are driven independently of those on the left side, permitting use of a skid-steering mechanism. The stripping header is suspended on a parallelogram linkage and can be hydraulically raised and lowered to the desired harvesting height.

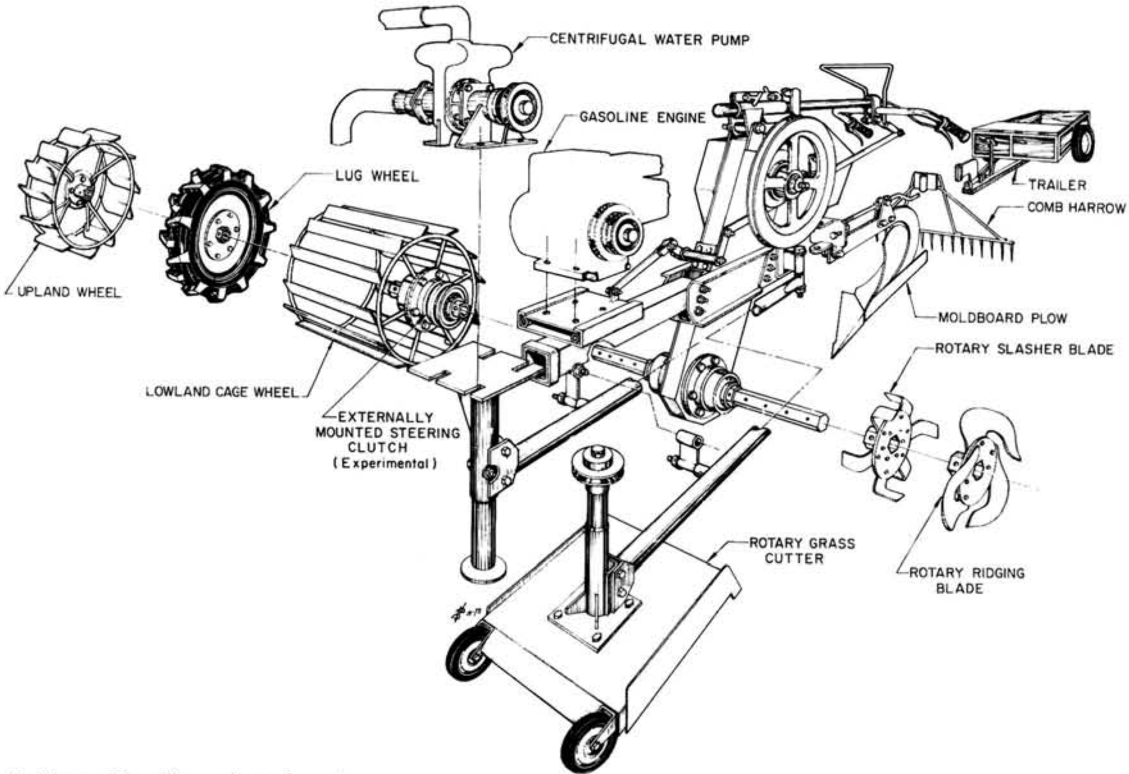
The slat chain conveyor was replaced with a solid rubber belt with metal slats. The rubber belt delivers the grain-chaff mixture onto a vibrating wire rake. A centrifugal blower winnows the grain as it falls through the vibrating rake, into a cross-feed auger, and to a grain elevator for delivery to bags or grain tanks.

Field evaluation of the new machine will be conducted in 1974.

5-hp to 7-hp tiller. The favorable market response in the Philippines continued, and approximately 3,000 IRRI-designed units were sold during 1973. Ten attachments are available for the tiller (fig. 4).



3. Six-row stripper harvester.



4. 5-hp to 7-hp tiller and attachments.

Several other manufacturers have now entered the market with similar designs. Three of these manufacturers requested that we evaluate their prototypes. We subjected each machine to our standard test procedure: operation for at least 100 hours. Each machine failed at least once during the tests. Failures were similar to those with the initial production prototypes of the IRRI tiller. Many failed because parts were improperly machined or components were incorrectly assembled. We provided full reports to the manufacturers with recommendations for improvement.

Testing of these and the IRRI-designed tillers revealed some items which required improvement. The tiller was originally designed for a 4-hp to 6-hp engine, but some manufacturers are using 7-hp to 9-hp engines; thus, stress on some components is higher than anticipated. We replaced the No. 40 roller chain with a No. 50 chain in the second speed reduction of the transmission to reduce chain strain and to provide an equal amount of chain stretch in the first and second speed reductions. The countershaft for the second stage speed reduction was increased in diameter from 1.91 to 2.54 cm. We modified the main drive clutch arrangement by replacing the belt idler system with a sliding engine base and an over-center lever. This modification lengthens life and makes it easier to switch the engine from the tiller to the axial-flow thresher. External steering clutches have been fitted onto the axle shaft as optional equipment. Evaluation of these and other improvements will continue.

8-hp to 14-hp tiller. We completed the 8-hp to 14-hp power tiller (1972 Annual Report) and compared it with a popular Japanese power tiller in tests. The prototype (fig. 5) used an automotive three-speed gearbox. Ground speed ranged from 3.8 to 8.4 kph. This speed is too fast, especially for tillage of lowland rice fields. The speed of the rotary tiller was designed to vary with ground speed. Tests showed that this was a detriment in the high gear. Failures occurred in the rotary tiller drive and the steering clutches. We are designing a transmission which will provide a better range of ground speeds with a lower first gear and improved steering clutches.

The rotary tiller drive will be independent of ground speed.

Contact herbicide applicator. The use of non-selective herbicides in crop production is limited by a lack of suitable applicators. Application by high-pressure spraying may damage crops.

We evaluated five concepts for applying direct-contact herbicides in row crops without crop damage: 1) a rag or bristle mop dipped in the solution; 2) a brush with a drip-feed mechanism; 3) a urethane foam ground roller with external drip feed; 4) a urethane foam ground roller with automatic roller feed; and 5) a urethane foam ground roller with automatic internal roller feed. The fourth concept (fig. 6) was selected for further development.

The herbicide solution flows by gravity from the herbicide tank to the pan where it is maintained at a constant depth. The pick-up roller transfers solution to the spring-loaded feed roller. The feed roller transfers a uniform film of solution to the ground roller. The operator can stop the flow of herbicide to the ground roller by pulling a cable which disengages the feed roller from the other two rollers. The ground roller applies the herbicide to the ground.

In a trial with rice under upland conditions, we evaluated four herbicides at five different rates of application. All four herbicides, MCPA-K salt, 2,4-D, glyphosate, and paraquat, were applied 25 days after seeding. We rated the crop for weed control and toxicity at 14 days and 30 days after the treatments. None of the treatments were generally toxic to the crop, except MCPA-K salt and 2,4-D at higher rates. Both glyphosate and paraquat gave good weed control at 14 days after treatment (fig. 7). Weed control was only fair on plots treated with 2,4-D and MCPA-K salt, probably because they were applied at an incorrect time.

We will continue tests using other herbicides or combinations of selective and non-selective herbicides, with particular attention on time of application.

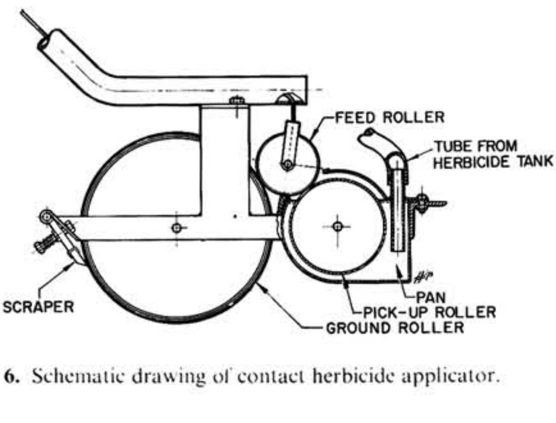
Moisture tester. Grain moisture is the primary index for determining the fitness of grain for harvesting, storing, and milling. A rapid, inexpensive moisture tester is needed because of increased rice production, a greater use of grain dryers, and the trend to sell grain based on

5. Prototype of 8-hp to 14-hp tiller.

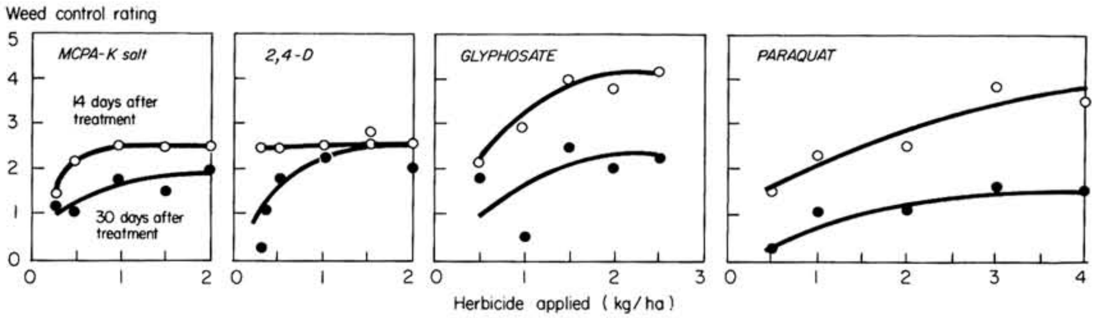
moisture content. We evaluated the construction and operating principles of four conductance-type moisture testers. We designed a circuit and constructed a prototype. The moisture tester (fig. 8) consists of a galvanometer, two selector switches, an electric circuit, a grain-measuring cell, a grain test cell, and a battery housed in a steel case. The tester is portable and operates on either AC or batteries.

We are calibrating the prototype using a standard oven method of measuring moisture by determining the moisture content of paddy at 12 to 30 percent moisture. To determine a temperature correction factor, we are making calibrations at 22, 27, and 32 C.

Batch dryer. The 1-ton batch dryer (fig. 9) was released for production in 1972. Since its release, the design of the dryer has been refined and its economics evaluated.



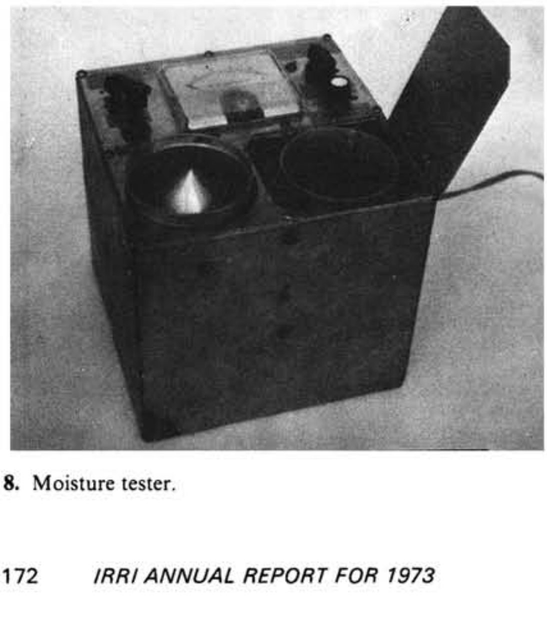
6. Schematic drawing of contact herbicide applicator.



7. Weed control rating and application rate for contact applicator.

An improved blade design increased the airflow of the axial vane fan from 49.5 to 58.0 cu m/min when operating at 2,200 rpm against a static pressure of 2 cm of water. To facilitate manufacture, the clearance from the blade tip to fan housing was increased to 0.5 cm.

Because of rapidly rising steel prices, we designed a bin made primarily of wood which uses 0.48 cm tempered hardboard for siding, expanded sheetmetal for the grain floor, plastic sheeting for the plenum floor, and rough lumber for the supporting frame. The bin area is 5.95 sq m (2.44 × 2.44 m), which is 0.94 sq m larger than that of the metal-bin model. The wooden bin uses standard 1.22 m × 2.44 m hardboard sheets, which minimizes wastage. The wooden bin has a capacity of 1.1 tons at a grain depth of 30 cm and 1.6 tons at a grain depth of 45 cm. The cost of the wooden bin is only a third that of the metal unit (Table 1). In tests, the average drying rate of the wooden bin was equal to that of the metal bin: 2 percent/h with grain at a depth of 30 cm, and 1.5 percent/h at 45 cm.

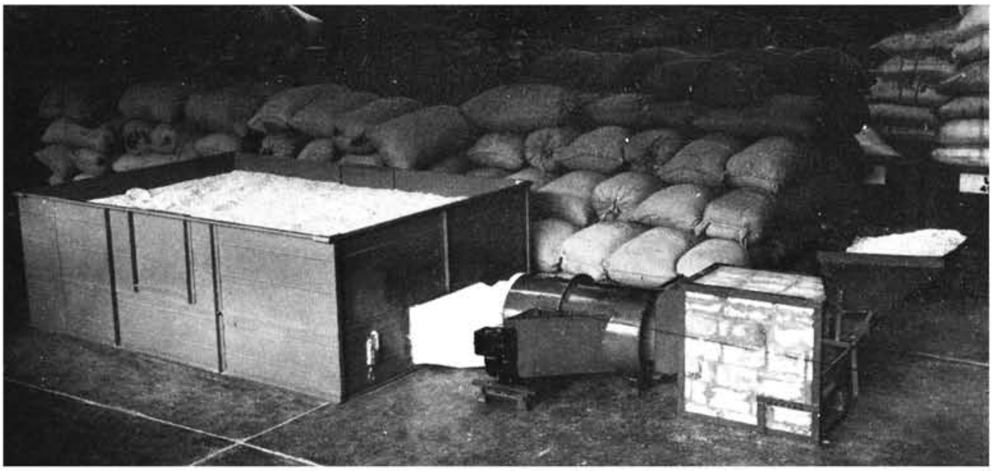


8. Moisture tester.

In cost comparisons, the life of a wooden bin is assumed to be 60 percent that of a steel bin (Table 1). This may be an unfair assumption because neither type has been used to destruction, and the wooden bin is easily repaired in the field. Drying costs of the IRRI kerosene burner and the rice-hull furnace are compared in figure 10. The number of hours of annual use significantly influences the average costs of drying.

Engleberg mill. The Engleberg mill is the most popular mill for small operations across Asia. But its milling yield is low and a high proportion of grains are broken. We have attempted to improve the Engleberg mill by reducing the loss of paddy from inefficient milling. We wanted to develop a design to modify existing components so that old mills could be modernized simply by replacing a few parts.

For test and development, we obtained a locally produced mill equipped with a 28-cm cylinder with a capacity rating of 175 to 265 kg/h paddy. We replaced the sliding gate at the grain outlet with an adjustable weight-loaded gate, which permits automatic variation of the discharge opening in response to pressure within the machine. We tested a cylinder with a continuous single-thread spiral section on the inlet end and two straight ribs along the remainder. A semicircular liner of sheetmetal was installed between the top case and the steel cylinder. This insert had four ribs, each 0.3 × 0.6 × 9 cm mounted at a 15° angle to the cylinder axis. A piece of flat steel was attached to the liner at the inlet end to constrict the space between the liner and the cylinder. Two full-length ribs, 0.3 × 0.6 cm, were attached to the bottom screen



9. IRRI batch dryer with rice hull furnace and metal bin.

(fig. 11).

Table 2 shows that maximum total milling and head rice yield were obtained with all four modifications using an average blade clearance of 0.7 cm.

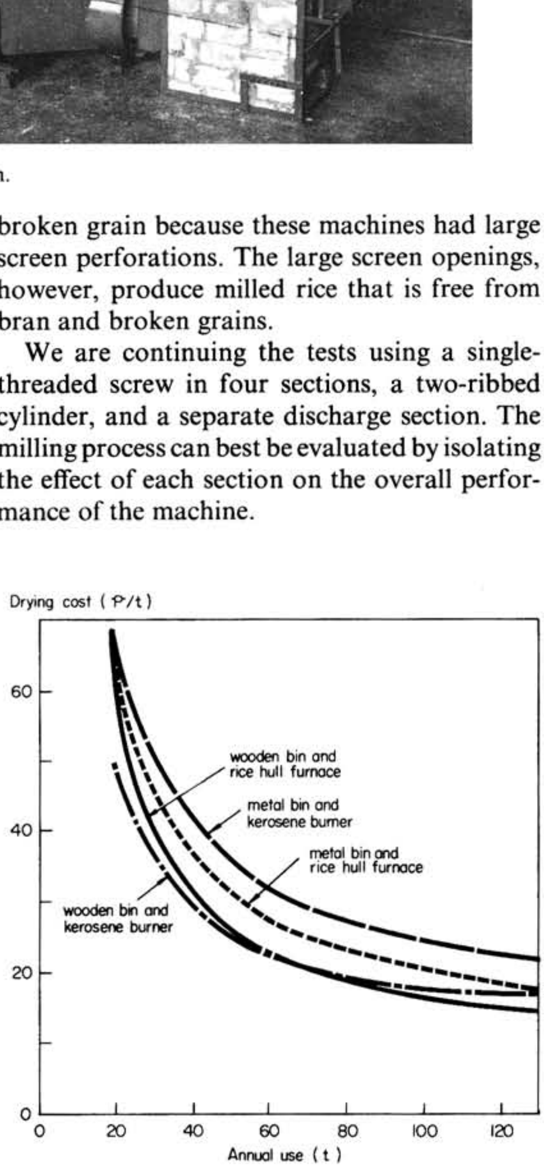
A series of tests using commercial Engleberg mills and similar samples of paddy gave lower total recovery and head rice yields than did the IRRI test mill. The bran from the commercial mills was coarse and contained fine pieces of broken grain because these machines had large screen perforations. The large screen openings, however, produce milled rice that is free from bran and broken grains.

We are continuing the tests using a single-threaded screw in four sections, a two-ribbed cylinder, and a separate discharge section. The milling process can best be evaluated by isolating the effect of each section on the overall performance of the machine.

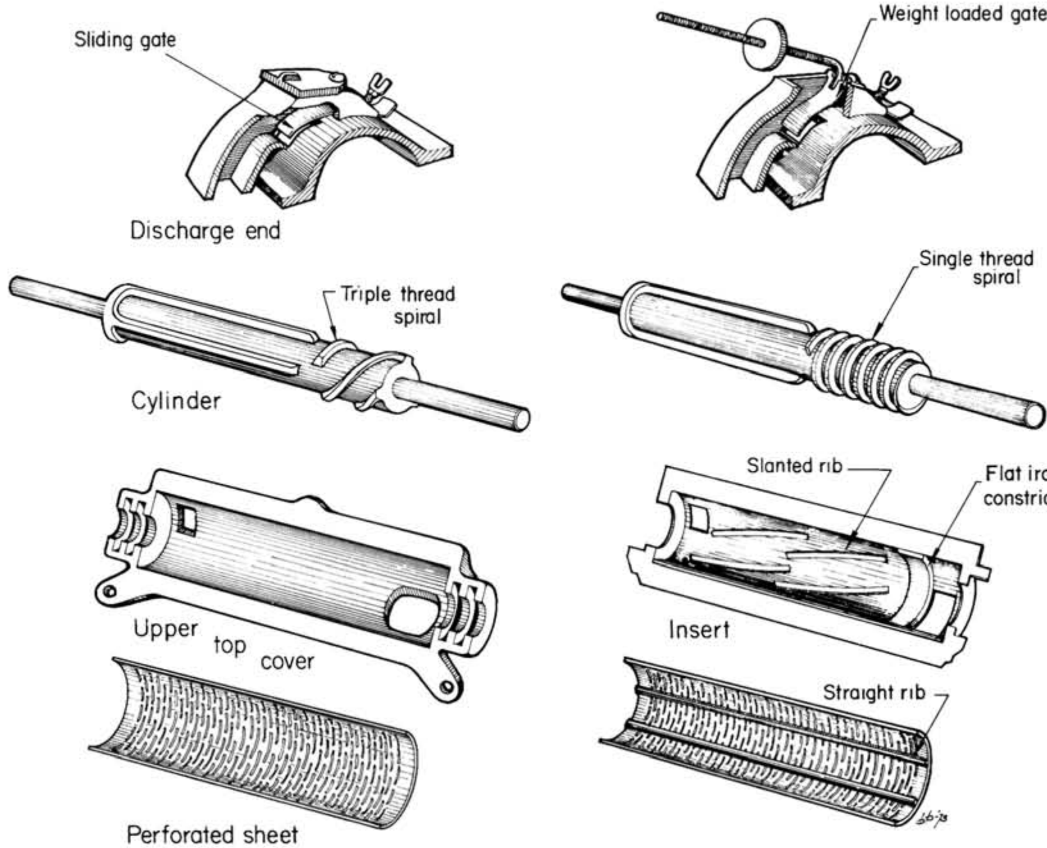
Table 1. Cost budget for four dryer assemblies.

Item	Costs (P)			
	Metal bin + kerosene burner	Metal bin + rice hull furnace	Wooden bin + rice hull furnace	Wooden bin + kerosene burner
Capital investment[a]	4210.00	4120.00	2570.00	2660.00
Fixed costs:				
Depreciation[b]	842.00	904.00	856.67	612.00
Interest[c]	252.60	246.20	154.20	159.60
Total	1094.60	1150.20	1010.87	771.60
Variable costs/h:				
Gasoline[d]	0.50	0.50	0.50	0.50
Kerosene/rice hull	1.15	0.28	0.28	1.15
Labor[e]	1.00	1.00	1.00	1.00
Variable costs/t[f]:				
30 cm depth	12.78	7.94	6.50	10.45
45 cm depth	10.18	6.04	5.28	8.91

[a]Metal bin = P2150; blower assembly = P820; burner assembly = P690; wooden bin = P600; hull furnace = P600; gasoline engine drive = P615. [b]Estimated service life: 5 years—metal bin, engine, blower, and burner. 3 years—wooden bin, hull furnace. [c]12% on average capital investment. [d]At P0.59/1. Kerosene at P0.641/1. Rice hull at P0.05/kg for transport and handling. [e]2 man-h for loading and unloading/batch + 1.25 man-h for tending dryer. [f]10% moisture removed at rate of 2%/h at 30 cm and 1.5% at 45 cm.



10. The relationship of average cost and annual use for four dryer assemblies. Paddy was dried from 24% moisture to 14% moisture at a depth of 30 cm.



11. Original parts of the Engleberg mill and proposed modifications.

ECONOMICS OF MECHANIZATION

Large tractor contract operations. We surveyed 142 large tractor operators, representing about 30 percent of the tractor population of Nueva Ecija province, Philippines, in 1972-73 to determine patterns of ownership and to assess the technical and economic efficiency of the machines.

Most tractor owners were farmers who owned and operated their own holdings. Of the 142 tractors in the survey, 123 were owned by such

Table 2. Comparative milling results using a modified Engleberg steel huller mill and two commercial huller mills.[a]

Tests[b]	Recovery		Milling rate	Blade adjustment		Grain temperature
	Total (%)	Head (%)	(kg/h)	In (mm)	Out (mm)	(°C)
(No modifications)	68	34	308	4.6	4.6	43
(1)	68	35	287	4.6	4.6	46
(1,2)	67	33	294	6.2	6.2	46
(1,2,3,4)	69	45	265	6.4	7.4	47
(1,2,4)	67	33	291	2.5	8.1	50
(1,4)	68	43	238	3.5	5.8	52
(Commercial mills)	63	34	398	4.8	6.9	47
(Commercial mills)	65	35	350	—	—	49

[a]Data represent average of three milling test runs using IR20 with 95% purity and 13% moisture content. [b]Letters in parentheses represent modifications on test mills: 1-Rice outlet changed from slide to weight-loaded gate. 2-Cylinder with two ribs and continuous spiral screw. 3-Lining insert—a thin metal sheet placed beneath the top cover with four ribs slanted 15°, a full-length straight rib opposite huller blade, and inlet restriction. 4-Two strips with full-length ribs mounted on perforated cylinder.

Table 3. Tractor characteristics, Nueva Ecija, Philippines, 1972.

	Light	Medium	Heavy	All classes
Number of tractors	15	59	68	142
Average age (years)	9.3	4.3	3.4	4.4
Average horsepower	39	58	72	62
Purchase price (₱)	20,808	29,883	47,835	34,548
		Percent		
Acquisition				
Cash	40	15	10	15
Installment	60	85	90	85
Financing				
IBRD[a]	33	68	82	73
Dealer	22	22	10	17
DBP[b]	33	4	8	8
PNB[c]	11	2	—	1
Other	—	4	—	1
Power steering	—	17	28	20
Speeds				
8F-2R[d]	26	24	76	49
6F-2R	60	66	21	44
12F-2R	7	7	3	5
5F-1R	7	3	—	2
Fuel type	diesel	diesel	diesel	diesel
Implements commonly included	disc plow disc harrow rotavator	disc plow disc harrow rotavator	rotavator disc plow disc harrow	disc plow disc harrow rotavator

[a]International Bank for Reconstruction and Development. [b]Development Bank of the Philippines. [c]Philippine National Bank. [d]F = forward; R = reverse.

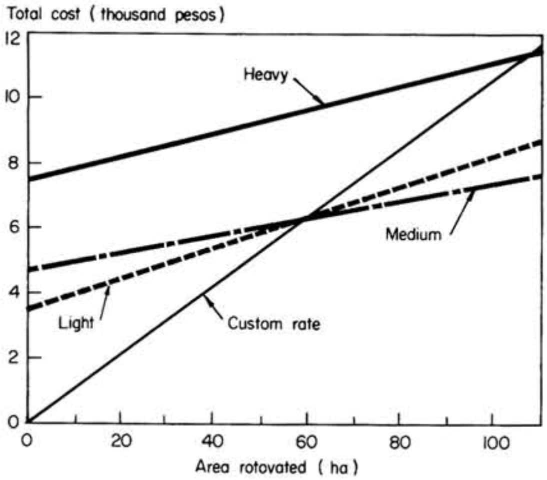
farmers. Only 10 machines were owned by operators with no land of their own, who only provide custom service. We found no apparent concentration of ownership among large landlords. Considering the amount of double-cropped irrigated land on farms with tractors, the average effective crop area is approximately 40 ha for all tractor sizes. The survey indicates a negative correlation between farm size and tractor size. Tractors were classified as light (below 50 hp), medium (50 to 65 hp), and heavy (above 65 hp). All tractors were diesel.

Initial investment requirements, sources of financing, and other related information are presented in Table 3. Note that investment costs for heavy tractors are slightly more than double those for light tractors. Heavy units are also more expensive per rated horsepower than are the lighter ones (₱664/hp vs ₱533/hp). While the price differential per horsepower reflects the differences in ages between the classes, it also indicates that we should rethink the usual assumption that there are increasing economies of scale for the purchase of large and small tractors.

The average age for light tractors was approximately 9 years. About 40 percent of them were purchased by cash. The average age of the heavy tractors was about 3-1/2 years. Ten percent of the heavy tractors were purchased with cash. The medium-sized tractors were of intermediate age and about 15 percent of them were purchased with cash.

The World Bank credit program provided most of the necessary funding for farm machinery purchase, including 80 percent of the large tractors. Commercial banks financed only a few tractors.

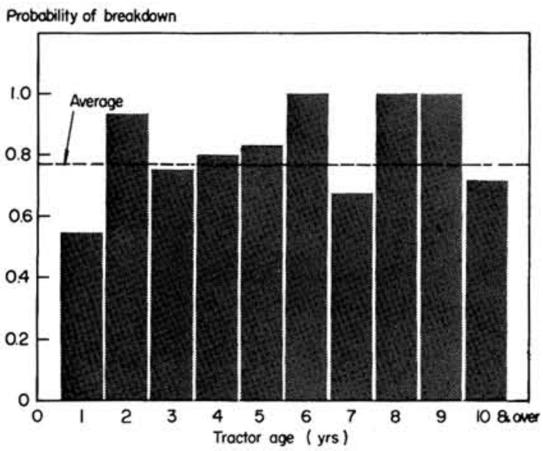
Tractors usually operated 11 hours per work day and were busy about 6 months per year. Annual hours of operation were about 1,400. Seventy-five percent of the total operating time was spent on custom work in the wet season and 84 percent in the dry season. The average maximum distance from home that tractors were taken to do custom work was 80 km. The tractors are used almost exclusively for land preparation. Other employment opportunities must be found to reduce the costs of operation. Figure 12 clearly shows that, at current market



12. Total costs of tillage with heavy, medium, and light tractors, Nueva Ecija, Philippines, 1972.

prices, heavy tractors are the most expensive form of power for land preparation.

The reliability of farm equipment is a major concern of mechanization, particularly in the tropics where machines must often work under conditions for which they were not designed. Breakdown probabilities are shown in figure 13. We excluded breakdowns due to wear because wear is normal and expected deterioration. More than 50 percent of the total breakdowns consists of hydraulic system failures. The major reason seems to be that the seals fail to effectively prevent soil, water, and other foreign material from penetrating into the operating systems.

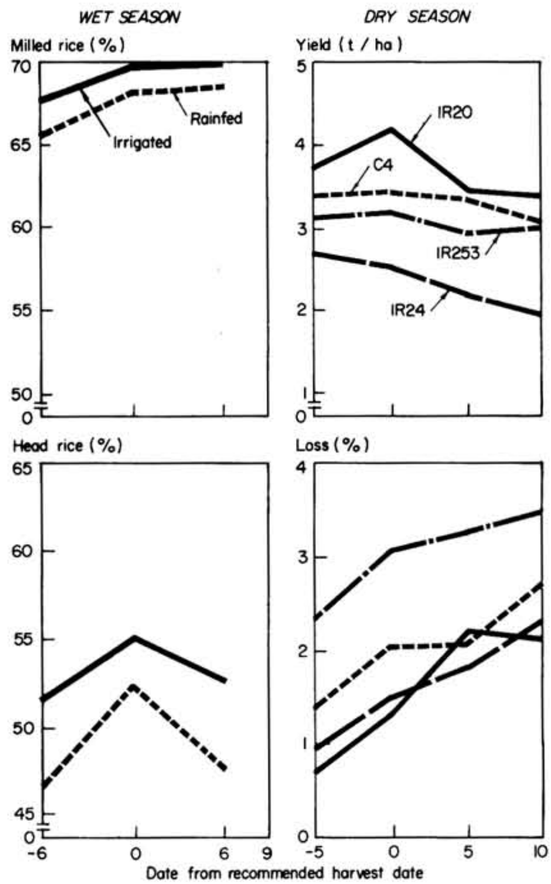


13. Annual probability of tractor breakdown at different ages, Nueva Ecija, Philippines, 1972.

An inverse relationship exists between tractor size and the *perceived* amount of animal power displaced by the tractor. Light tractor owners felt that their units replaced more animal power than did heavy tractor operators, which reflects the pattern of tractor use. The owners of light tractors used them on their farms for complete land preparation. The contract operator first tills by rotovator, and harrows and levels by carabao. Thus, the contract operator replaces the carabao only in initial plowing.

Grain loss study. We studied grain loss to determine the levels and patterns of field losses in harvesting and threshing, and to determine which factors are responsible for them.

Field work for the project was conducted during the 1972 wet and 1973 dry seasons in



14. Percent milled and head rice harvested at different dates before and after the recommended harvest date (30 days after 50% flowering), 1972 wet season, and yield and grain loss at different harvest dates, 1973 dry season.

Table 4. Percent milling recovery of irrigated and rainfed IR20 at different harvest dates using two drying methods, Gapan, Nueva Ecija, Philippines, 1972 wet season.

Type	Drying method	Harvest (days from recommended date)					
		−6		0		+6	
		Head rice (%)	Total milled rice (%)	Head rice (%)	Total milled rice (%)	Head rice (%)	Total milled rice (%)
Irrigated	Solar	52	68	55	70	53	70
	Mechanical	51	68	55	70	53	70
Rainfed	Solar	47	65	52	68	48	68
	Mechanical	48	66	53	68	48	69

Nueva Ecija, Central Luzon, Philippines. The 1972 wet season project included 50 sample farms located in one rainfed and two irrigated barrios. A medium-shattering variety, IR20, was used in the wet season study. The 1973 dry season project covered 50 sample farms in the two irrigated barrios. Four high-yielding varieties were used: IR20 and IR24 were medium-shattering, and C4-63G and IR253 were high-shattering. Harvest dates, based on previous studies, were set at 33 days after 50 percent flowering for the wet season and 30 days after 50 percent flowering for the dry season so the crops would be at or near-optimum yields. Two other dates, 6 days earlier and 6 days later, were also used for the wet season, and three additional dates, 5 days earlier and 5 days and 10 days later, were used for the dry season.

Wet season. Table 4 and figure 14 indicate that milled rice was 1.9 percent higher, and head rice was 4 percent higher, on irrigated farms than on rainfed farms.

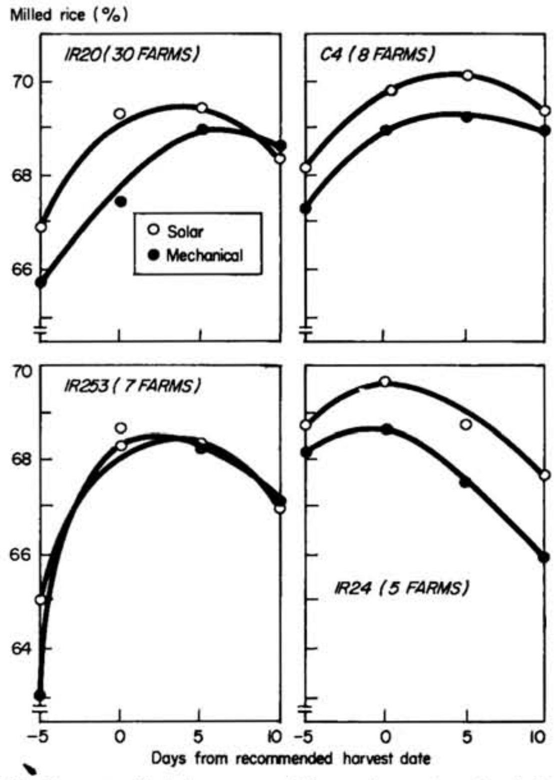
The first harvest gave the lowest percent head rice and the lowest percent milled rice in both irrigated and rainfed areas. The second harvest yielded percentages of head rice higher than (although significant only under rainfed conditions), and percentages of milled rice similar to those of the third harvest.

Harvest dates significantly affected grain yields in the dry season, but not in the wet season (Table 5). In the dry season, the yields of the second harvest were highest (3.9 t/ha), followed

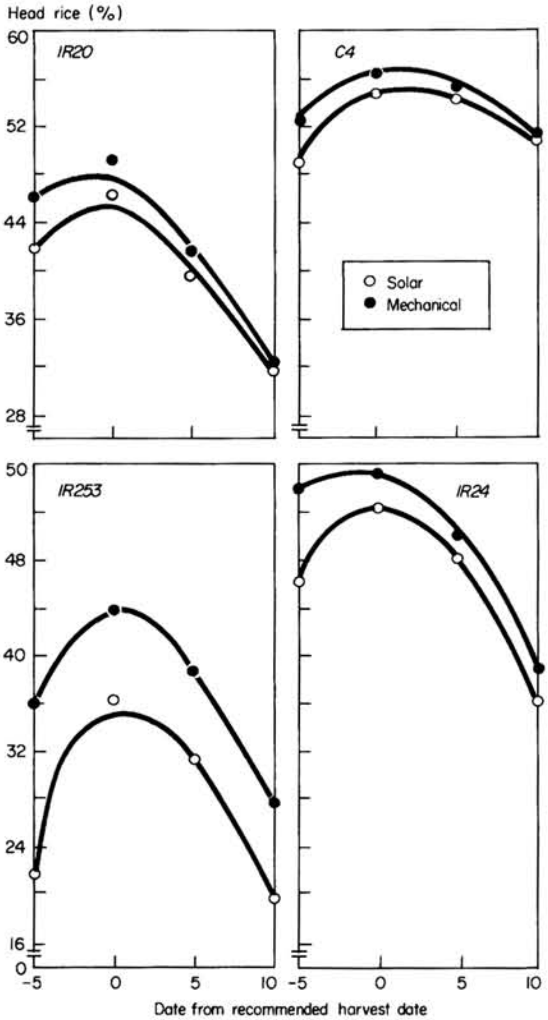
Table 5. Yields of four rice varieties by harvest date and season, Gapan, Nueva Ecija, Philippines, 1972 wet season and 1973 dry season.

Harvest (days from recommended date)	Yield (t/ha)	
	Dry season	Wet season
−5 to −6	3.6	2.9
0[a]	3.9	3.0
+5 to +6	3.4	2.9
+10	3.3	—
LSD (0.05)	0.18	0.12

[a]33 days after 50% flowering in wet season; 30 days after 50% flowering in dry season.



15. Percent milled rice recovered from solar- and mechanical-dried samples harvested at different dates before and after the recommended harvest date (30 days after 50% flowering), 1973 dry season.

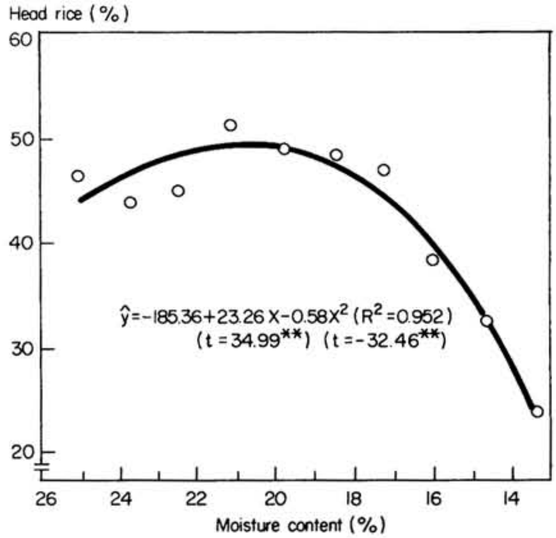


16. Percent head rice recovered from solar- and mechanical-dried samples harvested at different dates before and after the recommended harvest date (30 days after 50% flowering), 1973 dry season.

by yields of the first harvest (3.6 t/ha). The lowest yields were from the third and fourth harvests (3.4 t/ha). Mean yield levels were higher during the dry season (3.5 t/ha) than during the wet season (2.9 t/ha).

Harvest dates significantly affected the percent field losses during both seasons. In each season, percent field loss was lowest during the first harvest and increased at later harvest dates. Field loss was highest with IR253 (fig. 14).

Dry season. Table 6 and figure 15 show that harvest date and drying method (solar or mechanical), and the interaction of both factors,



17. Percent head rice recovery at different moisture content levels, 1973 dry season.

significantly affect the percentages of head rice and milling recovery. The percent milled rice was generally higher for solar-dried than for mechanically dried rice, particularly at early harvest dates.

For all farms, the earliest harvest, whether dried mechanically or by solar radiation, gave the lowest percent milled rice. The third harvest gave the highest percent milled rice, but was not significantly different from the second. Percent milled rice for the fourth harvest date was slightly lower than for the second and third. This trend was significant only when the rice was solar-dried.

For head rice recovery, Tables 5 and 6 and figure 16 show significant effects of harvest dates, drying methods, the interaction of harvest date and drying method, and the interaction of drying method and variety or line. Mechanical drying, in all cases, gave a higher percent head rice than did solar drying. The difference is greater at the first harvest date. We also observed some significant differential effects of varieties and lines; the largest was the difference in the line IR253 and the other varieties. IR253 is a chalky line that is susceptible to fracture during milling.

Although solar drying increased the percentage of milled rice, it decreased the yield of head rice when compared with mechanical drying. When we compared percent recoveries of head

Table 6. Percent milling recovery of four irrigated rice varieties at different harvest dates, using solar and mechanical drying methods, Gapan, Nueva Ecija, Philippines, 1973 dry season.

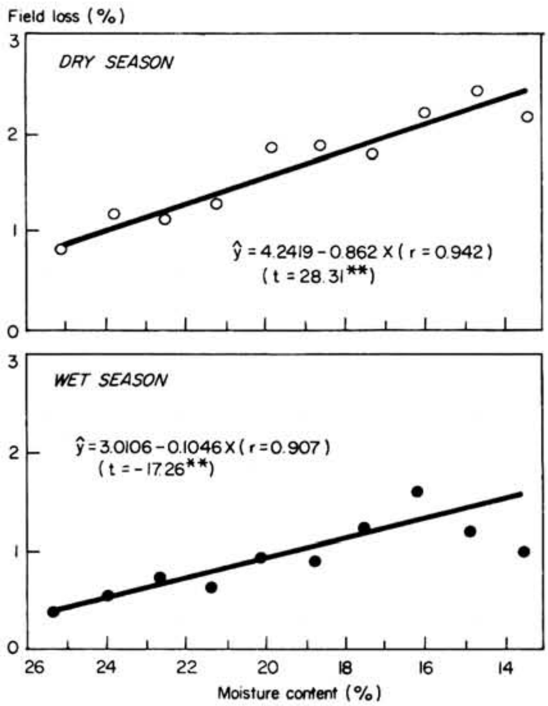
Designation	Drying method	Harvest (days from recommended date)							
		−5		0		+5		+10	
		Head rice (%)	Total milled rice (%)	Head rice (%)	Total milled rice (%)	Head rice (%)	Total milled rice (%)	Head rice (%)	Total milled rice (%)
IR20	Solar	42	67	46	69	46	69	32	68
	Mechanical	46	68	49	67	42	69	33	69
IR24	Solar	42	69	49	69	46	70	36	69
	Mechanical	49	68	55	69	48	68	37	66
C4-63	Solar	49	68	54	70	54	70	51	69
	Mechanical	52	67	56	69	55	69	51	69
IR253	Solar	22	65	36	68	31	68	19	67
	Mechanical	36	63	43	69	38	68	27	67

rice, we found IR253 to be slightly more sensitive to drying method than were other rices. The trend was more clearly defined at early harvest dates.

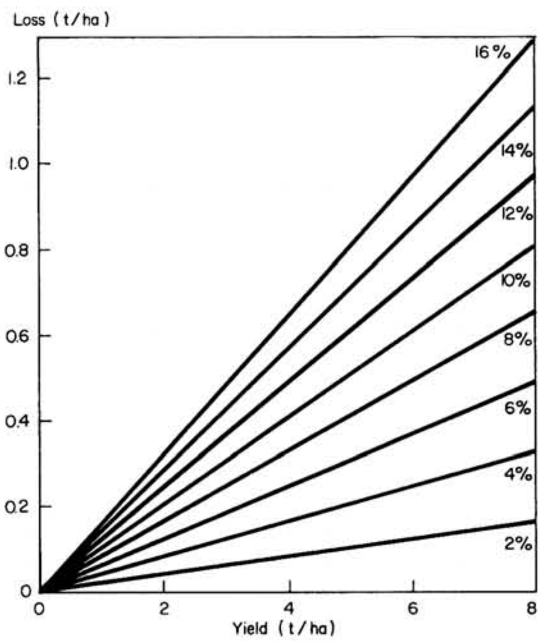
Head rice recovery and moisture content. A quadratic relationship exists between percent head rice recovery and percent moisture content at the time of harvest (fig. 17). This indicates that head rice recovery is low at low moisture content and increases gradually with higher moisture content. Maximum head rice recovery is at a moisture content of about 20 percent; it decreases as moisture content further increases.

When moisture content ranged from 13 to 26 percent at harvest, during both the dry and wet seasons, the percent field losses tended to decrease as moisture increased (fig. 18).

These results support the general principle that plants should be harvested as early as



18. Percent field loss at different levels of grain moisture at harvest. Data from 22 farms in 1972 wet season and 26 farms in 1973 dry season.



19. Relationship between yield and grain loss at various rates of loss.

Table 7. Value of grain losses at various paddy prices and loss levels.

Loss level (t/ha)	Value of loss (₱/ha) at			
	₱460/t	₱575/t	₱690/t	₱805/t
.2	92	115	138	161
.4	184	230	276	322
.6	276	345	414	483
.8	368	460	552	644
1.0	460	575	690	805

Table 8. Increased employment levels for five firms producing four IRRI machines, Philippines, 1973.

Labor added	Full-time employees (no.) added by				
	5-hp to 7-hp tiller	Batch dryer	Bellows pump	Multi-hopper seeder	All four machines
Manufacturing	124	12	2	11	149
Service	8	5	—	—	13
Marketing	18	4	—	1	23
Engineering	14	2	—	—	16
Total increase	145	24	2	12	201
Subcontractors (no.)	46	3	—	1	50

Table 9. Changes in capacity utilization and investment for five firms producing IRRI machines, Philippines, 1973.

Item	Firm					
	1	2	3	4	5	1 to 5 (total)
New investment (1000 pesos)	40	300	23	25	500	888
Workers added	45	57	16	11	72	201
Additional investment per worker (1000 pesos)	0.9	5.3	1.5	2.3	6.9	4.4
Capacity utilization (%)						
Current	75	50	85	85	85	—
Previous	45	30	65	65	60	—
Increase	30	20	20	20	25	—

possible after maturity.

The level of grain losses indicated by the study represents a conservative estimate of actual losses incurred in the field. Considerable care was exercised in taking replicated crop cuts and it is reasonable to assume that we did not account for all grain which was lost on the ground.

Figure 19 shows the quantitative losses which can be expected at various yield levels given the degree of severity of loss. In Table 7 we translate quantitative losses into economic terms. With low yields and moderate field losses, the economic impact, in absolute terms, may not be very significant. As yields increase, however, the economic level of loss also increases proportionately. This increase is a loss both to the farmer's income and to the quantity available for consumption.

Manufacture of IRRI machines. A selective survey of five IRRI-authorized manufacturers in the Philippines indicated that they produced slightly fewer than 2,300 IRRI machines during the first 9 months of 1973. Most were 5-hp to 7-hp tillers, although many multihopper seeders and batch dryers were also sold.

We examined the effects of production of IRRI designs on employment. The firms which adopted the designs increased employment by more than 200 fulltime workers or about 96 percent over previous levels (Table 8). The firms assessed their increases in plant and equipment utilization since they began producing IRRI equipment. Most of the firms had excess utilization capacity; by producing the IRRI design, they increased the use of existing plant and equipment by 20 to 30 percent (Table 9). All firms incurred some added investment costs, principally for jigs, fixtures, and light tooling. The added investment per additional worker was low.

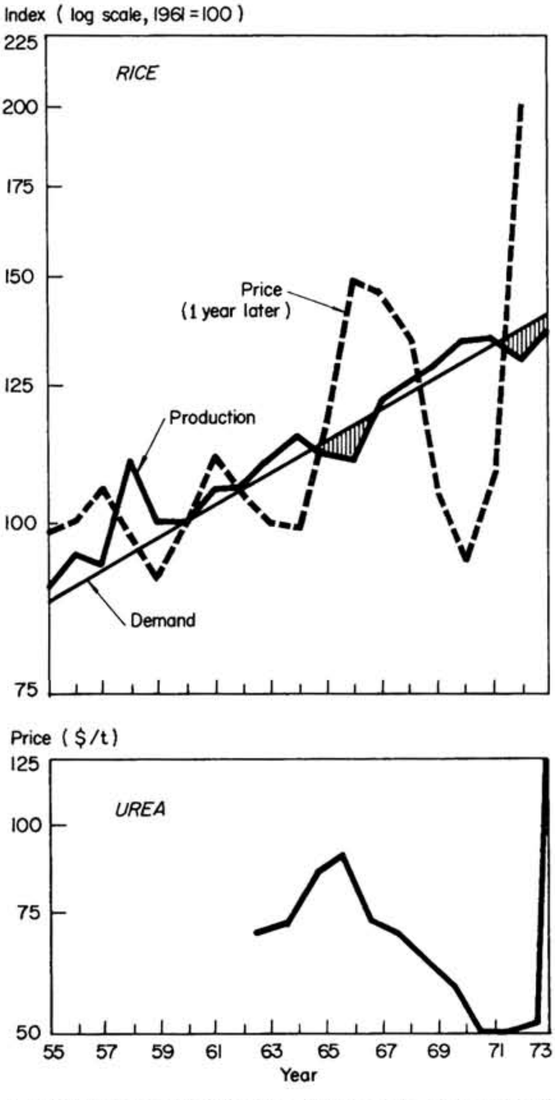
Perhaps even more significant are the numbers of jobs created when these firms link with subcontracting industries which produce assemblies and component parts. The five firms surveyed used the services of 45 subcontractors in the production of the IRRI equipment.

Agricultural economics

Although favorable weather in 1973 relieved the world rice shortage somewhat, the price of rice is expected to remain high while most Asian countries try to build up stocks. □ A comparative analysis of 30 Asian villages in which modern rice varieties have been well accepted indicates that farmers prefer to grow these varieties in the dry season, that farmers consider pests and diseases the most serious constraint to obtaining high yields for both modern and traditional varieties, and that governmental policies have discouraged farmers' acceptance of the new technology in some countries. About 50 percent of the farmers in the study villages reported increases in hired labor and in their own standards of living since the introduction of the new varieties, while 15 percent or less reported decreases in hired labor and living standards. □ A study in three villages of Central Luzon showed that input use, grain yield, and environmental factors affecting crop growth vary widely among farms and among villages. Good cultural practices by farmers help explain why some farms and villages have higher yields than others, but factors beyond the control of individual farmers, such as soil properties and irrigation supply, often are a more important explanation. □ Results from our field water management program indicate that the greatest yield loss due to moisture stress occurs for stress beginning just before panicle initiation, and in the presence of maximum evaporative demand. The amount of water supplied to large irrigated areas was found to strongly affect the duration of land preparation, with poorly irrigated and rainfed areas having the same duration. A new instrument for measuring water flows in irrigation canals was developed. A probabilistic model for estimating yields under rainfed conditions was constructed which predicted approximate yield levels of 3, 2, and 1 t/ha for expected rainfall in Central Luzon at the 0.5, 0.3 and 0.2 probability levels.

WORLD PRODUCTION AND DEMAND FOR RICE

Despite a good crop in 1973, the prices of rice and wheat remained high in international markets, and the world and Asian food grain supply was balanced precariously between shortage and surplus. Record high world rice prices occurred in 1973 after the poor weather of 1972 pushed production below the level of demand (fig. 1). Production must closely match the annual increase in the world demand for rice, slightly over 2.5 percent, or world rice prices will move sharply in response to shortage or surplus. Events in 1973 support this basic economic observation, just as they have throughout the past 15 years.



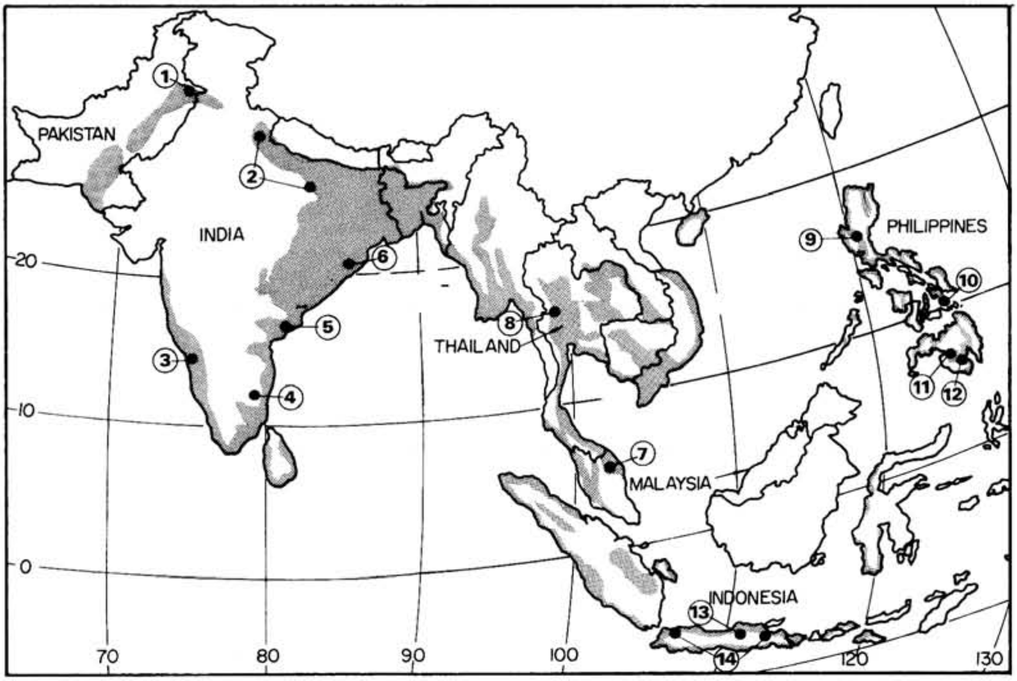
1. World demand, production, and lagged export price of rice; export price of urea.

Between 1961 and 1965 production of rice increased more rapidly than demand and so the price of rice fell from US$150 to $136 per metric ton. Then the poor crop seasons of 1965 and 1966 caused prices to rise over $200. Between 1967 and 1971 production once again increased more rapidly than demand, and, as a consequence, world rice prices fell to $138 per ton. Production fell slightly in 1971, causing a slight price rise in 1972, but in 1972 production fell by more than 3 percent, causing the very substantial price increase of 1973. That increase was reinforced by a shortage of wheat which kept wheat from being substituted for rice.

Production of rice in 1973 is reported to be substantially better than in 1972, but the exact size of the crop will not be known until the middle of 1974. Nevertheless, even if the most optimistic present estimates of production are accepted, the available supply will barely match world demand, indicating that high world rice prices will continue throughout 1974.

Good harvests in both India and China have contributed to the record harvest, and most other Asian rice-producing countries also had record or near-record production. Thailand recovered from a 14-percent reduction in 1972 with an equal increase in 1973. The Philippines expected to harvest a record 5.5 million tons of rough rice and Indonesia also expected a record harvest. These record harvests should, however, be viewed with care. They do not represent a "breakthrough"; rather, they represent the minimum production to match demand. Rice production must continue to increase at about 2.5 percent annually since it is clear that current Asian population growth rates will continue for sometime into the future.

In addition to the normal uncertainty about weather conditions, Asian farmers face an added uncertainty about fertilizer supplies. The radical change in the supply-demand situation for fertilizer, particularly nitrogen, occurred as the result of the low price of fertilizer in 1970 and 1971 (fig. 1) which discouraged investment in new plant capacity, the extraordinary increase in



2. Project locations for study of changes in rice farming in selected areas of Asia (1. Punjab, 2. Uttar Pradesh, 3. Mysore, 4. Tamil Nadu, 5. Andhra Pradesh, 6. Orissa, 7. Kelantan, 8. Suphan Buri, 9. Nueva Ecija, 10. Leyte, 11. Cotabato, 12. Davao, 13. Central Java. 14. East Java and West Java). Shading indicates approximate areas of intensive rice production.

food and feed grain prices in 1973 which increased the demand for fertilizer throughout the world, and the energy crisis which has caused a shortage of "feeder stock" or fuels that are the basic ingredients of nitrogen fertilizer.

The changing supply-demand balance will lead to a redistribution of world fertilizer supplies. As developed countries ensure their own supplies and exporters sell to the highest bidder, the developing Asian countries will have difficulty securing adequate supplies of feeder stock and fertilizer, just as they had difficulty securing adequate supplies of food grains during 1973.

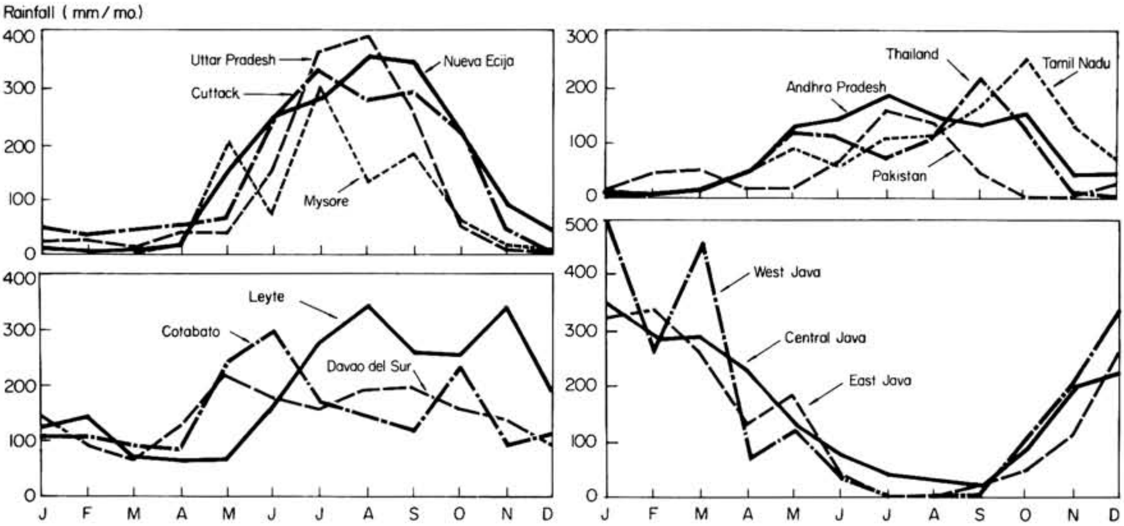
CHANGES IN RICE FARMING IN ASIA

Much has been written about the changes that are occurring with the introduction of the new rice technology. Despite this, it is difficult to find comparable studies at the village level which document the changes in production and production practices, and in the socio-economic factors such as income gain, the sharing of benefits, and employment. For this reason an investigation of change in rice farming was launched in 1971. The project has involved more than 30 scientists from six countries. Information was gathered from 36 rice-growing villages in 14 study areas (fig. 2).

Individual reports have been prepared for each of the study areas. In addition we analyzed data from all of the study villages to examine factors such as differences in environment and price relationships which account for variation in the use of the new technology *among* villages. We have also examined factors such as farm size and tenure status which greatly influence the use of the new technology among farmers *within* villages. Only the results of the analyses among villages are presented here.

The villages selected for the study are not typical—they are rather favorably situated for adoption of the new rice technology. At least one, and usually all, of the villages in each study area had an adequate supply of water for producing two or more crops in a year.

A random sample of 150 to 250 farms was drawn in each village. The farm interviews, consisting of two rounds, were conducted



3. Average monthly rainfall, 1967-71 at the different study sites.

between late 1971 and early 1973. A common core of information was gathered in all areas.

The 14 surveys were conducted over a broad geographic area reflecting wide differences in farming conditions (fig. 3). In the two study areas in north India and Pakistan, cold weather during the winter months favors the production of wheat as the dry season crop. In all other areas where two crops are grown under irrigation, rice is the principal second crop.

Although water control was standardized to a degree in the selection of the study sites, there is nevertheless a wide variation in the quality of the irrigation systems among the sites (Table 1). A majority are served by canal or gravity irrigation systems, most of which do not have water storage capacity but can serve a limited command area during the dry season. There is thus the possibility of too much or too little water, depending upon the season, on at least a portion of the irrigated farms in many of the survey areas. Excluding the rainfed and partly irrigated villages, about half of the villages have irrigation facilities which permit 100 percent of the rice area to be double cropped. In the remaining half of the irrigated villages, about three-fourths of the area is double cropped.

Monoculture and mixed farming villages. We found it useful for analytical purposes to distinguish between two types of villages: the monoculture rice village, where 90 percent or more of the cropped area in both the wet and dry season is planted to rice, and the mixed farming village, where at least one crop other than rice is of major importance (Table 1). In the study areas, the other major crops include wheat, sugarcane, tobacco, and corn. The crops are grown either in rotation, such as rice followed by wheat or corn, or on a different portion of the farmer's land during the same season, such as rice in combination with sugarcane or tobacco.

The difference in cropping pattern among these groups of villages reflects differences in environmental conditions. A rice-producing village that can grow a crop other than rice is likely to have a more favorable environment even for rice production as a result of better irrigation and drainage facilities. By contrast, the monoculture villages tend to have, largely for environmental reasons, no alternative to rice. Most monoculture villages are located in the heart of the traditional rice-growing areas (fig. 2). Of the villages shown in Table 1, four poorly irrigated or rainfed villages (Mahipon, Sa Krachom, Cabpangi, and Maluao) were eliminated from the analysis to make the group more homogeneous and two villages were excluded because data were not available at the time of the analysis (Tarna and Barain).

Introduction of modern varieties. It is becoming increasingly clear that "high yielding variety" (HYV) is not an appropriate name, since it implies that the variety so classified is high yielding under all conditions. It is also clear that no single term or phrase can adequately describe the increasingly diverse characteristics of the new varieties. We have thus decided to use the term "modern variety" since it suggests a time horizon which we regard as important for studying change. Our study is concerned with the changes that have been associated with the introduction of modern varieties developed and released to farmers since 1965. Varieties developed before 1965 are referred to as "local" varieties. These include the so-called "improved local" varieties developed through breeding programs and the "traditional" varieties of less certain origin.

Since nearly all villages in the study were considered well suited for the introduction of modern rice varieties, it is not surprising that most farmers have at least tried the modern

Table 1. Characteristics of the sample monoculture and mixed farming villages ranked according to the percentage of rice area double cropped.

Village	Farms in sample (no.)	Operated area (ha)	Rice area: Total[a] (ha)	Rice area: Irrigated (%) Wet season	Rice area: Irrigated (%) Dry season[b]	Rice area: Double cropped (%)	Irrigation quality[c]
Monoculture villages							
Beynte Nuwebe, Davao	66	1.7	1.7	100	100	100	4
Sinayawan, Davao	93	2.2	1.9	100	100	100	4
Bulucaon, Cotabato	40	2.0	1.8	100	100	100	3
Cidahu, West Java	77	0.5	0.5	100	100	100	2
Nganjat, Central Java	60	0.5	0.5	100	100	100	1
Meranti, Kelantan	133	1.0	0.9	94	94	100	3
Salor, Kelantan	157	0.9	0.8	100	100	100	3
San Nicolas, Nueva Ecija	55	2.5	2.5	100	100	93	2
Malimba, Nueva Ecija	66	3.1	3.1	100	100	92	3
Kandarpur, Orissa	57	0.6	0.6	100	97	83	3
Korpada, Orissa	112	0.6	0.6	98	100	83	3
Pedapulleru, Andhra Pradesh	185	4.7	4.4	100	100	66	3
Rai Rot, Suphan Buri	47	7.0	5.3	98	100	19	3
Nong Sarai, Suphan Buri	59	7.8	6.0	73	100	13	4
Sa Krachom, Suphan Buri	44	7.8	5.4	0	0	0	5
Mahipon, Nueva Ecija	72	3.8	3.8	0	0	0	5
Avg, monoculture villages[d]		2.9	2.5	97	99	82	2.9
Mixed farming villages							
Canipa, Leyte	49	1.7	0.8	90	90	100	3
Capayuran, Cotabato	36	1.9	1.3	100	100	100	3
Maluao, Cotabato	36	2.9	1.6	90	84	100	5
Kahuman, Central Java	60	0.6	0.6	100	100	100	1
Tab-ang, Leyte	56	1.2	0.7	100	100	100	3
Pluneng, Central Java	66	0.5	0.5	100	100	100	1
Marcos, Leyte	66	1.5	0.4	100	100	100	3
Sidomulyo, East Java	75	0.5	0.4	100	100	98	2
Cabpangi, Cotabato	48	3.9	1.4	100	100	95	5
Palvarthuvenran, Tamil Nadu	33	2.0	1.3	100	100	91	3
Manmalai, Tamil Nadu	66	1.8	0.7	100	100	89	2
D. Vijaipur, West Uttar Pradesh	51	6.0	3.2	65	[e]	[e]	3
Tarna, East Uttar Pradesh	43	1.2	0.5	92	[e]	[e]	3
Ashoknagar, Mysore	51	2.8	2.2	100	100	84	2
Maraliwala, Punjab	80	7.8	6.0	100	[e]	[e]	2
Aroop, Punjab	80	6.7	3.7	100	[e]	[e]	2
Hosahally, Mysore	43	4.8	1.9	100	100	61	2
Kariyamangalam, Tamil Nadu	52	4.1	1.4	100	100	61	2
Gajanur, Mysore	48	2.4	1.7	100	100	60	2
Barain, East Uttar Pradesh	57	1.2	0.7	31	[e]	[e]	4
Avg, mixed farming villages[d]		2.8	1.6	93	99	88	2.4
Avg (all villages)[d]		2.8	2.0	95	99	85	2.6

[a]Wet season. [b]Proportion of rice area planted that is irrigated. [c]Best = 1, poorest = 5. [d]Averages for rice area irrigated, quality of irrigation, and rice area double cropped exclude the two rainfed villages and irrigated villages with an irrigation quality rating of 5. [e]Second crop planted to wheat.

Table 2. Number of villages reporting stated proportions of farmers ever planting modern varieties, growing modern varieties in year of study, and area planted to modern varieties, 30 Asian rice-growing villages, 1971-72.

Season and type of farming	Total villages (no.)	Villages (no.) Proportion of farmers who have ever planted modern varieties			Proportion of farmers growing modern varieties in year of study			Proportion of rice area planted to modern varieties			Avg rice area in modern varieties (%)
		90% and above	50-90%	under 50%	90% and above	50-90%	under 50%	90% and above	50-90%	under 50%	
Total	30	26	3	1	—	—	—	—	—	—	—
Wet season	30	—	—	—	15	12	3	11	7	12	65
monoculture[a]	14	—	—	—	5	6	3	5	0	9	51
mixed farming	16	—	—	—	10	6	0	6	7	3	76
Dry season	27	—	—	—	24	0	3	17	6	4	86
monoculture	14	—	—	—	12	0	2	8	4	2	85
mixed farming[b]	13	—	—	—	12	0	1	9	2	2	86

[a]Villages where 90% or more of the cultivated area is planted to rice. [b]Three villages in Pakistan and India plant wheat during the dry season.

varieties in one season or another (Table 2). But the modern varieties are more popular in the dry season and more popular in mixed farming villages than in the monoculture villages. The high level of solar energy in the dry season frequently accompanied by low levels of insect and disease incidence makes it possible to attain a high proportion of the yield potential of the modern varieties.

Twelve of the 30 villages in the wet season and four of 27 villages in the dry season planted less than half of their rice area to modern varieties. The reason for this low adoption rate can best be understood by examining specific situations. In all five mixed farming villages that planted under 50 percent to modern varieties the price of the local varieties was considerably higher than that

Table 3. Farmers' preferences for varietal groups, 30 Asian rice-growing villages, 1971-72.

Type of farming	Villages (no.)	Farmers' preference (%) Local	Early modern[a]	Recent modern[bd]
		Wet season		
Monoculture[c]	12	46	20	34
Mixed farming	16	33	46	21
		Dry season		
Monoculture[c]	12	28	27	45
Mixed farming	13	24	70	6

[a]Varieties first released 1966-68: IR8 and IR5 (in Indonesia, PB8 and PB5), C4-63, Jaya, and IR6-156-2 (known officially in Pakistan as Mehran 69). [b]Varieties first released 1969-71: IR20, IR22, IR24, Ratna, Pankaj, RD1, and RD5. [c]Data missing for the two Malaysian villages. [d]Although both Jaya and IR20 were released in 1969, Jaya, whose characteristics closely resemble those of IR8, has been classified in the early modern group, while IR20, bred specifically for resistance to insects, has been classified in the late modern group.

of the modern varieties. Price seems to have been the main reason for the popularity of the local varieties in Kahuman, Central Java, during the dry season and in Aroop and Maraliwala in the Pakistan Punjab during the wet season. In Pakistan, Basmati rice provides substantial foreign exchange earnings, but it has not yet been possible to develop a high yielding Basmati rice for export so the government has found it profitable in terms of foreign exchange earnings to raise the local price of Basmati rice to as much as twice the level of the modern varieties.

Among the 11 monoculture villages with less than 50 percent planted to modern varieties, the relative prices of local and modern varieties do not seem to have been important. In the villages in Orissa and Andhra Pradesh, located in the flood plains along the eastern coast of India, suitable modern varieties are not yet available for the wet season. In an experiment comparing Mahsuri with modern varieties in Andhra Pradesh in the 1972 wet season, Mahsuri yielded 4.4 t/ha at zero nitrogen while the average yield of Jaya and IR8 was 2.3 t/ha at zero nitrogen. Neither showed any response to nitrogen at rates up to 200 kg/ha. In the village of Cidahu in West Java about half of the wet-season crop was destroyed by gall midge. Farmers noticed that attacks were much more severe on modern varieties, such as IR5, than on local varieties, so the farmers reverted to local varieties. While similar severe losses were reported due to tungro virus in several areas of the Philippines, resistant modern varieties were available and they replaced the susceptible varieties.

Low adoption of modern varieties was also reported in Kelantan, Malaysia, and in Suphan Buri, Thailand. In Malaysia, where the completion of the Muda River Irrigation Project has moved the country close to self-sufficiency, new technology has not been emphasized in areas like Kelantan which are outside the Muda River area. Farmers in Kelantan at the time of the study had only one modern variety available, a Malaysian selection of the variety IR5 which was still segregating and gave a very uneven stand. As in Andhra Pradesh, Mahsuri tended to perform better than the modern variety.

In Thailand, as in Pakistan, priority has been given to protecting existing export markets and foreign exchange earnings. The first modern varieties developed in Thailand, RD1 and RD3, were released in 1970 and were bred specifically to meet the standards of the export market. While these varieties were widely planted in the dry season in Suphan Buri, they occupied less than half of the rice-growing areas in the two irrigated villages in the 1971 wet season, and according to recent reports have declined still further. This suggests that environmental factors, specifically the frequent flooding that occurs in this area, may be discouraging the use of short, modern varieties in the wet season (the latest Thai release, RD5, is 50 percent taller than RD1 and RD3). Suphan Buri also had the most unfavorable fertilizer-rice price ratio of any of the study areas.

The farmers surveyed were asked in both the wet and dry seasons what variety they preferred. We grouped their responses as local varieties, modern varieties released from 1966 to 1968, and modern varieties released from 1969 to 1971 (Table 3). The early modern varieties are distinguished from the later modern varieties primarily by the greater disease and insect resistance and higher market quality which has been bred into many of the more recent releases. At the time of the survey, 1972, the early modern varieties were still dominant in the mixed farming villages in both seasons. But in the monoculture villages, the preference for the more recent releases surpassed the preference for the early modern varieties in both seasons, but local varieties were still strongly preferred, particularly in the wet season. Local varieties have remained popular in some areas because modern varieties suited to local environmental conditions were not available or because the local varieties had a large price advantage over the modern varieties.

Thus three factors seem to explain much of the differences between villages in area planted to modern varieties: 1) the availability of suitable modern varieties, 2) differences in the rice-growing environment (including climate, irrigation, and drainage), and 3) the price relationships between improved and local varieties, and between rice and inputs such as fertilizer (Table 4). These three factors taken together reflect both the profitability and risk associated with the use of modern varieties. The suitability of available varieties is of course closely related to the environment. All three factors can be influenced by government policy.

Constraints to higher yield and fertilizer use. On the average, mixed farming villages had higher yields in both seasons. Likewise, mixed farming villages tended to use more nitrogen (Table 5). In villages that planted both local and modern varieties, the modern varieties outyielded the local varieties (Table 6). This is due in part to the higher level of fertilizer use on modern varieties. But it often appears that the modern varieties received better management in general and were planted on better soils than the local varieties. These results do not mean that the area now in local varieties should be shifted to modern varieties. The smallest differences between the yields of the local and modern varieties occurred

Table 4. Correlations between the level of adoption and several factors, 30 Asian rice growing villages, 1971-72.

Factor	Correlation with level of adoption
Price nitrogen (kg)/price modern varieties (kg)	−0.44
Price local varieties (kg)/price modern varieties (kg)	−0.41
Time since modern varieties first introduced	0.56
Proportion of rice area irrigated	0.27
Rainfall in harvest month and month before harvest[a]	−0.32

[a]High rainfall means low available solar energy.

Table 5. Average yield and nitrogen input for modern varieties in monoculture and mixed farming villages, 30 Asian rice-growing villages, 1971-72.

Type of farming	Villages (no.)	Yield (t/ha)	Nitrogen applied (kg/ha)
	Wet season		
Monoculture	14	3.0[a]	50
Mixed farming	16	4.3[a]	93
	Dry season		
Monoculture	14	3.3	60
Mixed farming	13	4.5	92

[a]Adjusted for serious damage from tungro virus and gall midge in some of the villages.

Table 6. Average yields and nitrogen input for modern varieties and local varieties in villages which planted both types of varieties among 30 Asian rice-growing villages, 1971-72.

Type of farming	Villages (no.)	Yield (t/ha)		Nitrogen applied (kg/ha)	
		Modern	Local	Modern	Local
		Wet season			
Monoculture	9	3.0	2.6	54	43
Mixed farming	13	4.6	2.9	110	52
		Dry season			
Monoculture	7	3.9	2.9	87	60
Mixed farming	5	5.4	4.4	118	70

Table 7. Grain yield, nitrogen input, and area in modern varieties by nitrogen level and type of farming, 30 Asian rice-growing villages, 1971-72.

Villages characterized by nitrogen use[a]	Villages (no.)	Rice area in modern varieties (%)	Nitrogen applied (kg/ha)	Yield (t/ha)
		Wet season		
Low nitrogen	11	77	24	2.9
High nitrogen				
monoculture	9	39	69	3.0
mixed farming	10	72	129	5.4
		Dry season[b]		
Low nitrogen	7	99	17	2.8
High nitrogen				
monoculture	9	76	86	3.6
mixed farming	9	80	123	5.4

[a]Low nitrogen = village avg of 45 kg/ha N or less. [b]Data not available for the two Davao villages in the dry season.

in monoculture villages during the wet season. This supports the idea that the modern varieties are not yet well adapted to wet-season conditions in many monoculture areas.

We also investigated why some villages obtained much higher average yields than others. Part of the answer lies in the yield potential of a given environment. But we also found the correlation between average yield and nitrogen input of the villages to be 0.86. Thus, we tried to determine why in some villages farmers were using low nitrogen levels on modern varieties. Based upon experimental results at IRRI, and excluding risk factors, 60 kg/ha N can be profitably used on modern varieties even under wet-season conditions. We assumed that village-average nitrogen use of 45 kg/ha or less is a low level of input and grouped villages by season and by nitrogen use (the high nitrogen-level villages were subdivided by type of farming, but because there were relatively few low-nitrogen villages, they were not further subdivided).

There is a marked difference in the level of nitrogen input for the three village groupings in each season (Table 7). Nevertheless, the low-nitrogen villages averaged only 0.1 t/ha less yield than the high-nitrogen monoculture farms during the wet season. Surprisingly, the low-nitrogen villages have a high rate of adoption of modern varieties.

The low-nitrogen villages tend to have a poorer irrigation, a less favorable fertilizer-rice price ratio, poorly developed institutional-lending facilities (and hence higher interest rates for credit), and larger-than-average farm size and area planted to rice (Table 8). Constraints to higher yield and nitrogen input appear to be linked to both environmental and institutional factors.

Farmers were asked how they viewed certain factors as constraints to higher yields on their farms (Table 9). They said diseases, insects, and pests were the most serious obstacles to higher rice yields. The high fertilizer users in the mixed farming villages appeared to be more concerned about inability to obtain fertilizer and credit than the low-fertilizer users. Thus providing more adequate facilities for distributing fertilizer and credit is unlikely by itself to lead to higher nitrogen use in the low nitrogen villages.

The 11 low-nitrogen villages are located in the southern Philippines, in Thailand, and in Pakistan. In two of the three southern Philippine study areas more than half of the farmers were not applying fertilizer on modern varieties. In Thailand and Pakistan about 20 percent of the

Table 8. Nitrogen use in relation to environmental and institutional factors in the wet season, 30 Asian rice-growing villages, 1971-72.

Villages characterized by nitrogen use	Villages (no.)	Harvest rainfall[a] (mm/mo)	Irrigation quality[b]	Fert/rice price ratio[c]	Users of credit[d] (%)	Farm size (ha)	Rice area (ha)
Low nitrogen	11	152	3.2	3.7	15	3.8	2.7
High nitrogen							
Monoculture	9	238	2.6	3.0	28	1.6	1.5
Mixed farming	10	128	2.0	3.0	44	2.6	1.5
Correlation with N use	—	−0.26	0.72	−0.33	0.45	−0.35	−0.40

[a]Avg of 5 years rainfall in the month of harvest and month prior to harvest. High rainfall is associated with a low level of solar energy since a high level of solar energy is needed for high yields. [b]Highest quality = 1, lowest quality = 4. [c]Nitrogen price (kg) divided by price of modern varieties (kg rough rice). [d]Farmers indicating banks, cooperatives, or government agencies as their major source of cash loans.

Table 9. Relation between nitrogen level and proportion of farmers' viewing selected factors as constraints to higher yield in the wet season, 30 Asian rice-growing villages, 1971-72.

Villages characterized by nitrogen use	Villages (no.)	Farmers (%) regarding yields constrained by				
		Inability to obtain			Poor irrigation	Diseases insects, pests
		Seeds	Fertilizer	Credit		
Low nitrogen	11	7[a]	21	16[a]	21	66
High nitrogen						
Monoculture[b]	9	16	19	22	26	84
Mixed farming	10	9	37	29	13	64

[a]Data available for 9 of the 11 villages. [b]Data available for 5 of the 9 villages.

farmers were applying no fertilizer. In all other areas, fertilizer was used by at least 90 percent of the farmers.

In the Philippines, Central Luzon, which includes Nueva Ecija, has received far more infrastructure development and other facilities to promote technological change than the outer regions of the country. Outside Central Luzon, the cost of inputs are higher and the price received for rice is lower. For example, in the Cotabato study area in the southern Philippines, the price of nitrogen was 50 percent higher and the price of rice a third lower than in Nueva Ecija. Furthermore, less than 5 percent of the farmers in Cotabato borrowed from institutional or formal credit sources, while in Nueva Ecija over 20 percent did. Unfavorable price relationships and high interest rates have caused low profits from fertilizer use in Cotabato. Despite the low level of fertilizer use in the southern Philippine study areas, all of the farmers have adopted modern varieties, and close to 100 percent are using insecticides.

Suphan Buri, Thailand, and Punjab, Pakistan, are in the center of major rice-producing areas. Nevertheless, they have the least favorable ratios of nitrogen to rice price among all the study villages. Furthermore, the average farm size is larger in these two sites than in any of the other study areas. Farm size tends to be inversely correlated with the intensity of cultivation (Table 8), and rice is a crop that responds to intensive care. Contrast, for example, a 6-hectare farm in Rai Rot, Suphan Buri, with a 0.6-hectare farm in Kahuman, Central Java. Farms in each area are the major means of support for families of six to seven. A Rai Rot farmer with a minimal yield of 2 t/ha on 6 hectares will in one season produce twice the annual output of a Kahuman farmer obtaining a 5-t/ha yield twice a year on 0.6 hectare. Farmers in Kahuman use a much higher level of labor as well as of cash inputs per hectare. Under optimum economic conditions we would expect a lower yield in Rai Rot.

In summary, in most areas a combination of both environmental and institutional factors explain the low level of fertilizer application and consequently the low yield of rice. Identifying the precise sequence of steps needed to alleviate the constraints to higher yield will require more detailed investigation.

Changes in farming practices and labor use. The relation of the introduction of modern varieties to the adoption of other modern inputs was explored by analyzing adoption rates at three stages: 1) before modern varieties were introduced, 2) the year of greatest first adoption of modern varieties, and 3) some years after the year of greatest adoption. Only farmers who had tried planting any of the modern varieties were included in this analysis. The improved practices can be classified into potentially yield-increasing practices such as new seeds, fertilizer, and insecticide use, and potentially labor-saving practices such as use of tractors, mechanical threshers, and herbicides. There appears to be little difference in the rate of adoption between monoculture and mixed farming villages. Adoption of modern inputs seems to have been affected considerably by differences in national policies, however. Thus the villages have been grouped according to country.

The governments of India, Indonesia, and the Philippines have strongly promoted the use of modern yield-increasing inputs. In the study villages in all three countries, a substantial increase in the adoption of fertilizer and insecticides accompanied the introduction of the

Table 10. Adoption of new practices by farmers who have tried modern varieties, 1971-72.

Location/type of farming	Villages (no.)	Users before modern varieties (%)	First adopters (%) in: Years of largest adoption of modern varieties	First adopters (%) in: Later years	Total users in survey year[a] (%)
		Chemical fertilizers			
India	10	48	40	2	100
Indonesia	5	76	20	4	99
Malaysia	2	82	10	8	94
Pakistan	2	81	1	0	78
Philippines	9	37	42	7	73
Thailand	2	57	23	2	69
Monoculture	14	47	35	7	83
Mixed farming	16	56	30	8	92
		Insecticides			
India	10	40	40	11	88
Indonesia	5	71	23	5	93
Malaysia	2	48	10	0	49
Pakistan	2	48	4	6	58
Philippines	9	48	45	5	97
Thailand	2	61	15	6	71
Monoculture	14	56	29	3	85
Mixed farming	16	46	36	8	86
		Tractors			
India	10	9	2	18	27
Indonesia	5	1	2	12	3
Malaysia	2	10	10	80	96
Pakistan	2	70	1	5	71
Philippines	9	27	19	14	58
Thailand	2	18	7	12	25
Monoculture	14	37	6	17	56
Mixed farming	16	10	3	15	24
		Herbicides			
India	10	0	1	1	0
Indonesia	5	0	0	0	0
Malaysia	2	0	9	0	6
Pakistan	2	0	0	0	0
Philippines	9	33	31	9	66
Thailand	2	10	1	3	8
Monoculture	14	25	9	3	34
Mixed farming	16	2	6	5	10

[a]Among modern-variety adopters.

modern varieties (Table 10). In the villages in Malaysia, Pakistan, and Thailand, however, the introduction of modern varieties is less closely related to the adoption of yield-increasing technology. Our results suggest that government efforts to promote modern inputs have been an important reason for their adoption.

There appears to be relatively little relationship between the introduction of modern varieties and the adoption of tractors and herbicides (Table 10). Tractors are widely used in the Malaysian, Pakistan, and Philippine villages. In Malaysia, tractors were adopted after the introduction of modern varieties; in Pakistan, they were adopted before modern varieties; and in the Philippines, the growth in tractor use began before modern varieties and continued with their introduction. Herbicides have become popular only in the Philippines, and there they have performed a yield-increasing rather than a labor-displacing role (1971 Annual Report).

A large proportion of farmers reported an increase in family or hired labor following the adoption of modern varieties (Table 11). Villages with a high proportion of farms reporting an increase in pre-harvest labor requirement tended to have a high proportion of their rice area in modern varieties. Tractor adoption is related to a decrease in family labor (Table 12). But the proportion of farmers reporting a decrease in pre-harvest labor requirement is much smaller than the proportion of farmers who adopted tractors during or after the adoption of modern varieties.

Benefits from the new technology. Whether or not an individual feels that he has benefited from the new technology depends not so much on his absolute yields or income level, but rather on the progress he feels that he has made. Although mixed farming villages obtained significantly higher yields than monoculture villages, we found that in both groups about 60 percent of the farmers reported a higher profit from rice and 50 percent reported a higher level of living (Table 13).

It seems logical, however, to expect that villages with a higher level of technology (a higher level of adoption of modern varieties or a higher level of nitrogen input) would report relatively more beneficiaries (Table 13). In six villages—Pedapulleru in Andhra Pradesh, Ashoknagar in Mysore, the two villages in the Punjab, and the two villages in Davao—less than a third of the farmers reported higher profits from rice and a higher standard of living. All but one of these villages, Ashoknagar, were in the low-adopter group.

The new rice technology was not the sole source of higher incomes and standards of living. Only about half the farmers attributed their higher income to higher rice profits alone. More than a quarter of the farm families reported an increased off-farm income, some of which may have been the indirect result of the introduction of new technology.

Finally, farmers in most villages were generally optimistic about the trend of income in the next 5 years. The notable exceptions were the two villages in the Punjab, where nearly all of the farmers expected a decline in future incomes, and

Table 11. Farmers reporting a change in pre-harvest labor requirements following the introduction of modern varieties by location and by type of farming, 1971-72.

Location/type of farming	Villages (no.)	Farmers reporting (%)					
		Family labor		Hired labor from			
				village		outside	
		More	Less	More	Less	More	Less
India	10	27	2	82	3	65	0
Indonesia	5	26	2	18	12	11	4
Pakistan	2	8	0	2	0	0	0
Malaysia	2	51	18	36[a]	5[a]	—	—
Philippines	9	62	15	65	7	20	7
Monoculture[b]	12	42	13	55	4	24	3
Mixed farming	16	36	4	56	7	33	4

[a]Includes hired labor from outside village. [b]Data from two Thai villages not available.

Table 12. Tractor adopters reporting a decrease in pre-harvest labor requirement by location following the adoption of modern varieties, 1971-72.

Location	Villages (no.)	Tractor adopters (%)	Tractor users (%) reporting decrease in		
			Family labor	Hired labor from	
				villages	outside
India	10	18	2	3	0
Indonesia	5	2	2	12	4
Pakistan	2	1	0	0	0
Malaysia	2	86	18	5[a]	—
Philippines	9	31	15	7	7

[a]Includes hired labor from outside village.

Table 13. Farmers' opinions of changes in income and standard of living following the introduction of modern varieties by type of farming and by technical level, 30 Asian rice-growing villages, 1971-72.

Type of farming/ level of adoption	Villages (no.)	Farmers reporting (%)					
		Profit from rice		Level of living		Increased off-farm income	Higher future income[a]
		higher	lower	higher	lower		
Monoculture	14	59	18	47	13	23	68
Mixed farming	16	63	7	53	7	31	71
Low technology[b]	13	49	17	37	13	24	59
High technology	17	70	8	60	7	30	79

[a]Expect higher income in next 5 years. [b]Villages with less than 50% of area in modern varieties or using 45 kg/ha N or less.

the villages in Andhra Pradesh, Orissa, Suphan Buri, and Leyte where 40 to 50 percent of the farmers expected a decline.

BARRIERS TO HIGHER YIELDS AND INCOME

The substantial difference between the yields obtained with the new rice production technology on experiment stations and the yields of farmers using similar technology demands investigation. Farmers' yields are generally far below the economic level implied by experimental results, but this phenomenon is not universal. To what extent are low farm yields due to poor management, and to what extent are they due to environmental or other factors beyond the individual's control? This question formed the basis for a study combining intensive monitoring of 60 farm paddies and a management-package experiment using IR20 in three barrios in Gapan, Nueva Ecija, Philippines during 1972 and 1973.

Farm-level management and environment. We previously reported the detailed design of the study that was used during the 1972 wet season (1972 Annual Report). The 1973 dry season study was similar except that only two barrios were included since the rainfed barrio did not produce rice during the dry season. Soil characteristics, land preparation, and cultural practices were observed. Detailed measurements to reflect water adequacy, changes in soil properties, solar radiation, input applications, insect and disease attack, and weed control were made throughout the growing season. Yields were measured by crop cuts.

Substantial differences in mean yields, input use, and crop environment were observed between the three barrios and two seasons (Table 14). Dry-season yields were 1 t/ha higher than wet-season yields in the irrigated barrios, San Nicolas and Malimba. Yields in San Nicolas were 0.4 t/ha higher than in Malimba in both seasons and 1.6 t/ha higher than in the rainfed barrio of Mahipon during the wet season. When the yield and input data are compared for the wet season, there is a high degree of consistency, with yields positively related to inputs, negatively

Table 14. Average grain yield, input use, and environmental factors in three barrios of Gapan, Nueva Ecija, Philippines, 1972-73.

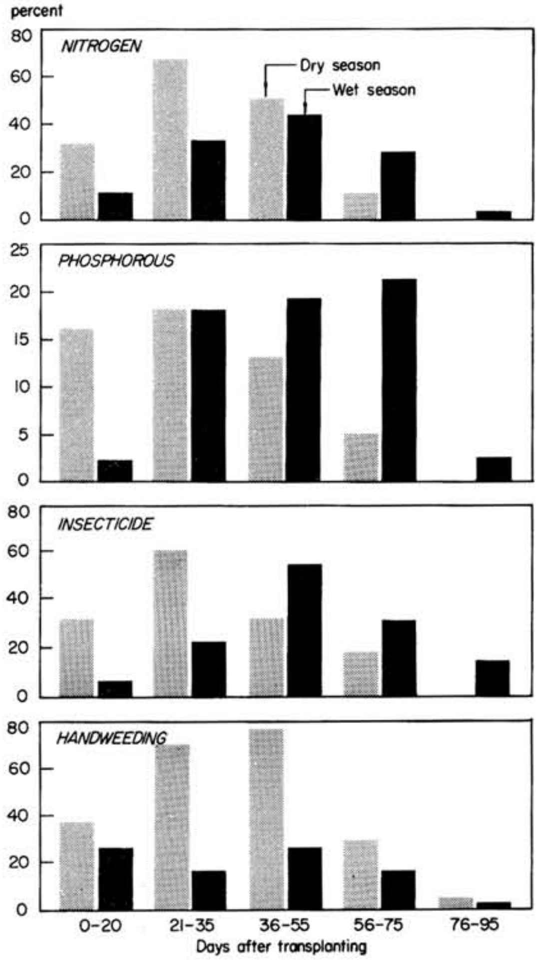
Barrio	Yield (t/ha)	Nitrogen applied (kg/ha)	Insecticide expenditure (P/ha)	Hand weedings[a] (no.)	Weeds[b] (kg/ha)	Insect attack[c] (index)	Disease attack[d] (index)	Moisture stress[e] (days)	Soil clay content (%)
				1972 wet season					
San Nicolas	3.6	68	19	1.5	132	7.0	2.6	2.8	48
Malimba	3.2	42	15	0.7	168	12.8	2.0	3.4	48
Mahipon	2.0	31	11	0.6	256	11.2	3.0	4.5	25
				1973 wet season					
San Nicolas	4.6	107	10	2.4	90	6.6	5.7	0.1	48
Malimba	4.2	88	18	2.4	254	10.7	3.6	1.5	48

[a]Avg number of weedings including those fields not weeded. [b]Dry wt of weeds harvested 20 days after transplanting. [c]Avg of the percentage of hills attacked by whorl maggot, leaf-feeding insects, and stem borers at 20, 35, and 55 days after translating. [d]Avg of the percentage of hills infected by grassy stunt virus, tungro, bacterial blight, bacterial leaf streak, and Cercospora leaf spot at 20, 35, and 55 days after transplanting. [e]One moisture stress day is registered for each day after third day that a field is continuously without standing water.

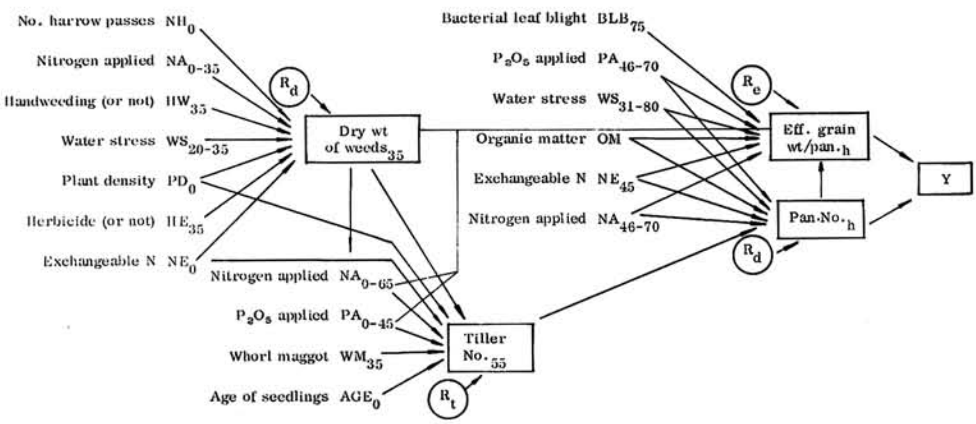
related to factors causing damage, and related, as one would expect, to moisture stress and soil texture. The pattern is not as clear for the dry season, but even then nitrogen, weed incidence, insect attack, and moisture stress have the expected relationship with yield. Statistical analysis failed to show significant differences among barrios in the levels of most of the measured variables, indicating that input variability within barrios was substantial.

The study revealed substantial differences in the timing of input application in the two seasons (fig. 4). Nitrogen was applied earlier and to a higher proportion of fields during the dry season than during the wet season. The application of phosphorus was especially delayed during the wet season, with application to almost 20 percent of the fields occurring between 56 and 75 days after transplanting. Insecticide was also used earlier during the dry season than during the wet season. Almost all farmers weeded during the dry season, but a substantial number waited until 35 to 55 days after transplanting to do their hand weeding. Although these observations showed that many operations were not performed at the optimum time, we have not measured the effect of timing on yields.

Two regression models were used to quantify the yield effects of various controllable and uncontrollable factors. Model I, estimated for each season separately, is a multi-stage system of equations (fig. 5). Weeds, tiller number, effective grain weight, and panicle number are explained



4. Proportion of fields receiving input treatments by crop stage. Gapan, Nueva Ecija, Philippines, 1972 wet season and 1973 dry season.



5. Three-stage model of crop development. Subscripts refer to stage of growth measured as days after transplanting.

Table 15. Variables included in two regression models designed to explain farm level yield variability.

Variable	Included in	
	Model I	Model II
Environmental		
Organic matter in soil	√	
Clay content of soil		√
Exchangeable soil nitrogen	√	
Solar radiation[a]		√
Potentially controllable		
Moisture stress days	√	√
Insect attack index[b]	√	√
Disease attack index[b]		√
Seeding age	√	
Managerial		
Transplanting density	√	
Weeding control	√	√
Land preparation	√	
Herbicide	√	
Nitrogen fertilizer	√	√
Phosphorus fertilizer	√	√

[a]For the 40 days preceding harvest. [b]For the first 55 days after transplanting.

by the variables shown, with yield per unit area equal to the product of effective grain weight per panicle and number of panicles per unit area. Model II uses a single equation to explain yield variability directly, with the data pooled across seasons as well as across barrios.

In the past we classified the factors affecting yield as environmental and managerial, but this classification obscured the possibility that certain variables may be environmental from the farmer's viewpoint but may be potentially controllable by other individuals or groups, either through joint action or investment by society. An example is moisture stress. It should be possible to prevent moisture stress in canal-irrigated areas like Malimba and San Nicolas, and it may be possible to extend irrigation to rainfed areas like Mahipon. Another example is the damage caused by insects and diseases, factors which are potentially controllable through the development and adoption of proper pest control practices carried out on a community-wide basis, or over the long run, by developing resistant varieties. Seedling age is potentially controllable since transplanting can only be started when ample water is available. We have therefore classified variables by the degree to which they can be managed. Environmental variables are those completely outside man's control, such as solar radiation and soil texture. Managerial variables are those within the control of the individual farmer, such as fertilizer application and cultural practices. Other variables such as moisture stress, insect and disease attacks, and seedling age are classed as potentially controllable. Table 15 shows the specific variables of each class that are included in Model I and in Model II.

Model I was relatively successful in explaining the yield difference of 1.64 t/ha between San Nicolas and Mahipon in the wet season, predicting a difference of 1.58 t/ha (Table 16). It was less successful, however, in explaining the smaller yield difference between San Nicolas and Malimba in the wet season. The dry-season results of Model I were even less useful, and are not shown. Model II, incorporating different variables and specified after examining the results of Model I, predicted the yield differences

Table 16. Yield differences predicted by two models used to explain yields in three barrios of Gapan, Nueva Ecija, Philippines, 1972-73.

Barrio[a] and season	Model	Actual yield differences (t/ha)	Predicted yield differences (t/ha) attributed to			
			All variables	Environmental variables	Potentially controllable variables	Managerial variables
SN (wet) vs ML (wet)	I	0.47	0.19	0.07	0.08	0.04
	II	0.47	0.68	.07	.21	0.40
SN (wet) vs MH (wet)	I	1.64	1.58	.73	.49	0.36
	II	1.64	1.57	.67	.25	0.63
SN (dry) vs SN (wet)	II	0.95	0.57	−.09	.06	0.61
SN (dry) vs ML (dry)	II	0.31	0.29	−.16	.12	0.32
SN (dry) vs ML (wet)	II	1.41	1.25	−.02	.27	1.01
SN (dry) vs MH (wet)	II	2.58	2.14	.59	.31	1.25

[a]SN = San Nicolas; ML = Malimba; MH = Mahipon.

between all the situations examined with a higher degree of accuracy.

The models separated the yield differences caused by the observed differences in the environmental, potentially controllable, and managerial factors. Environmental differences between San Nicolas and Malimba in the wet season were so small that they caused a yield difference of only 70 kg/ha, while environmental differences between San Nicolas and Mahipon in the wet season were large enough to cause a yield difference of about 700 kg/ha—nearly half the measured difference. Environmental differences between San Nicolas in the dry season and three of the other four combinations of barrio and season accounted for 160 kg/ha or less of yield difference, while environmental differences between San Nicolas dry season and Mahipon wet season accounted for about 600 kg/ha of yield. Indeed, the environmental factors in San Nicolas were very similar to those in Malimba, and were surprisingly similar in the 1972 wet season and the 1973 dry season. In those two seasons there was less than 5 percent difference in solar radiation during 40 days before harvest. That is the primary reason why relatively little of the yield difference is attributed to environmental factors except between San Nicolas and Mahipon, and there the major environmental factor was the difference in soil texture (48% clay in San Nicolas and 25% clay in Mahipon).

Differences in the levels of managerial factors explained much of the observed yield differences for all situations. In the wet season, higher fertilizer use and better weed control resulted in 400 to 630 kg/ha more production in San Nicolas than in the other two barrios (Model II). Dry-season input use in San Nicolas exceeded dry-season input use in Malimba enough to cause a 320-kg/ha higher yield, and it exceeded wet-season input use in San Nicolas by enough to cause a 610-kg/ha difference in yield. The largest yield effects due to managerial inputs predicted by the model are 1,250 kg/ha between San Nicolas dry season and Mahipon wet season, and 1,010 kg/ha between San Nicolas dry season and Malimba wet season.

The potentially controllable variables caused yield differences ranging from 80 kg/ha to 490 kg/ha, but with little discernable pattern. The incidence of insects, disease, and water stress did not differ greatly among barrios, so the lack of pattern is not surprising.

The study confirms that poor management practices are a major factor constraining yields on many farms, but also that poor environment has a substantial yield-reducing impact, too. Further, several factors that were beyond the individual farmer's control, but which are potentially controllable by institutional or group action also constrain yields under farm conditions. Assuming that the production functions of all farms are adequately described by the equations, it appears that managerial factors can account for almost all yield difference between barrios with similar physical resources, even when comparing barrios in different seasons. But the share of yield difference attributable to management factors declines to about one-third to one-half of the total difference in yield between an irrigated and a rainfed barrio. The direct effects of poor environment are strong and, in addition, may limit the expected effects of management factors.

Farm level experiments. A test of the assumption that all farmers have the same production function is provided by the experimental aspect of the research in Gapan. Experiments were conducted on two farms in each barrio in the wet season to determine whether a simple management package of fertilizer, chemical weed control, and insect control could give substantially higher yields and profits than farmers were able to obtain. In the dry season, similar experiments were conducted on four farms in each of the two irrigated barrios.

With one exception yields in the wet season were greater on the plots with the management packages than on the farmers' own adjacent plots, although the differences were not significant (Table 17). Because there were only two experiments in each barrio during the wet season, the differences would have to be quite large and nearly identical in each experiment to be statistically significant. It is obvious that the nitrogen level in the treatments was not responsible for the yield advantage because the farmers' adjacent paddies had higher levels of nitrogen

Table 17. Grain yields on experimental paddies and adjacent farmers' paddies, and the barrio averages in a trial of several input combinations. Gapan, Nueva Ecija, Philippines, 1972-73.

Plot	Chemical weed control	San Nicolas		Malimba		Mahipon[a]	
		$N-P_2O_5$ (kg/ha)	Yield (t/ha)	$N-P_2O_5$ (kg/ha)	Yield (t/ha)	$N-P_2O_5$ (kg/ha)	Yield (t/ha)
			Wet season				
Treatment 1	yes	60-0	4.1	60-0	3.7	60-0	2.0
2	yes	60-40	4.6	60-40	4.3	60-40	2.5
Adjacent plots	no	86-0	3.5	72-54	2.8	48-25	2.3
Barrio average[b]	no	77-1	3.5	38-14	3.0	25-29	1.9
			Dry season				
Treatment 1	yes	100-0	4.8	100-0	4.5	—	—
2	yes	100-60	5.1	100-60	5.0	—	—
3	no	100-0	4.3	100-0	3.6	—	—
4	no	100-60	4.7	100-60	4.7	—	—
Adjacent plots	no	110-0	3.9	104-17	4.1	—	—
Barrio average[b]	no	113-6	4.7	71-25	4.1	—	—

[a]Rainfed. [b]Excluding experimental and adjacent plots.

than the treatments, but a lower yield. Therefore, in San Nicolas and Malimba, the average yield response of 0.8 t/ha in the wet season in the treatment without phosphorus is due to better weed and insect control. An additional 0.5 t/ha was achieved by adding 40 kg/ha P_2O_5.

In Mahipon the mean yield of Treatment 1 was lower than that of the adjacent farmers' plots, and the yield of Treatment 2 was only slightly higher. This is because good weed control was not achieved by the herbicide (2,4-D) on these rainfed treatments. Phosphorus appears to be a critical component of a management package for the Mahipon soils, and farmers are already using it, but in general the management package was not effective in the poor environment in raising yields significantly above the farmers' level.

In the dry season, all of the treatments gave higher yields than those of the farmers' plots. As in the wet season, farmers applied slightly higher levels of nitrogen on the adjacent paddies than were used in the treatments, so the extra yield is attributable to weed control, and to phosphorus in treatments that included 60 kg/ha P_2O_5. Regardless of barrio or season phosphorus consistently gave about 0.5 t/ha higher yields than the comparable treatment without phosphorus. Thus, as in the survey described previously, we conclude that significant yield improvements from management practices are more likely to be achieved under good environmental conditions than under poor environmental conditions.

Bias in farmers' yield estimates. The intensive nature of our study required us to measure yields by making crop cuts on the farms of the participating farmers. This gave us an opportunity to check the crop-cut yield measurements against yield estimates obtained directly from the farmers of the three barrios in Gapan.

In most studies, yield estimates are obtained by asking farmers their total rice production and their rice area. Errors may arise from a bias in either area or production estimates. For our study, we obtained accurate estimates of the area actually harvested by each farmer by asking them to point out boundaries of their paddy fields on enlarged aerial photographs. We excluded creeks and areas planted to trees and bamboo in measuring the area. Components of production that are often not reported, such as gleaning, heaping of the containers used to determine harvester's and thresher's shares, and extra shares given to relatives and friends were determined through intensive questioning of the farmers.

Table 18 compares the reported yield data with the yields obtained when measured area is used instead of reported area, when measured area is used and unreported components accounted for, and when crop cuts are used to estimate yields. Comparing tenure categories we found that owner-operators understated their yields by 18 percent, share tenants by 42 percent, and leasehold tenants by 47 percent. When the data were grouped according to crop cut yield, it was

Table 18. Yield estimates as obtained by farmer interviews, as corrected by enlarged aerial photographs of area measured and intensive questioning, and as obtained using crop cuts, Gapan, Nueva Ecija, 1972-73[a].

Method of estimating yield	Yield (t/ha)							
	By tenure			By cropcut yield			By farm size	
	Owner operator	Share tenants	Lease-holders	High	Medium	Low	2 ha and below	over 2 hectares
Reported production area	2.7 a	2.3 a	2.7 a	3.3 a	2.7 a	1.8 a	2.6 a	2.4 a
Reported production and measured area	2.8 a	2.5 ab	2.8 a	3.1 a	3.0 a	2.0 a	3.0 a	2.1 a
Adjusted reported production[b] and measured area	3.0 a	2.7 ab	3.1 a	3.4 a	3.3 ab	2.2 a	3.3 ab	2.2 a
Crop cut	3.1 a	3.2 b	4.0 b	4.9 b	3.9 b	2.2 a	3.8 b	3.4 b

[a]Any means in the same column followed by the same letter are not significantly different at 5% level. [b]Adjusted by adding estimates of gleaning, heaping of containers while apportioning shares, and extra shares given relatives and friends.

evident that farmers with high and medium yields significantly understated their yields, by 47 and 44 percent. On the other hand, those with low yields understated yields by only 22 percent, an amount which was not statistically significant.

Large and small farmers significantly understated yields to about the same degree, although the source of underestimation is different for large and small farms. On small farms, area is somewhat overestimated thereby tending to depress reported yields, while on large farms area is underestimated, tending to increase reported yields. Offsetting this, the degree of underestimation of total production is more on large farms than on small farms so that the net effect is an understatement of yields by both groups of about 45 percent.

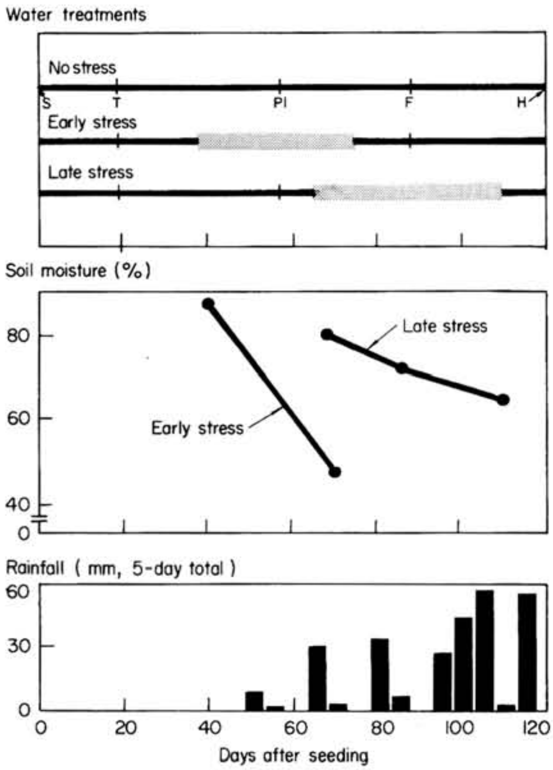
Farmers' estimation of their crop area shows no significant difference from the measured area in the strata tested, which means that most understatement occurs in estimates of production. Although some yield loss (12 to 16%) is normally expected during and after harvest, which would account for part of the difference, it is clear that the remainder (29 to 33%) represents reporting bias on the part of farmers. Underreporting is especially large for farmers with high yields and for tenants and leaseholders whose rental payments are computed as a percent of their harvest.

WATER MANAGEMENT

Our program in water management examines the contribution of water to grain yield, and ways to deliver the required supplies efficiently and economically. Except for one experiment at the IRRI farm, all projects were conducted in cooperation with Philippine irrigation systems and farmers.

Solar radiation, moisture stress, and yield. Previous research has shown that yield reduction in lowland rice can be related to the length of time that soils are drained. The nature of that relationship is unclear, however, because factors such as the growth stage of the crop during the drained period, the variety, nitrogen management, evaporative demand, soil properties, and depth of water table interact with the stress effect. An experiment in the 1973 dry season was designed to test the reaction of several lowland rice varieties and experimental lines to extend periods of field draining on different soils and with different water tables. The drained periods were planned to last for 30 days before panicle initiation (early stress) or 30 days after it (late stress), but both periods were lengthened to compensate for unexpected rainfall during the treatments (fig. 6).

The experiment was carried out with three fertilizer treatments: 100 kg/ha N basal, 50 kg/ha N basal plus 50 kg/ha N topdressed near panicle initiation, or 50 kg/ha N basal. All combinations of variety, nitrogen application, and stress were subject to three levels of evaporative demand. One treatment permitted all incident solar radiation to reach the crop, while in the other two treatments 30-cm-wide black polyethylene strips were placed over the crop at 30-cm or 45-cm intervals to block out some of the solar radiation. The strips ran north-south so that the pattern of alternate sunshine and shadows moved evenly across the plots without producing a banding effect.



6. The drained periods, soil moisture content, rainfall at different growth stages, and average yield of IR1561-228-3 under three water treatments. (S = seeding, T = transplanting, PI = panicle initiation, F = flowering, H = harvest.) IRRI, 1973 dry season.

The experiment was laid out as a split-split-split-plot design with stress treatments as the main plots, random placement of the shading treatments within them, and random nitrogen treatments within each level of shading. Seven varieties and lines were banded across the nitrogen treatments in each radiation block, but because of severe insect and disease damage, grain yield could be calculated only for the early maturing line IR1561-228-3. The other varieties planted were IR20, IR1529-680-3, and IR442-2-58 (medium maturity), and IR5, C4-63, and Intan (late maturity).

The two shading treatments reduced mean incident solar radiation, measured by recording actinograph, to 63 percent and 56 percent of that received by the unshaded treatment (478 cal $\cdot$ cm^{-2} $\cdot$ day^{-1}). Reduction in evaporative demand as indicated by Class A evaporation pans was not as great as that for radiation, due to the advective effect of the winds. Mean evaporation was 84 percent and 78 percent of the unshaded values (7.5 mm/day). The differences between the unshaded treatment and either of the shaded treatments were significant both for radiation and evaporation but the differences between the two shaded treatments were not.

The mean plant height at harvest for all varieties and nitrogen levels was reduced by stress, particularly early stress, while the mean tiller number was reduced by low solar radiation. Early stress reduced plant height on the average by 13 percent, but under maximum solar radiation the reduction was 18 percent. The taller, longer duration varieties showed less reduction in plant height, both absolutely and relatively, than the short-statured, short-duration line IR1561. The stress treatments also reduced the tiller count of this line more than they did that of the other varieties.

One hypothesis behind this experiment was that grain yield responds strongly to radiation as long as no moisture stress occurs, but under extended dry periods the crops grown with less solar energy may outyield those in hotter, drier areas. This would be expected since higher levels of internal plant stress would build up for crops subject to greater incident energy. Yields of the IR1561 line in the two shaded treatments were not significantly different, but the yield differences between shaded and unshaded treatments were significant for both no-stress and late-stress conditions (Table 19). Early stress caused a significant yield loss under all radiation levels. Late stress resulted in about 1 t/ha loss from the no-stress treatments, an insignificant difference, under all radiation levels.

Thus, while early stress produced rather uniformly low yields under all radiation treatments, the yield loss (relative to the no-stress treatment) was considerably greater with the maximum solar radiation treatment. Yield losses due to late stress were about the same, both absolutely and relatively, under all three radiation treatments. One explanation of these findings is that early stress lasted well beyond panicle initiation (fig. 6) resulting in substantial sterility. Because of the degree of sterility, the amount of solar radiation during grain filling was less important than normal. Second, late stress was not very intense due to rainfall during the treatment, and the favorable direct effect of radiation on grain yield dominated. Third, the shaded treatments received much less radiation for carbohydrate formation, but almost as much evaporative demand due to advective energy, which accentuated the stress effects. Plants in the shaded treatments were therefore exposed to almost as much internal stress as those in direct sunlight, but were deprived of much of the radiation necessary for attaining high yields.

No significant differences in grain yield were found for IR1561-680-3 among the three nitrogen treatments, or in interactions of nitrogen with either stress or radiation. Plots with stress treatments retained only half as much exchangeable soil nitrogen (KCl method) as plots with no stress and late stress, which also helps explain the low yield levels found with early stress.

Pump irrigation. Jointly with the University of the Philippines College of Agriculture, we surveyed the physical and economic performance of ground-water irrigation for lowland rice. The study was conducted in the wet and dry seasons of 1971-72 in three towns in southern Luzon.

Ground-water irrigation of rice has expanded considerably in recent years due to government incentives and the profitability of the new rice technology, but pump performance remains quite variable. To explain some of this variation we selected locations with different soil textures (sands, loams, and clays) and water table depths (less than 4 m, 4 to 6.5 m, and greater than 6.5 m). No locations could be found combining light soils with intermediate or deep water tables, but a total of 52 pumping units were finally selected from the other seven combinations of soil texture and depth of water table. The sample was evenly divided between pumps that had suction openings 4 inches (10.2 cm) and 5 inches (12.7 cm) in diameter. All pumps were powered by diesel or gasoline engines, and drew water from open wells. The 65 farmers who received water from the 52 pump units used it solely for lowland rice.

The mean capital investment required to buy and install a 5-inch pump was ₱15,000, about 40 percent more than for 4-inch models. The area served by pumps of both sizes was essentially the same, 4.5 hectares in the wet season and 3.9

Table 19. Grain yield of IR561-228-3 in relation to three treatments of moisture stress and solar radiation. (Each value is mean of three levels of nitrogen and two replications.) IRRI, 1973 dry season.

Solar radiation level	Yield[a] (t/ha)			
	No stress	Early stress	Late stress	Avg
100%	7.0	2.5	5.8	5.1
63%	4.7	2.4	3.8	3.6
56%	4.0	1.8	2.6	2.8
Avg	5.2	2.2	4.1	3.8

[a]LSD (5%) between two stress means, 2.0 t/ha; between two radiation means, 1.9 t/ha.

hectares in the dry season. Despite their greater size and cost, 5-inch units pumped only 8.1 liters of water per second of operation, compared with 9.0 liter/s for 4-inch pumps, based on mean discharge measurements taken four times throughout the year.

The depth of water table made little difference in pump discharge rates. Averaging other effects, deep water tables permitted mean irrigated areas of 3.0 hectares in the wet season and 2.9 hectares in the dry season, while comparable areas served from intermediate water depths were 5.5 and 4.5 hectares. The area irrigated from shallow ground-water conditions was not as large as that for intermediate ground-water depth for similar-sized pumps. One reason pumps at deeper water depths performed relatively well was that many farmers lowered their pumps part way into the open wells as the water table fell. That transferred part of the total lift from suction lift to discharge lift, which is more efficient for the centrifugal pumps in our sample.

The mean discharge from pumps operating on light soils was significantly higher than that from pumps on the other two soil classes. The greater hydraulic conductivity of light soils results in rapid resupply of water into the well. Water-use requirements, however, are higher for rice grown on light soils due to faster percolation of water into the soil. These high levels of both supply and demand of water tend to compensate for each other, and the area planted was essentially independent of soil class.

The average yield of the modern rice varieties found almost universally in the sample was 2.1 t/ha for both seasons. Neither depth of water table nor soil texture caused differences in yields.

Table 20. Mean annual operating costs for two sizes of groundwater pumps irrigating two crops per year. Quezon and Batangas, Philippines, 1971-72.

Costs	Operating cost (P)	
	4-inch pumps[a]	5-inch pumps[a]
Cash costs	352	441
Fuel[b]	116	154
Lubricants	19	31
Repairs and parts	217	256
Other costs	519	706
Depreciation and interest[c]	477	664
Unpaid labor[d]	42	42
Total	871	1147

[a]26 units of each size. [b]Assuming 4-inch pumps irrigate 4.4 ha, in the wet season and 3.9 ha in the dry season, and 5-inch pumps irrigate 4.6 and 4.0 ha, respectively. [c]Using linear depreciation plus 12% interest on undepreciated value of pump. [d]Based on 100 days of irrigation per season and 16 h/day.

Assuming a farm value of ₱0.725/kg of rough rice, a farmer's gross return from 1 hectare of pump-irrigated rice was slightly greater than ₱1,500 in each season. His costs of production, including the average irrigation cost, came to approximately ₱1,000/ha leaving about ₱500/ha net return per season. Thus, the benefit-cost ratio for farmers growing pump-irrigated rice was about 1.5 to 1. The most important influences on the profitability of pump operation appear to be the quality of the well and the groundwater aquifer.

The average cost of operating and maintaining the pumps, computed from interviews with the owners, was ₱871/ha per year for 4-inch pumps and ₱1,149/ha for 5-inch pumps (Table 20). These costs are substantially more than the irrigation payments made by farmers who do not have their own pumps. The payment is generally fixed at 20 percent of gross returns less costs of seed, harvesting, and threshing, which averages only ₱452/ha per year for those buying water from pump operators. It is apparent that farmers who buy pumps pay for them from their net farm returns and sell excess water cheaply to neighboring farmers. But farmers who buy water this way are likely to be deprived of it during periods of water shortage.

Location effects within canal systems. Last year we reported the attitudes of farmers in different locations within irrigation systems regarding their water management problems (1972 Annual Report). This year we analyzed the water-use and water-adequacy data from that study for further insights into differences caused by location. The data were collected in a 1969-70 joint study by the University of the Philippines College of Agriculture and the National Irrigation Administration.

The original study involved daily accounting of all water entering and leaving 11 irrigated sites, together with measures of water inadequacy and resulting grain yield reduction. The average site area was 25 hectares and the project was conducted in essentially the same sites in both the wet and the dry season. Through the use of a stress-day concept, the supply of water in relation to other water-use parameters was used to estimate yield reduction at each site (1972 Annual Report).

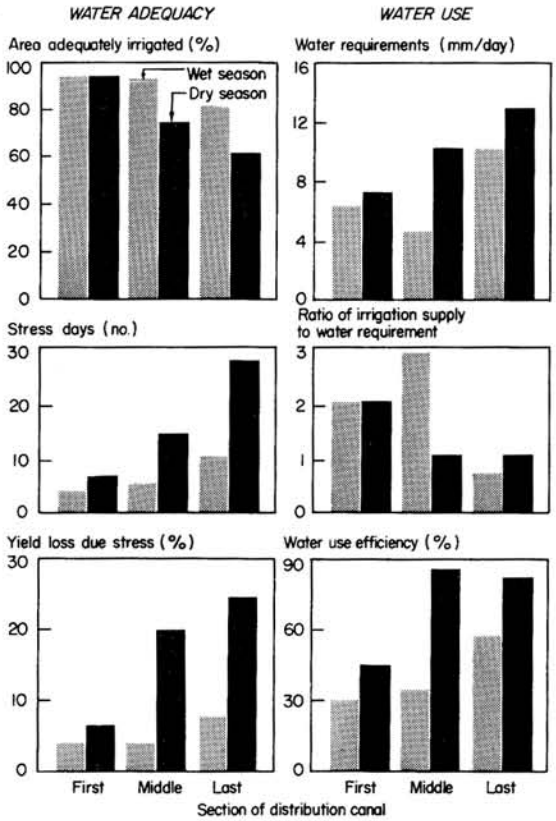
To evaluate possible location effects, we ranked each site according to whether it was served from the first, middle, or last section of its supply canal. The ranking applied to all 22 crop sites together, although the sites were actually irrigated by different canals. The breakdown did not take into consideration how far away from the canal the site was located, since each site was either bisected by the canal or was adjacent to it.

Water adequacy and water-use measures showed great sensitivity to location (fig. 7). In the wet season, sites in the first and middle sections had about 95 percent of their area adequately irrigated (flooded) throughout the season, while sites in the last section were only 85 percent adequately irrigated. In the dry season, first-section sites also were 95 percent adequately irrigated, but the middle section had only 70 percent adequacy, and last-section sites had less than 60 percent. Stress-days and yield reduction also tended to be greatest in the last section. Sites located at the ends of canals in both seasons had somewhat greater water requirements and much less water supplied relative to demand. Water-use efficiency (defined as the water requirements for evapotranspiration plus seepage and percolation divided by total rainfall plus irrigation) was very low for first-section sites, and much higher for the middle and last sections, particularly in the dry season. It appears that sites near the beginning of canals are over-irrigated leading to excessive drainage losses, while those at the ends of the canals suffer from being deprived of that water. Conditions in sites along the middle reaches are associated with those of first-section sites in the wet season, but with those of last-section sites in the dry season, indicating that the distribution of water along canals gets worse as the demand for water increases.

A more intensive study of water adequacy along a single lateral canal (Lateral C) of the Peñaranda River Irrigation System was carried out during the 1973 dry season. The presence or absence of standing water on sample paddies was assessed by observing the reflection of the sun from the surface of sample paddies while flying over the command area in a light airplane. Bright sunlight is clearly reflected by water even through a dense plant canopy. The water adequacy measures were verified on the ground the following days and mapped. The area within each section was stratified accordingly to assist in subsequent crop-cut yield sampling.

We found a striking decrease in the area adequately irrigated, and in mean grain yield, for each successive section (Table 21). Over 90 percent of the first section was well irrigated on the date of the survey, while all the 423 hectares planted in the last section were without water. Yields dropped from 2.5 to 0.4 t/ha from the first to last sections. Conditions along this canal were particularly acute because the river supplying the irrigation system has low flow during the dry season, and other canals in the system had a higher water-use priority. Nevertheless the problem of adequately irrigating the farther sections of canals is common in many irrigation systems.

A large and rapidly growing area exists on the higher land outside the command areas of sections 1 and 2 of Lateral C, which is being irrigated by pumps drawing water from Lateral C. That illustrates the attractiveness of pump irrigation where a dependable source of water is available. The upper reaches of Lateral C are dependable water sources since the irrigation of the canal's command area depends on water passing through the first two sections. Pumps lifting water from the canal are thus able to irrigate an otherwise rainfed area equal in size to more than one-fourth the irrigated command area, but at the expense of even greater inequality among the regular sections of Lateral C.



7. Mean water-adequacy and water-use measures for 11 sites irrigated by the first, middle, or last sections of distribution canals. Luzon, Philippines, 1969-70.

The use of an airplane in surveying the water status of the rice crop has several advantages where the area is large and land access is limited. For this survey, north-south flight lines were marked on the ground with signboards measur-

Table 21. Area adequately irrigated on March 24, 1973 and subsequent mean grain yields by consecutive sections served from Lateral C, Peñaranda River Irrigation System, Gapan, Nueva Ecija, 1973 dry season.

Section[a]	Production area			Planted area	
	Total (ha)	Planted (%)	With water (%)	With water (%)	Yield (t/ha)
1[b]	1559	91	82	91	2.5
2[b]	1171	82	55	67	2.2
3	873	58	20	35	1.5
4	1907	22	0	0	0.4
Total	5510	60	36	61	2.0

[a]Section 1 is at the beginning of the lateral and Section 4 at the end. [b]Includes 274 ha in Section 1 and 168 ha in Section 2, which are outside the command area of those sections but were fully irrigated by pumps drawing water from the lateral.

ing 0.5 sq m placed approximately every 2 km. Flight lines were spaced at 1 km but sample observations were taken every 8 or 9 seconds, depending on plane speed, to sample every 200 m along the line. The survey was not expensive and was found to be accurate through ground checks. Complete coverage of the 5,500-hectare area was done in less than 2 hours of flying time. The major difficulties with the aerial surveys were the need for a large number of pre-positioned signboards to guide the pilot along each flightline, the problem of locating the next flightline while turning at the end, and the heavy crosswinds which tended to blow the plane off course. The technique is most useful in large areas which dry out progressively and irreversibly.

Effect of irrigation on land preparation. The date of planting greatly affects the irrigation water requirements of a rice crop and its possible exposure to moisture stress. In the wet season, delayed plantings frequently result in continued crop growth beyond the usual end of the wet season. Although particularly damaging for rainfed rice, such delays are also costly in irrigated areas since most irrigation systems themselves depend directly on rainfall. Dry-season crops are planted with reference to the expected duration of irrigation supply, so that delay in transplanting also raises the risk of water shortage during the critical later stages of crop growth.

Insufficient water to complete land preparation is the major cause of late planting. Land preparation usually consists of three phases: land soaking, in which the land is softened as it absorbs water, plowing, and puddling. Farmers do not begin plowing most heavy rice soils until the soil has been near saturation for several days, and the puddling process requires full saturation throughout. Thus, supplemental irrigation is potentially beneficial to yields in helping to meet the crop's water needs throughout the growing season, and in allowing timely land preparation so that the crop's water needs will coincide with periods of maximum available rainfall and irrigation. The second effect may be as important as the first for many irrigation systems in the humid tropics.

In a project with the National Irrigation Administration we attempted to relate the timing of the land preparation processes in the wet season to the supply of water to several irrigated and rainfed areas. We are not determining the minimum water requirement for land preparation, for which we presented data last year (1972 Annual Report). In this study we measured the gross water actually supplied to the areas, recognizing that this was always more than the minimum requirement.

For our irrigated areas we took the entire command areas of lateral canals to avoid possible bias in selecting small sites which might be located favorably or unfavorably within the irrigation systems. These command areas are broken down administratively into blocks of approximately 150 hectares under the control of ditchtenders. We asked at least half the ditchtenders from each area to report weekly when land soaking, plowing, harrowing (puddling), and transplanting were begun, and when each step was essentially completed, for each farmer within his jurisdiction. By spot checks we were assured that systematic error in the ditchtenders' responses was negligible. The irrigation water entering the area was measured continuously by water-level recorders fitted to Parshall flumes. These readings were evaluated for total weekly flow and prorated over the canal's entire command area, which was determined from aerial photographs and system maps, to give mean application depths in millimeters per week.

Rainfed areas close to the irrigated ones were selected for comparison. Here farmers were randomly contacted from three strata, those located on the top third of a watershed, those located in the intermediate range, and those located on the lowest third. Relative topography was the criterion, rather than absolute elevation. These farmers were interviewed weekly for the same information described for the irrigated farms. Rainfall for both irrigated and rainfed areas was measured with a network of rain gauges, and weekly totals were computed.

The minimum time required from the first irrigation until half of the farms were transplanted was about 8 weeks for the irrigated areas (Table 22). The time required for 50 percent completion of transplanting in the Gapan rainfed area was 3 weeks longer than in the adjacent Peñaranda irrigated area. The cumulative depth

Table 22. The duration of the land preparation period and water applied during it for three irrigated and two rainfed areas. Luzon, Philippines. 1973 wet season.

Location	Duration of land preparation (wk)	Water applied during: Land preparation plus early cropping		Water applied during: Land preparation only[f] (mm)
		Total (mm)	Rainfall (%)	
Santa Cruz system[a]				
50% transplanted	8.5	1327	34	1140
100% transplanted	9.5	1471	35	1274
Angat system[b]				
50% transplanted	7.5	1494	10	1410
100% transplanted	10.0	1957	11	1488
Peñaranda system[c]				
50% transplanted	7.5	695	55	615
100% transplanted	13.0	1222	50	729
Gapan rainfed[d]				
50% transplanted	10.5	603	100	450
100% transplanted	15.0	786	100	407
Bustos rainfed[e]				
50% transplanted	8.0	634	100	570
100% transplanted	13.0	742	100	592

[a]Sub-lateral A2, Pila, Laguna. Land soaking began Aug. 1, 1973 following heavy rainfall. Total command area: 216 ha. [b]Lateral B, Baliwag, Bulacan. Land soaking began April 20, 1973. Total command area: 618 ha. [c]Lateral C, Gapan, Nueva Ecija. Land soaking began June 16, 1973; data for first 2 weeks estimated. Total command area: 5,780 ha. [d]Approximately 1,000 ha located adjacent to the Peñaranda system. Heavy rainfall began on the week ending June 23, 1973. [e]Approximately 500 ha. First heavy rainfall during the week ending June 23, 1973. [f]The sum of weekly rainfall and irrigation multiplied by the percentage of area not yet transplanted.

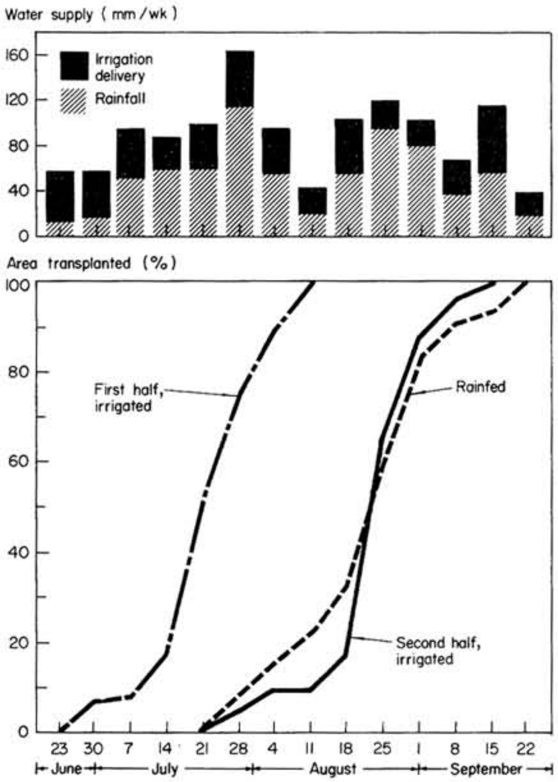
of water applied prior to 50 percent transplanting ranged from 443 and 603 mm for the rainfed areas, to over 1,500 mm for one irrigated area with abundant water.

The time span between the dates of 50 percent and 100 percent completion of land preparation varied with the size of the area and its water supply. About 5 weeks were required to complete transplanting of the second 50 percent of farms in the larger irrigated and rainfed areas, but for the smaller Angat and Santa Cruz systems, which applied considerably more water, only 2.5 weeks and 1 week, respectively, were required (Table 22).

As land preparation proceeds, an increasing portion of the total area is planted and additional supplies of water are allocated between the newly cropped areas and those still unplanted. Rigorous partitioning of water use is impossible since there are no borders separating early plantings, but previous research (1972 Annual Report) indicates that the mean daily rate of water supplied to irrigated sites remains roughly the same during the periods before and after transplanting. Although land preparation requires more water, the efficiency of water use also tends to be higher before transplanting, resulting in approximately equal daily rates of supply. Thus, we assume that the weekly amount of water applied only to land undergoing preparation is roughly the total weekly amount times the proportion of the area still unplanted (Table 22).

The water supplied for land preparation was substantially higher than the theoretical minimum requirement for two reasons. First, large amounts of the water were not used effectively because of drainage losses. Second, little rain fell in the early part of the study, resulting in an extended period of land preparation in the rainfed sites and in one of the irrigated areas with insufficient water. Extended duration requires additional water to make up for the daily evaporation losses.

The adjacent irrigated and rainfed areas in Gapan provide a basis for examining the effect of irrigation on the date of transplanting (fig. 8). Irrigation enabled farmers that had favorable access to water—farmers in the first half of the canal—to plant about 4 weeks earlier than rainfed farmers. But farmers in the second half were not able to plant any earlier than rainfed farmers; in fact, while waiting for the expected irrigation, they were even slower than rainfed



8. Weekly rainfall, irrigation and cumulative percentage of farms transplanted by date in sections of an irrigation canal and on adjacent rainfed farms. Gapan, Nueva Ecija, Philippines, 1973 wet season.

farmers in getting started. Farmers near the beginning of the canal apparently took advantage of the heavy rainfall and abundant irrigation in late July, but the others had to wait for a second period of sustained water supply in excess of 100 mm/wk, which did not occur until August. These results indicate that location effects within canal systems apply to irrigation deliveries before as well as after transplanting.

Insignificant difference was found in the speed of land preparation among rainfed farmers in the three topographical strata. Although rainfall was later than expected, once started it was generally sufficient for all elevations in the watershed. This may not happen during years of more variable rainfall.

A model for estimating yield of rainfed rice. Last year we reported (1972 Annual Report) a water-balance model using the concept of stress-days for estimating yield reduction of irrigated rice. This year we applied the model to rainfed rice receiving rainfall at several probability levels.

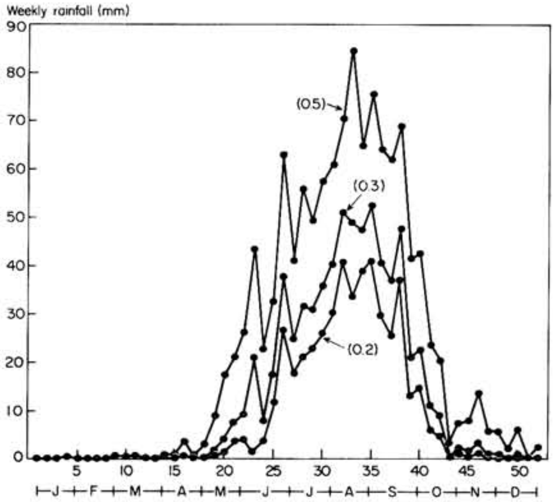
Since much of our research is conducted in Central Luzon we computed weekly estimates of rainfall for Cabanatuan City, based on 20 years of rainfall data (fig. 9). The computations are based on the incomplete gamma distribution, a skewed distribution which we believe fits tropical rainfall patterns. The probability estimates show the build-up of rainfall beginning approximately midyear, and the danger is in growing rainfed rice beyond the last weeks of October. During the critical weeks at the beginning and end of the wet season, the maximum expected rainfall at the 0.3 probability level (equivalent to a drought year encountered 3 years in 10) is less than half that expected for a median year of rainfall.

The water-balance model accounts for daily increments of water (rainfall) to the paddy, and daily losses (evapotranspiration, and seepage and percolation). When rainfall exceeds losses, the water depth in the paddy rises until it reaches the effective height of the paddy bunds; rainfall in excess of that is computed as surface drainage. At low levels of rainfall the calculated depth of water falls until the soil surface is drained (negative water depth), and moisture stress builds up. Days of moisture stress, defined as the number of days in excess of three during which the paddy has no standing water, can then be computed given an assumed daily evaporation rate (5 mm/day), daily rainfall, and a seepage and percolation rate. Refinements in the model include a stochastic procedure for dividing the weekly rainfall estimates into representative daily parts, and reduced rates of evapotranspiration and seepage and percolation as the simulated water depth drops below the soil surface. The water required for land preparation is not considered.

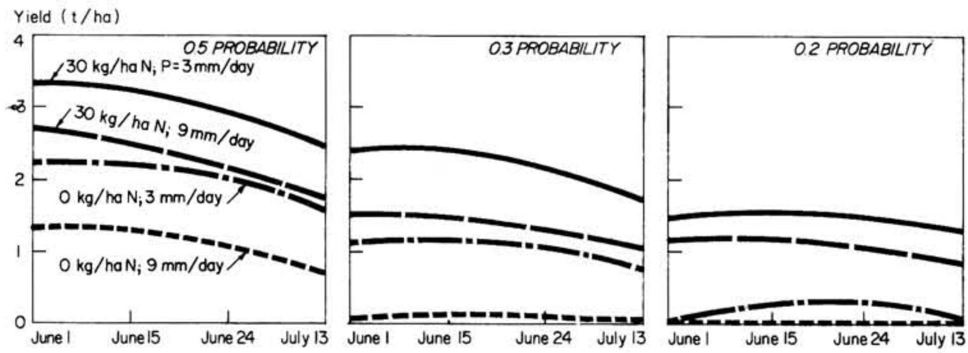
An approximation of the yield impact of the stress-days computed by the model can be determined by a modification of the wet-season yield regression on nitrogen and stress days previously found for irrigated conditions (1972 Annual Report). That relationship did not consider stress-days during the last 30 days of crop growth since few were found during that period and their effect was not significant. For rainfed rice, however, stress often starts building up more than 30 days before harvest, and gets progressively worse if the rains stop. This condition is similar to that found in irrigated dry-season sites when the irrigation supply is prematurely cut off. Furthermore, rainfed rice usually matures about a month later than irrigated wet-season crops, and is therefore often exposed to the beginning of the dry season. Consequently, for our rainfed relationship we used the irrigated wet-season yield relationship, but substituted the stress coefficient for the later stage of growth from the irrigated dry-season equation: $Y = 2790 + 41.5(N) - 0.5(N^2) - 50.2(S_1) - 94.4(S_2) + 0.76(NS_1)$ where Y is grain yield in kilograms per hectare, N is nitrogen fertilizer in kilograms per hectare, S_1 is the number of stress-days computed throughout vegetative growth and S_2 is stress-days for the first 30 days of reproductive growth.

Yields can be estimated given the daily rainfall pattern, the seepage and percolation rate, and the nitrogen applied. For rainfall, we used expected values over four 16-week periods beginning at different dates between early June and mid-July to determine the effect of delayed planting. The daily rate of seepage and percolation in irrigated areas is often about 3 mm/day, but it is higher in rainfed areas. Separate analyses were therefore made using seepage and percolation rates of 3 and 9 mm/day. Two levels of nitrogen use, 0 and 30 kg/ha N, were also explored.

These yield relationships (fig. 10) indicate that increasing nitrogen use from 0 to 30 kg/ha N can compensate for a stress effect brought about by soils with the higher water-use rate, or for a 0.3 probability drought (but not both). At low rainfall levels, nitrogen appears crucial for achieving essentially any yield at all. This is a result of the positive NS_1 interaction which can be explained by greater root development under high applications of nitrogen, such that the crop is better able to cope with drought. Assuming that the planting date, percolation rate, and nitrogen use are all favorable, the indicated yield levels are about 3, 2, and 1 t/ha for expected rainfall at the 0.5, 0.3, and 0.2 probability levels, respectively. Under similarly favorable conditions, a delay in transplanting from early June until mid-July could be expected to give about 1 t/ha of yield loss, based on the Cabanatuan City rainfall pattern.



9. Maximum expected weekly rainfall for Cabanatuan City, Nueva Ecija, Philippines, at three probability levels.

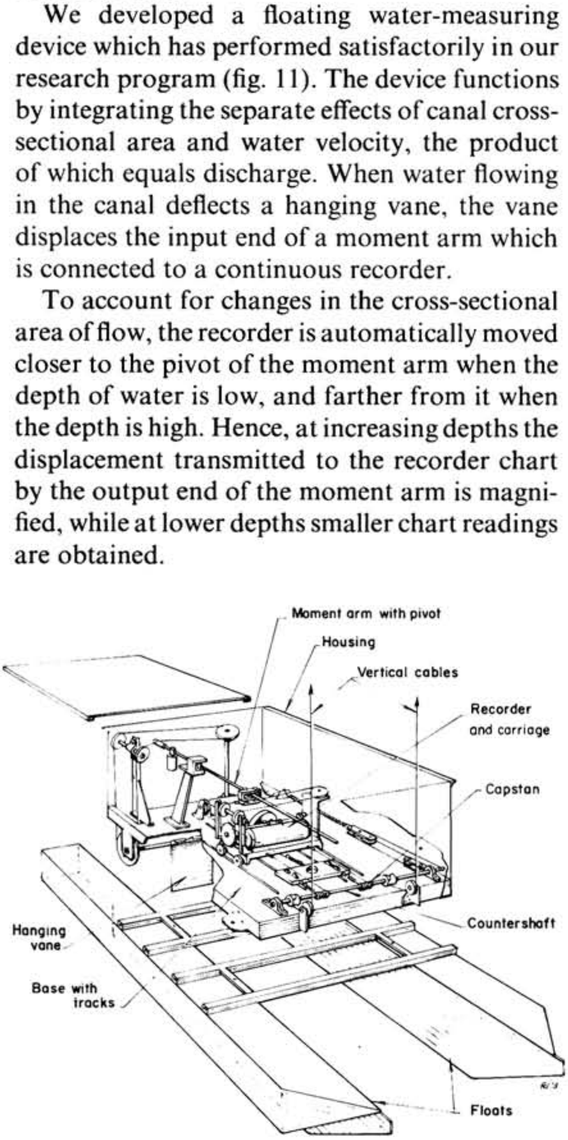


10. Synthesized grain yield at four dates of planting for four combinations of nitrogen application and water percolation rates, using expected rainfall at three probability levels in Cabanatuan City, Nueva Ecija, Philippines.

Instrumentation for measuring open-channel flow. A major reason water supply in canal systems is hard to manage is the difficulty in accurately measuring volume flows of water in canals. In the Philippines, this difficulty stems from the unpredictable and wide variation of flow within very short periods and the almost level (1:3000) design of many canals. Instruments must therefore be capable of recording zero flows, and must be able to operate with little head loss.

We developed a floating water-measuring device which has performed satisfactorily in our research program (fig. 11). The device functions by integrating the separate effects of canal cross-sectional area and water velocity, the product of which equals discharge. When water flowing in the canal deflects a hanging vane, the vane displaces the input end of a moment arm which is connected to a continuous recorder.

To account for changes in the cross-sectional area of flow, the recorder is automatically moved closer to the pivot of the moment arm when the depth of water is low, and farther from it when the depth is high. Hence, at increasing depths the displacement transmitted to the recorder chart by the output end of the moment arm is magnified, while at lower depths smaller chart readings are obtained.



11. Floating water-measuring device for canal irrigation systems.

A system of capstans and cables fitted to a countershaft and mounted on the front of the device moves the recorder closer to or farther from the pivot of the moment arm. The rotation of the shaft in one direction winches the recorder closer to the pivot through a light cable running horizontally to the recorder and an idler pulley behind it. Torque is imparted to the shaft by a reel wrapped with a light cable running vertically to a fixed crosspiece mounted above the canal and anchored in the embankment. Thus, as the water depth in the canal recedes, the instrument falls and the vertical cable plays out from the reel, causing clockwise rotation of the shaft and moving the recorder toward the pivot. When the height of water in the canal increases the instrument rises, a retracting spring turns the shaft in the counterclockwise direction, and the recorder moves away from the pivot.

A critical assumption underlying the use of the device is the linear relationship between water velocity and angular deflection of the vane (and therefore the angular displacement of the moment arm). Nearly linear relationships can be shown theoretically within a moderate range of deflection, and field calibration has confirmed it and fixed the maximum reliable deflection. Weight was added to the vane to keep its sensitivity within the range of velocities encountered.

A second assumption is that the ratio of the velocity of water at the surface (where it is measured) to its average velocity is constant over all conditions of flow. Field calibration has shown that this ratio varies between 0.77 and 0.86. A third assumption is that the canal has a rectangular cross-section. That can usually be achieved with wooden reinforcing along the canal embankments if a rectangular section does not already exist.

A useful feature of the device is that discharge readings can be scaled directly from the chart. Once calibrated, the instrument can be used in any rectangular canal section and the scaling factor changes only with the canal width and the ratio of surface velocity to average velocity. The instrument has to be zeroed initially for both height in the canal and deflection of the vane.

The device has performed satisfactorily in preliminary trials. Debris floating in the canal can be a problem, but this has been largely remedied by a floating deflector placed upstream of the instrument. Another problem is that the recorder charts can be changed only by wading into the canal. The instrument does not require any external power source, and is self contained. It provides a continuous weekly recording of discharge which we believe is $\pm$ 8 percent of actual flow. All parts of the device including the recorder are made in the Philippines at a cost of about US$400.

Entomology

Analysis of plant tissue revealed that plants absorbed about 10 times more insecticide when it was applied to the root zone than when applied to the soil surface or incorporated in the top soil. Even at 40 days after treatment, the concentration of insecticide in plants receiving the root-zone application was about twice the maximum in the other treatments. When sprayed on the basal half of plants, perthane and chlordimeform provided long lasting control of *Nilaparvata lugens*. ☐ The varieties Ptb 21 and Ptb 27 were found highly resistant to *Recilia dorsalis*. Progenies of several crosses exhibited resistance to *Chilo suppressalis* and several species of leafhoppers and planthoppers. ☐ In some cases it was profitable to grow IR20 with a low-cost insecticide treatment; in others no treatment at all was economically advantageous. When many flying planthoppers were reinfesting the fields every day, however, it was difficult to prevent damage even with repeated treatment of the fields. ☐ In the greenhouse we observed a 30-percent yield loss due to damage by *Hydrellia philippina*, but we could not show a significant yield gain in the field by protecting the crop at the early stage when this maggot damages the plants. Loss in yield from damage by *Nephotettix virescens* and *N. lugens* was significant when the plants were young, and at the booting to flowering stage. Plants could usually tolerate 5 to 10 nymphs per tiller for 2 weeks without yield loss. ☐ A population of *N. lugens* grew best on IR22 plants that were 70 to 90 days old. ☐ One predator (*Cyrtorhinus lividipennis*) could kill 0.6 caged *N. lugens* nymphs per day or 50 *N. virescens* nymphs per day, for at least 4 days in a row. This predator prefers *N. virescens* to *N. lugens*.

VARIETAL RESISTANCE

Studies on varietal resistance consist of identifying sources of resistance, investigating the nature and causes of resistance, and, in cooperation with the plant breeders, combining resistance to several insects as well as different sources of resistance to one insect.

Stem borers. Studies on the striped borer, *Chilo suppressalis*, were focused on accumulating resistance from resistant varieties through diallele selective crossing of resistant varieties. The F_1 populations are tested by the mass screening technique (1972 Annual Report). Several progenies were identified that are more resistant than any of the parents used in these crosses. They have been crossed in all possible combinations and their hybrids will be tested. This process will be repeated until a desirable level of resistance is obtained. In addition, about 700 varieties and promising breeding lines were evaluated for striped borer resistance by the mass screening technique, which has worked well. But the borer population declined considerably if most test lines planted inside the screenhouse were resistant to the borer. To overcome this problem, we kept about one-third to one-fourth of the area in the screenhouse planted to susceptible varieties.

Leafhoppers and planthoppers. About 2,000 rice collections and hybrids of selected lines were evaluated for resistance to the green leafhopper, *Nephotettix virescens*. (Distant), the brown planthopper, *Nilaparvata lugens* (Stal), and the white-backed planthopper, *Sogatella furcifera* (Horvath). Several new sources of resistance have been identified for each insect and some progenies have exhibited resistance to all these insects.

TKM 6 has been used in several crosses as the source of brown planthopper resistance. We believe it possesses the same gene for resistance as Mudgo. We studied the survival of first-instar brown planthopper nymphs on a few TKM 6 and Mudgo progenies (Table 1). Their mortality was significantly higher on these lines than on Taichung Native 1, but was significantly lower than on Mudgo. Besides possessing *Bph 1*, a major gene for brown planthopper resistance, Mudgo probably carries some minor genes for resistance to this insect.

In a new project on resistance to the zigzag leafhopper, *Recilia dorsalis* (Motschulsky), 44 of 1,500 varieties tested were found resistant. The level of resistance in some of the varieties is high. All nymphs caged on the varieties Ptb 21 and Ptb 27 died; those caged on several other varieties had low survival (Table 2). On the susceptible check variety, Taichung Native 1, most of the nymphs became adults in about 12 days after caging, but on the moderately resistant varieties they usually needed 16 to 18 days to complete the nymphal period. The variety Ptb 21 is also resistant to the green leafhopper and the brown planthopper, but several other varieties resistant to one or both of these insects, such as ASD 7, Mudgo, and Su-yai 20, were susceptible to the zigzag leafhopper. Thus resistance to the zigzag leafhopper appears to be unrelated to resistance to the green leafhopper or the brown planthopper.

To further study the resistance of some varieties we recorded the survival of each nymphal instar on them (Table 3). All instars had very low survival on Ptb 21 but the last-instar nymphs had greater survival on Ptb 27 and Rathu Hinatee. The somewhat higher survival of the last-instar nymphs on these varieties is understandable since the larger nymphs are

Table 1. Survival of first-instar brown planthopper nymphs on selected lines 2 to 15 days after infestation. IRRI, 1973.

Designation	Cross	Survival[a] (%)			
		2 days	5 days	10 days	15 days
IR1402-38-38	Mudgo/IR8	34 b	22 b	18 b	10 ab
IR1514A-E666-7	IR20/TKM 6	82 d	66 d	52 c	29 c
IR1514A-E597-2	IR20/TKM 6	53 c	41 c	39 c	28 c
IR1541-76-3-3	IR24/TKM 6	61 c	29 bc	25 b	19 bc
Mudgo (resistant check)	—	17 a	8 a	6 a	4 a
TN1 (susceptible check)	—	96 e	92 e	92 d	92 d

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

expected to be more tolerant to adverse conditions, but the high survival (29%) of the first-instar nymphs on Balamawee is not yet understood.

Whorl maggot. Among several thousand more varieties and breeding lines evaluated for resistance to the rice whorl maggot, *Hydrellia philippina* Ferino, no resistant variety was discovered. So far about 12,000 germ plasm collections and breeding lines have been screened. A few moderately resistant varieties are being used in a diallele selective crossing program to determine whether the level of rice whorl maggot resistance can be further increased. These varieties are Ma-li-bin, Gin-shan-tsan 18, MGL 2, ARC 12260, ARC 10299, ARC 11094, WC 1253, and RDR 2.

Combining resistance to several pests. A few promising selections of IR1514A were further evaluated during the 1973 wet season. When grown without insecticide, they had significantly lower incidence of dead hearts, white heads, and virus infection than many of the other test varieties (Table 4). The virus incidence was particularly severe on the check varieties during this experiment but all IR1514A lines had only 5 percent or less virus-infected plants. Several of these lines yielded almost 6 t/ha, which was about 1 t/ha more than the yield of IR20. The susceptible check variety Taichung Native 1 was severely damaged and yielded only 0.6 t/ha. When grown with maximum insect protection (treated with paddy water application of carbofuran every 20 days), several lines yielded more than 7 t/ha. The IR1514A-E597 selections performed best since they also exhibited field resistance to the cercospora leaf spot, while most of the other lines were heavily infected.

Based on retestings of selected varieties in field plots, 13 varieties were identified as having broad resistance to the common insect pests. These varieties were crossed with IR20 to increase and broaden their spectrum of resistance. The undesirable plant types were rogued out during the F_2 and F_3 generations. The selected F_3 and F_4 populations were tested in greenhouse and in field experiments. Several lines in most of these crosses were resistant to the brown planthopper, the green leafhopper, and the white-backed planthopper (Table 5).

Table 2. Survival of first-instar zigzag leafhopper nymphs on selected rice varieties 1 to 12 days after infestation, IRRI, 1973.

Variety	Survival[a] (%)				Nymphs becoming adults[b] (%)
	1 day	3 days	6 days	12 days	
Ptb 21	53	19	10	0	0
Ptb 27	78	36	3	0	0
Balamawee	86	64	49	27	22
Rathu Heenati	86	69	48	30	27
DNJ 24	87	73	61	47	41
DS 1	91	78	67	45	33
ASD 7	93	81	69	62	61
Mudgo	95	83	72	61	53
BJ 1	96	89	83	81	81
Su-yai 20	98	86	72	56	53
Sudurvi 306	99	90	84	78	76
TN1	100	99	99	98	98

[a]Avg of 10 replications. In each replication 10 insects were caged on a 20-day-old plant. [b]Observed at 20 days after caging.

The field planting of the F_4 lines was exposed to a heavy brown planthopper infestation that developed just a few days after transplanting. This allowed a rigorous evaluation of these lines for resistance to the brown planthopper. Most of the susceptible lines had complete hopperburn (Table 6). Also, the grassy stunt virus was really severe and eliminated a large proportion of those varieties that had survived hopperburn. Several lines from IR2755, IR2757, IR2759, and IR2763 had less than 20 percent grassy stunt virus infection. In addition, many had a low incidence of dead hearts and were resistant to bacterial blight. Several were also resistant to the white-backed planthopper in a greenhouse experiment (Table 6).

Cooperative variety trials. Varieties and selec-

Table 3. Survival of zigzag leafhopper nymphs on 10-day-old seedlings of selected varieties. (100 nymphs were observed for each instar. Temperature was 29 ± 2°C.) IRRI, 1973.

Variety	Survival (%)				
	1st instar[a]	2nd instar[a]	3rd instar[a]	4th instar[a]	5th instar[b]
Ptb 21	0	0	0	0	0
Ptb 27	2	2	2	0	30
Rathu Heenati	6	20	32	18	72
Balamawee	29	5	7	7	26
TN1	99	100	100	100	100

[a]3 days after caging. During this period the insects on the susceptible variety molted to the next instar. [b]4 days after caging. During this period the insect on the susceptible variety *became* adult.

Table 4. Performance of selected lines when grown with and without insect control. IRRI, 1973 dry season.

Designation	Whorl maggot 41 DT[a]	Virus-infected plants (%) 108 DT	Dead hearts[b] (%) 82 DT	Grain yield (t/ha)	
				Without insecticide	With insecticide[c]
IR1514A-E583-1	3.0	2 d	5 bc	4.74 b	5.84 de
-E597-2	2.5	5 d	4 c	5.75 a	7.29 ab
-E597-3	2.6	5 d	5 bc	5.22 a	7.44 a
-E597-6	2.6	5 d	4 c	5.66 a	6.98 abc
-E597-7	3.0	5 d	3 c	5.93 a	7.16 ab
-E661-4	2.5	3 d	4 c	4.82 b	6.57 bcd
-E661-5	2.0	4 d	4 c	4.31 bc	6.53 bcd
-E666-7	2.5	3 d	3 c	5.61 a	6.58 bcd
-E670-5	2.8	3 d	3 c	5.87 ab	6.59 bcd
-E670-7	2.3	4 d	4 c	5.76 a	6.93 abc
-E670-11	3.3	2 d	3 c	5.96 a	6.79 abc
-E670-12	3.1	2 d	3 c	5.92 a	6.43 bcd
-E671-2	2.9	3 d	4 c	5.71 a	6.61 bcd
IR1514A-102-2	3.6	21 c	5 bc	4.53 b	5.94 de
IR1541-102-6	3.5	20 c	3 c	4.38 b	5.82 de
IR20	3.3	6 d	8 ab	4.75 b	6.31 cde
IR22	3.3	32 b	4 c	3.63 c	5.56 ef
IR8	4.0	64 a	10 a	1.30 d	4.92 f
Taichung Native 1	4.0	61 a	6 abc	0.55 e	3.47 g

[a]Days after transplanting. [b]The incidence of whiteheads was low and did not significantly differ among various treatments. [c]Carbofuran applied to the paddy water at 2 kg/ha a.i. every 20 days. The first application was made at 2 DT.

tions were tested without insecticides for field resistance to insect pests at three stations of the Philippine Bureau of Plant Industry—Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station.

In the dry season, 31 selections and varieties were evaluated. Because insect infestation was low at the Maligaya and Bicol stations, we are only reporting stem borer damage at Visayas where *Tryporyza innotata* (Walker) is common. The overall level of damage was high, and no highly resistant selections were apparent. IR442-2-58, IR833-6-2, IR1480-116, IR1529-680-3, and IR1721-14-6 were more susceptible than IR20 to dead hearts or white heads or both.

In the wet season we evaluated 33 selections and varieties for stem borer resistance after

Table 5. Reaction (R = resistant, I = moderately resistant, S = susceptible) of F_3 selections to different species of leafhoppers and planthoppers. IRRI, 1973.

Designation	Cross	Lines tested (no.)	Lines (%) Brown planthopper R	I	S	Green leafhopper R	I	S	White-backed planthopper R	I	S
IR2750	IR20/Lusi 513	189	2	0	98	0	0	100	0	24	76
IR2751	IR20/BJ 1	10	0	0	100	10	50	40	0	0	100
IR2752	IR20/DV 139	7	0	0	100	28	14	57	0	0	100
IR2753	IR20/Charnock	17	24	6	70	24	18	58	0	0	100
IR2754	IR20/Tadukan	76	4	0	96	3	3	94	0	7[a]	93[a]
IR2755	IR20/H 5	80	51	9	40	41	28	31	10	14	76
IR2756	IR20/Mean Dawn	31	6	6	87	61	32	6	0	0	100
IR2757	IR20/SLO 12	25	36	12	52	0	8	92	0	8	92
IR2759	IR20/CO 10	31	3	32	65	3	10	87	0	0	100
IR2760	IR20/Mudgo/IR8	169	3	33	64	0	1	99	0	0	100
IR2761	IR20/Vishnu Parag	26	0	4	96	4	12	84	—	—	—
IR2762	Thmar/IR20	73	12	7	81	34	14	52	4	4	92
IR2763	I-Li-Chung/IR20	12	83	0	17	0	0	100	58	0	42
IR2764	Dahanala 2014/IR20	7	14	0	86	28	28	43	14	43	43
IR2765	Hashikalmi/IR20	1	0	0	100	0	100	0	0	0	100

[a]Only 67 lines were tested.

Table 6. Reaction of selected F_4 lines in a field experiment. IRRI, 1973.

Designation	Lines planted (no.)	Selections (no.) with Resistance to brown planthoppers	Less than 20% grassy stunt[a]	Less than 6% dead heart[a]	Resistance to bacterial leaf blight[a,b]	Resistance to white-backed planthopper[a,c]
IR2750	261	8	0	6	2	0
IR2751	3	0	[d]	[d]	[d]	0
IR2753	12	50	8	50	17	92
IR2754	46	15	0	9	0	0
IR2755	297	65	6	56	61	15
IR2756	23	43	30	30	9	4
IR2757	97	74	46	40	73	8
IR2759	57	84	38	51	40	5
IR2760	448	83	3	32	56	4
IR2761	119	0	[d]	[d]	[d]	0
IR2762	124	18	8	14	6	0
IR2763	22	91	54	77	91	27
IR2764	7	100	0	86	100	86

[a]Hopperburned lines excluded. [b]Data obtained by plant pathology department after artificial inoculation of the plants. [c]Based on a greenhouse experiment. [d]All plants had hopperburn.

flowering. At the Maligaya and Visayas stations the infestation was severe enough to reveal large differences among selections. The selections IR1561-228-3 and IR2061-464-2 had very low percentages of white head and few borers per 100 tillers; in fact they were not significantly different from the resistant check TKM 6.

INSECTICIDES

In laboratory experiments, insecticides were tested for their contact toxicity to the green leafhopper and the brown planthopper adults, but in greenhouse and field experiments they were evaluated as foliar sprays, applied to the paddy water, as root-soak and root-coat treatments, and as root-zone treatments. The procedures were similar to those described in earlier annual reports.

Contact toxicity and foliar sprays. Compounds that exhibited high contact toxicity to the green leafhopper and the brown planthopper are listed in Table 7. Besides these, diazinon, GS 13005, MC 2420, and azinphos ethyl killed about 100 percent of the green leafhopper but were ineffective against the brown planthopper. Methyl parathion was moderately effective against the green leafhopper but not against the brown planthopper. Naled was moderately effective against the brown planthopper, but not against the green leafhopper. Several insecticides used as foliar sprays caused high initial mortality of the insects and had long residual effects as well (Table 8). Although the compounds MIPC, toxaphene + methyl parathion, and M 3571 caused high mortality of the test insects at 1 day after treatment, they were not effective 4 days later. The compounds chlorfenvinphos, PP 156, LS 69-473, AC 92 100, Bayer

Table 7. Contact toxicity of 0.04% insecticidal sprays on adult insects treated in a Potter's spray tower. Variety Taichung Native 1.

Chemical	Formulation[a]	Insect mortality[b] (%) *N. lugens*	*N. virescens*
Carbofuran	75 WP	100	100
BPMC	50 EC	.96	100
CGA 13608	50 WP	93	100
AC 92,100	200 E	84	100
BPMC + Trichlorofon	20 + 40 EC	82	100
Chlorfenvinphos	20 EC	17	100
Fenitrothion	50 EC	50	100
Mecarbam	68 EC	65	100
NC 6897	80 WP	73	100
Phorate	26.8 EC	81	100
Zectran	25 EC	41	100
Promecarb	25 EC	78	99
Carbaryl	85 S	49	98
Fenthion	50 EC	31	96
TBPMC + XMC	50 WP	32	78
Dicrotophos	20 EC	52	71
Demeton-S-methyl	25 EC	60	62
Vamidothion	40 EC	36	50
Monocrotophos	16.8 EC	73	27
Naled	8 E	56	0

[a]DP = dispersable powder; E = emulsifiable; EC = emulsified concentrate; S = soluble; SP = soluble powder; WP = wettable powder. [b]At 48 h after treatment. Values adjusted using Abbott's formula.

Table 8. Evaluation of insecticides applied as foliar sprays (0.04%) on potted plants of Taichung Native 1.

Chemical	Formulation[a]	Mortality[b] (%)							
		N. lugens				*N. virescens*			
		1 day	5 days	10 days	15 days	1 day	5 days	10 days	15 days
Carbofuran	75 WP	100	100	100	100	100	100	100	100
Cabaryl	85 S	92	69	34	5	100	100	100	60
Fenitrothion + Surecide	30 + 15 EC	92	45	18	5	100	100	100	—
Du Pont 1410-L 25%[c]	25.2% liquid	100	78	38	37	100	100	92	97
Oxydemeton methyl	25 EC	98	47	3	10	100	100	92	82
Monocrotophos	16.8 EC	100	87	27	5	100	100	92	76
EMD 7021	25 EC	95	59	0	0	100	100	88	59
Carbophenothion	8 E	100	92	49	15	100	100	85	95
Propaphos	50 EC	87	0	10	7	100	100	73	90
RE-15223-4	60 WP	88	11	3	0	100	92	12	5
Acephate	75 SP	88	13	8	3	100	88	15	10
Perthane	45 EC	95	76	32	5	95	18	0	2
Dicrotophos	20 EC	55	11	0	0	100	70	12	27
Bux	24 EC	73	10	1	—	86	72	26	5
MIPC	75 WP	85	8	3	0	100	15	0	0
M 3571	25 WP	92	0	0	8	92	2	0	0

[a]DP = dispersable powder; E = emulsifiable; EC = emulsified concentrate; S = soluble; SP = soluble powder; WP = wettable powder; Liquid = miscible with water. [b]Mortality in 48 h adjusted using Abbott's formula. [c]Used as 0.12% spray as suggested by manufacturer. Less effective at lower concentration.

5546, and M 3019 were effective against the green leafhopper, but not against the brown planthopper. Chlordimeform killed 95 percent of the brown planthoppers caged on sprayed plants at 1 day after treatment, but was not effective against the green leafhopper.

The knockdown effects of selected compounds used as foliar sprays on brown planthopper were investigated in a greenhouse experiment. Carbofuran, bux, and Mobam had fast knockdown effects (Table 9). Carbofuran, DDT, Perthane, and toxaphene + methyl parathion had long

Table 9. Knockdown and residual effects of selected insecticides 1 to 15 days after application as foliar sprays (0.04% a.i. + 0.2% Tenac sticker) on *Nilaparvata lugens* caged 1 to 24 hours on treated plants.

Chemical	Formulation	Mortality[a] (%)					
		1 day				5 days	15 days
		1 h after caging	4 h after caging	7 h after caging	24 h after caging	24 h after caging	24 h after caging
Carbofuran	75 WP	100	100	100	100	88	95
Bux	24 EC	60	95	100	100	8	0
Mobam	80 WP	45	95	98	98	13	2
MIPC	50 WP	20	61	69	100	3	2
Carbaryl	85 S	10	37	82	100	57	12
M 3571	25 WP	10	18	39	100	31	2
DDT[b]	75 WP	8	37	49	98	68	28
Perthane	45 EC	8	34	51	95	80	22
Omethoate	50 EC	8	23	47	92	6	0
Monocrotophos	50 EC	5	67	88	100	51	0
Propaphos	50 EC	5	29	51	98	18	0
Toxaphene + methyl parathion	66 EC	5	13	41	92	51	32
Acephate	75 SP	2	44	78	98	47	0
Oxydemeton methyl	25 EC	2	39	68	98	23	0
Carbophenothion	8 E	0	6	8	85	27	2
Fenitrothion + Surecide	30 +15 EC	0	3	23	80	34	5

[a]Adjusted using Abbott's formula. [b]Used as 2% spray.

Table 10. Effect of foliar sprays (0.05% every 14 days) on insect control[a] (variety IR22). IRRI, 1973 wet season.

Chemical	Whorl maggot damage[b] 35 DT	Dead hearts (%) 60 DT	White heads (%) 92 DT	Virus (%) 92 DT	Brown planthoppers (no./hill) 55 DT	Green leafhoppers (no./10 sweeps) 2 days after 3rd spray	Green leafhoppers (no./10 sweeps) 13 days after 3rd spray	Grain yield (t/ha)
Methamidophos	2.4*	1.6*	0.4**	11**	20	0.8**	9.5	3.51**
Monocrotophos	1.6**	0.6**	0.1**	9**	6**	0.0**	2.8**	3.50**
Carbophenothion	2.1**	3.0	1.5	14*	7**	0.8**	1.0**	3.23**
Omethoate	1.4**	3.0	0.5**	14*	19	0.8**	4.8**	3.08*
EMD 7021	2.2*	1.7	0.8**	10**	19	0.8**	4.0**	3.05
Cartap	2.5	1.1*	0.3**	15*	15*	3.2	4.5**	3.01
Mobam	2.4*	6.0	2.0	16	13**	0.0**	4.0**	2.95
Hoe 2982	2.6	5.0	1.4	22	31	1.0**	7.8*	2.72
TBPMC	3.0	4.0	1.4	23	12**	0.5**	8.0*	2.58
AC 92,100	3.0	4.0	1.8	19	19	2.2	11.0	2.55
Untreated control	3.0	4.0	2.0	24	23	4.5	15.5	2.64

[a]Four replications. [b]On a scale of 0 to 5. Larger number indicates greater damage.

residual effects. Bux was more effective when sprayed with 0.2 percent Tenac (methyl cellulose —a sticker) solution than when sprayed without Tenac while C 10015 was more effective without Tenac than with Tenac. Addition of Tenac did not alter the effectiveness of other insecticides.

When sprayed every 14 days on a lowland rice crop, several of these compounds provided significant protection to the crop from rice whorl maggot, stem borer, and virus infection (Table 10), although the level of control was not as good as that usually obtained by applying insecticides to the paddy water or to the root zone of the rice plants. Monocrotophos and cartap were most effective against the stem borer. The monocrotophos-treated plot also had the fewest brown planthoppers, green leafhoppers, and virus-infected plants. Monocrotophos has some systemic effect when used as foliar spray. Thus uniform coverage of the foliage by this material is not as necessary as for nonsystemic insecticides.

The compounds were also tested on upland rice. The brown planthopper and the rice leaf folder occurred in epidemic proportion during this experiment. Bux, chlordimeform, monocrotophos, acephate, and BPMC significantly reduced the number of brown planthopper nymphs (Table 11). While subsequently, the brown planthopper population remained low in these plots, in other treatments it increased considerably, causing extensive hopperburn. BPMC however, was less effective against the brown planthopper than bux, chlordimeform, monocrotophos, or acephate. The compounds

Table 11. Effect of foliar sprays (0.05% every 15 days) on the control of insects infesting upland rice (variety IR442-2-58). IRRI, 1973 wet season.

Chemical	Brown planthopper nymphs[a] (103/meter-row) 1 day before 3rd spraying	Brown planthopper nymphs[a] (103/meter-row) 2 days after 3rd spraying	Hopper-burned area (%) 70 DS	Leaf folder damage[b] 57 DS
Bux	352	87**	0**	3.4*
Acephate	357	146**	0**	0.5**
Chlordimeform	656	177**	0**	0.9**
Monocrotophos	276	178**	1**	0.5**
BPMC	411	293**	8*	4.6
Chlorpyrifos	612	564	17	0.5**
Fenthion	558	586	28	3.6*
Endosulfan	426	762	51	4.5
Fenitrothion	610	1092	39	3.5*
Azinphos ethyl	696	1126	76	2.8**
Surecide	574	1291	90*	0.6**
Untreated control	517	664	42	4.8

[a]Few adult insects were present during these observations. [b]On a scale of 0 to 5. Larger number means greater damage.

Table 12. Effect of insecticidal foliar sprays (0.05%) on brown planthopper adults[a] infesting upland rice (variety IR442-2-58). IRRI, 1973 wet season.

Chemical	Formulation	Brown planthoppers (no./meter-row) 1 day after treatment[b]	Brown planthoppers (no./meter-row) 3 days after treatment[b]
Perthane	45 EC	44	500
Acephate	75 WP	63	450
Carbofuran	75 WP	91	200
BPMC	50 EC	212	2700
Toxaphene + methyl parathion	66 EC	500	2200
Carbaryl	85 S	512	2200
Monocrotophos	50 EC	540	900
Chlordimeform	800 SP	827	1700
Azinphos ethyl	40 EC	1334	3800
Methyl parathion	50 EC	1955	11000
Untreated control		8600	20000

[a]Most of the insects immigrated from heavily infested surrounding plots. [b]Plants sprayed 60 days after seeding.

chlordimeform, acephate, monocrotophos, chlorpyrifos, and surecide provided excellent protection to the plant from the rice leaf folder.

Several insecticides were further evaluated by spraying them on 1-meter-long rows of 60-day-old upland rice plants which were heavily infested with the brown planthopper. Each treatment was replicated four times. Several compounds rapidly reduced the number of brown planthoppers and kept it low until the subsequent observation 3 days after the treatment (Table 12). During this period the number of insects increased greatly in several treatments and the untreated control plots started developing hopperburn, so the experiment had to be discontinued.

In another experiment on upland rice selected compounds were sprayed in four replications of 3.5- × 11.5-m plots. The first spraying was done after the plots were heavily infested with brown planthopper and the second when the residual effects of the treatments appeared to have worn off (Table 13). Since the brown planthoppers feed near the base of the plants, the nozzles of the sprayers were held so that only the lower halves of the plants were sprayed. This manner of spraying was also expected to be less hazardous to parasites and predators, many of which usually dwell on the upper parts of the foliage.

Perthane, bux, chlordimeform, and MIPC kept down the number of brown planthoppers up to 14 days after the treatment. There were only moderate differences among plots in the number of adult brown planthoppers present at 21 days after the treatment but the number of nymphs recorded 14 days later was distinctly low in several treatments. This indicated that the residual effects of the insecticides at 21 days after treatment were too weak to control the adults. But apparently a few insecticides had some influence in suppressing the nymphal population even 2 weeks later.

The rather long residual effects of Perthane,

Table 13. Effect of foliar sprays on the control of upland rice pests (variety C12). IRRI, 1973 wet season.

Chemical	Brown planthoppers (no./25-cm row)						Green leafhoppers (no./10 sweeps)		
	Nymphs		Adults		Nymphs				
	1 day before spraying	2 days after 1st spraying	14 days after 1st spraying	21 days after 1st spraying	35 days after 1st spraying	4 days[a] after 2nd spraying[b]	1 day before spraying	2 days after spraying	21 days after spraying
Perthane	184	1**	4**	5	13	1**	1	0**	6
Chlordimeform	160	1**	2**	6	16	0**	1	1**	10
Bux	135	1**	2**	4*	12	1**	3	0**	7
MIPC	88	2**	4**	7	24	6*	3	0**	6
Acephate	167	10**	13**	7	31	24	3	0**	6
Monocrotophos	107	17*	26	9	53**	26	3	0**	3**
CPMC	189	20*	16*	6	32*	29	2	1**	8
Triazophos	180	21	28	8	96**	67**	4*	0**	2**
Carbaryl	139	47	38	4*	56**	36	2	0**	3**
Dicrotophos	108	52	64	8	78**	34	3	0**	7
Methyl parathion	87	54	78	8	49**	34	3	0**	6
Untreated control	141	84	104	8	14	22	1	3	11

[a]The low number of nymphs apparently occurred because the damaged plants were less attractive to the adults for oviposition. This has been a common reaction in many experiments. [b]Done after counting the number of insects at 35 days after first spraying.

chlordimeform, and bux may have resulted from spraying the insecticides on the basal half of the plants where they were less exposed to rain and sunshine than they would have been on the upper foliage. Also, the numbers of spiders in Perthane-treated and untreated control plots were similar (Table 14). Spiders are important natural enemies of the brown planthopper.

Perthane, chlordimeform, bux, and MIPC, in that order, were most effective in controlling the brown planthopper.

Microgranules. Microgranules (105-297 μm in size) are a recent invention developed to minimize the drift problem of dusts. They also are believed to penetrate the foliage better than the dusts. Like dusts, however, they are likely to be washed off the foliage by rains.

Some commonly available microgranular insecticides were tested on lowland rice. They were dusted on the crop at 2 kg/ha a.i. every 15 days. Several provided significant protection to the plants from the rice whorl maggot, and from the dead heart damage of the stem borer but, like sprays, the microgranules were not as effective against these insects as granules applied to the paddy water or to root zone. Only sumithion + metacrate and sumibal significantly reduced the population of the adult brown planthopper, but all insecticides tested were highly effective against brown planthopper nymphs (Table 15). But none were effective in protecting the plants from the grassy stunt virus, which is transmitted by the brown planthopper.

Table 14. Effect of foliar sprays (0.05%) at the basal half of the plants on spiders in an upland rice field (variety C12). IRRI, 1973 wet season.

Chemical	Spiders (no./10 sweeps)		
	1 day before spraying	2 days after spraying	21 days after spraying
Perthane	2 ab	2 b	4 b
Chlordimeform	3 ab	1 ab	2 ab
Bux	2 ab	0[a] a	2 ab
MIPC	2 ab	1 ab	2 ab
Acephate	2 ab	1 ab	3 ab
Monocrotophos	1 a	1 ab	2 ab
CPMC	2 ab	2 b	4 b
Triazophos	3 ab	0[a] a	1 a
Carbaryl	4 ab	1[a] abc	3 ab
Dicrotophos	6 b	1[a] ab	1 a
Methyl parathion	2 ab	1 ab	3 ab
Untreated control	2 ab	2 b	3 ab

[a]Difference in density at 1 day before spraying from that at 2 days after spraying significant statistically at the 5% level.

Root-zone application. Because the results of applying insecticides in the root zone of rice plants (1972 Annual Report) were encouraging, we conducted experiments to identify additional insecticides that are effective when applied in the root zone, and to determine the appropriate rates of application and the durations of residual effects. In most experiments, we used gelatin capsules instead of paper straws used in earlier experiments. Gelatin capsules dissolve in water, so there is no need to punch holes in them. The capsules were pushed by hand to about 2.5 cm below the soil surface at approximately 2.5 cm from each hill.

Table 15. Effect of microgranules (2 kg/ha a.i. every 15 days) on rice insect pest control (variety IR22). IRRI, 1973 wet season.

Chemical	Whorl maggot damage[a] 30 DT	Dead hearts (%) 50 DT	Brown planthoppers (no./hill)				Virus-infected hills[b] (%) 50 DT
			Adults		Nymphs		
			1 day before application	2 days after application	1 day before application	2 days after application	
MTMC	2.0**	2.2	28	18	105*	1**	34
Osbac	2.0**	2.1	24	22	100**	4**	33
Meobal	2.3*	3.0	26	18	127	3**	33
Sumithion	2.0**	1.7	29	20	101**	6**	35
Diazinon	1.0**	2.4	32*	18	200	3**	30
Sumithion + metacrate	1.7**	0.9*	28	9*	109*	1**	33
Sumibal	1.7**	0.7**	23	6**	104**	1**	34
MIPC Dust	1.3**	2.6	33*	21	125	2**	32
MIPC spray	3.0	2.3	20	19	91**	8**	34
Control	3.0	3.8	21	25	159	25	33

[a]On a scale of 0 to 3; larger number indicates greater damage. [b]Mostly grassy stunt.

Table 16. Effects (1 to 30 days after treatment) of applying insecticides in the root zone of potted TN1 plants (12.5 mg/hill a.i.) at 45 days after sowing.[a] IRRI, 1973.

Chemical	Mortality[b] (%)										
	Nephotettix virescens				*Nilaparvata lugens*				*Chilo suppressalis*		
	1 day	5 days	10 days	30 days	1 day	5 days	10 days	30 days	5 days	10 days	15 days
Carbofuran	100	100	100	100	100	100	100	100	24	48	68
AC 64,475[c]	100	100	100	20	43	77	57	0	72	75	41
BHC + Aprocarb	100	100	100	43	100	100	100	60	9	45	7[d]
MTMC	100	100	100	3	100	100	67	10	0	0	0
Metacrate	100	100	100	10	100	100	97	17	0	0	—
Acephate	—	100	98	—	—	100	92	—	58	71	—
MC 2420	100	97	100	13	63	67	73	17	100	100	7[d]
BPMC	100	93	100	70	80	87	100	30	22	13	—
Dimethoate	100	100	93	7	63	52	39	0	7	23	7
Aprocarb	100	97	80	17	93	93	57	14	0	7	0
TBPMC	90	83	100	37	67	77	70	23	14	7	—
PFL 13917	72	98	51	100	3	28	22	18	—	—	—
Mobam	69	100	100	100	3	13	2	8	—	—	—
MIPC	43	48	40	47	37	35	43	31	0	14	0
Cytrolane[c]	30	69	43	3	23	28	17	0	76	59	31

[a]41 insecticides were tested. [b]48 h after caging; adjusted using Abbott's formula. The experiment was conducted in a greenhouse (24-38°C and 30-100% humidity). [c]Some phytotoxic effects manifested as burning of leaf tips. [d]At 25 days after treatment.

In greenhouse experiments, the root-zone application of 41 compounds was evaluated for the control of the green leafhopper, the brown planthopper, and the striped borer. About 25 of these compounds were highly effective against the green leafhopper—several caused almost 100 percent insect mortality up to 30 days after the treatment (Table 16). Fewer compounds were effective against the brown planthopper, however. Only carbofuran and BHC + aprocarb caused high mortality of the brown planthopper at 30 days after treatment. Several compounds were effective against striped borer larvae.

Such compounds as BHC, phorate, and AC 92, 100, which are highly effective when applied to the paddy water (1963, 1972 Annual Reports), showed low insecticidal activity when placed in the root zone of the rice plant. When applied to paddy water, BHC is absorbed by the plant through the leaf sheath and the roots. It moves up between the leaf sheath and the stem by capillary action and its vapors kill the insects. But more is absorbed through the leaf sheath than through the roots. When BHC is placed in the root zone of the rice plant, it becomes available to the plants primarily through the roots, and is not effective.

Most of the compounds tested in the greenhouse were also evaluated in a field experiment. The rice whorl maggot, stem borers, and virus diseases were severe during the experiment. Several compounds were highly effective and some treated plots yielded four to five times more than the untreated control plots (Table 17). Some insecticides, such as acephate, JF 4089, and dimethoate, were highly effective during the first 40 days after treatment, but the treated plots later developed a high incidence of stem borer and virus diseases (mostly grassy stunt) and consequently produced low yields. On the other hand, the yields of plots treated with cytrolane and AC 64,475 were apparently suppressed by some initial phytotoxic effects, although both these insecticides were highly effective in controlling the various pests.

During the entire crop MIPC + cartap, carbofuran, TBPMC + cartap, promecarb + chlordimeform, and cartap were highly effective against the insect pests and protected the plants from virus infection. Cartap and chlordimeform were more effective than carbofuran against the stem borer while carbofuran was more effective against the whorl maggot and the virus vectors (the green leafhopper, which transmits the tungro virus, and the brown planthopper, which transmits the grassy stunt virus). We also found that carbofuran applied to the root zone controlled insects longer than did carbofuran

CRM 81 (a special slow-release formulation developed for use on forest trees and which is supposed to last for 2 to 3 years under upland conditions) placed on the soil surface near the base of the rice plants. Both treatments looked equally good during the first 40 to 50 days after treatment.

These insecticides were further evaluated in the field. Several insecticides were consistently effective against the rice whorl maggot, the green leafhopper, the brown planthopper, and the stem borers, and protected the plants from virus infection. In one experiment the effect of the root-zone application of carbofuran, cartap, and chlordimeform was compared with that of the paddy water application of carbofuran at 2 kg/ha a.i. every 20 days. The latter is one of the most effective methods of insect control. All treatments effectively controlled the rice whorl maggot and all, except the root-zone application of diazinon and a single application of carbofuran to the paddy water at 3 days after transplanting, effectively protected the plants from virus infections (Table 18). Also, the root-zone application of diazinon and one application of carbofuran to the paddy water failed to protect the plants from dead hearts and white heads caused by stem borers. Thus, these treatments had short residual effects.

Insect control from root-zone applications of carbofuran, cartap, and chlordimeform and that from paddy water application of carbofuran every 20 days were not significantly different. The plots with root-zone application of carbofuran or paddy water application of carbofuran every 20 days produced the highest and statistically similar yields. But the root-zone application used only 2 kg/ha of carbofuran while the paddy application every 20 days required a total of 8 kg/ha.

In a similar experiment, root-zone application of cartap + MIPC gave greater rice yield than the application of carbofuran to the paddy water every 20 days (fig. 1).

Several experiments also have revealed that for some insecticides the rate of root-zone application can be reduced to 0.5 to 1.0 kg/ha a.i. The insect control by the root-zone application in these experiments was identical to that obtained by the paddy water application at 2 kg/ha every 20 days—generally a total of three to four applications or 6 to 8 kg/ha a.i. of the insecticides. The total amount of insecticide needed for the root-zone application is even less than that needed for foliar sprays, which is generally 0.7 to 1.0 kg/ha a.i. per spray, repeated every 10 to 15 days for effective pest control. Thus the root-zone application of insecticide

Table 17. Effect of placing insecticides at 2 kg/ha a.i. (12.5 mg/hill) in the root zone of Taichung Native 1 seedlings at 3 days after transplanting (DT). IRRI, 1973 dry season.

Chemical	Whorl maggot damage[a]	Virus (%) 89 DT	Dead hearts (%) 68 DT	White heads (%) 89 DT	Grain yield (t/ha)
MIPC + cartap	1.6**	6**	2**	0.1**	5.07**
Carbofuran	0.1**	2**	2**	1.3	5.04**
TBPMC + cartap	2.7**	8**	2**	0.0**	4.70**
Promecarb + chlordimeform	1.9**	7**	7**	0.4**	4.06**
Cartap	2.6**	16**	2**	0.1**	3.95**
BPMC	1.8**	10**	11	2.7	3.86**
Hoe PFL 812	2.2**	10**	10	1.7	3.80**
Cytrolane	0.2**	7**	4**	0.7*	3.76**
BHC + MTMC	1.8**	14**	12	2.0	3.69**
Mecarphon	0.6**	16**	16*	2.5	3.27**
BHC + aprocarb	0.1**	8**	17*	2.7	3.18**
AC 64,475	0.2**	14**	6**	3.2	3.17**
Hoe PFL 13917	2.5**	18**	11	2.3	3.14**
Carbofuran CRM 81[b]	0.5**	7**	12	6.5**	3.13**
Fensulfothion	1.3**	17**	15	2.9	3.01**
Fenitrothion + meobal	2.5**	26**	13	2.7	2.96**
Metacrate	2.9**	19**	14	1.8	2.97**
MTMC	2.8**	21**	15	2.1	2.91**
Promecarb	2.8**	22**	13	2.2	2.86**
JF 4089	1.3**	23**	15	2.1	2.75**
Fenitrothion + metacrate	2.5**	23**	11	2.4	2.74**
Triazophos	1.9**	29**	12	2.7	2.56**
Mecarbam	0.4**	24**	16*	2.7	2.49**
Acephate	1.9**	23**	15	1.2	2.47**
Meobal	3.1**	18**	15	2.5	2.45**
BHC + carbaryl	3.2**	26**	14	2.5	2.37**
Formetanate	2.1**	31**	13	2.4	2.32**
Dyfonate + phosmet	2.4**	39**	11	1.6	2.17**
Dimethoate	0.9**	27**	16*	1.7	2.17**
TBPMC	3.9*	38**	10	2.2	2.12**
Phosmet	3.8**	47*	12	1.3	1.58*
BHC	4.3	67	13	1.4	1.24
Endrin	4.3	75	12	3.1	0.96
Abar	4.6	61	11	2.0	0.87
Endosulfan	4.3	74	11	1.5	0.80
Fenitrothion	4.3	88**	12	1.3	0.74
Control[c]	4.5	66	12	2.0	1.01

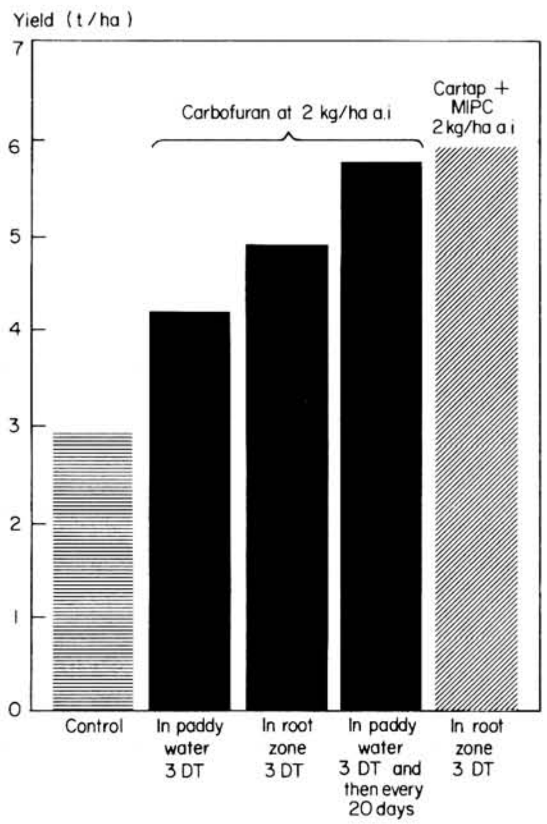
[a]On a scale of 0 to 5. Lower number represents lesser whorl maggot damage. Data presented are avgs of three observations made 13, 24, and 34 DT. [b]Applied to paddy water. [c]Avg of 16 replications.

Table 18. Effect of placing insecticides (2 kg/ha a.i.) in the root zone of Taichung Native 1 plants at 3 days after transplanting (DT) on insect pest control compared with effect of applying them in paddy water. IRRI, 1973 dry season.

Chemical	Whorl maggot damage[a]	Virus-infected hills (%) 69 DT	Dead hearts (%) 36 DT	Dead hearts (%) 49 DT	White heads (%) 90 DT	Grain yield (t/ha)
			Root-zone application			
Carbofuran	0.1 a	11 a	3 a	3 ab	0.7 abc	3.77 ab
Cartap	0.3 abc	18 a	3 a	2 a	0.1 a	2.94 bc
Chlordimeform	0.2 ab	16 a	2 a	3 ab	0.3 ab	2.91 bc
Diazinon	0.4 bc	29 b	6 b	13 c	1.5 c	1.94 d
			Application in paddy water			
Carbofuran[b] (3 DT)	0.5 c	27 b	10 b	18 c	1.2 bc	2.50 cd
Carbofuran[b] (3 DT and every 20 days)	0.3 abc	16 a	4 a	6 b	0.0 a	4.30 a
			Control			
None	1.2 d	50 c	9 b	14 c	1.6 c	0.96 e

[a]Based on the youngest leaves of the main tillers on a scale of 0 to 3. Larger number indicates greater damage. Data are avgs of observations made at 19, 29, and 41 DT. [b]At 2 kg/ha a.i. per treatment.

potentially is the cheapest and most effective method of applying insecticides. Furthermore, it should be less hazardous to the parasites and predators and other non-target organisms in the rice environment than the foliar spray or paddy water application.



1. Effect of method of insecticidal application for insect control on rice yield. Variety IR22. IRRI, 1973 dry season.

Absorption of chlordimeform in root-zone application. The insect control obtained by root-zone application of insecticides is highly efficient and long lasting apparently because the chemical is readily available to the roots of the rice plants, is shielded from sunshine, heat, and volatilization, and is less likely to be washed off by overflowing paddy water. We have demonstrated that when applied to the root zone, chlordimeform was absorbed by the plants in a greater quantity than when it was broadcast on the soil surface or broadcast and incorporated in the topsoil (fig. 2). The insecticide was applied at 2.12 kg/ha a.i. and all treatments were made at 3 days after transplanting, except the incorporation of chlordimeform in the soil just before transplanting. The chlordimeform hydrochloride and its metabolites present in the plant were determined by electron-capture gas-liquid chromatography.

The insecticide applied in the root zone was rapidly absorbed and translocated to the stem and leaves of the rice plant. Its concentration in the plant tissues was about 8 to 10 times higher than in any of the other treatments. Furthermore, even at 40 days after treatment the concentration of the insecticide was about twice the maximum concentration in any of the other treatments, including the currently used standard method of paddy water application (fig. 2).

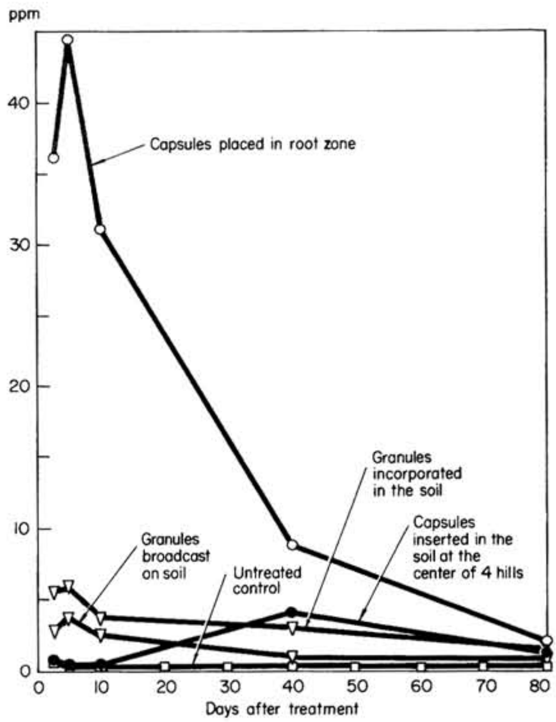
When the insecticide was placed below the soil surface, but in the center of four hills instead of near the roots of each hill, it was apparently not absorbed by the plants until the roots reached the site of application. It is not clear why the amount of the insecticide absorbed was not equal to that on root-zone application, but the insecticide may possibly have undergone some degradation. Although the incorporation of the insecticide with the top layer appeared more efficient than the standard paddy water treatment, it was much less effective than the root-zone application.

Future prospects of root-zone application of insecticides. These results illustrate the high efficiency of the root-zone method of insecticide application. But considerable work is needed to standardize the appropriate formulation and method of placing insecticides in the root zone of the rice plants. Manufacturers provided us with cartap tablets (2 cm in diameter, 0.7 cm thick) and large granules of chlordimeform (0.84 cm in diameter). We tested them at the rate of one tablet or one granule per hill and found them satisfactory. For commercial use, these formulations will need to be coated with resin or other suitable material to prevent them from dissolving or crumbling on contact with water during application. IRRI engineers are working on a mechanical applicator. We are also investigating the feasibility of using fertilizers instead of inert materials for formulating granules or tablets. Nitrogen fertilizers when placed in the soil 10 cm deep are better used by the plants than when they are applied to the soil surface or are incorporated into the soil before transplanting rice. Thus insecticide-plus-fertilizer formulations for root-zone application may not only be less expensive than the added separate costs of each but may also improve the use of the fertilizer and the insecticide.

Seedling root-soak and root-coat treatments. The root-soak and root-coat treatments for seedlings, before transplanting, provide the seedlings with some protection against various pests but the results have been inconsistent (1971 and 1972 Annual Reports). We conducted an experiment to see if the efficiency of these treatments would improve if more than one seedling per hill were transplanted. At 20 days after transplanting, all root-soak and root-coat treatments had significantly lower whorl maggot damage than the untreated control plots (Table 19). The whorl maggot damage also declined as the number of treated seedlings per hill increased. The trends in dead heart incidence and in virus infection were similar but the root-coat treatments were more effective than the root-soak treatments. The effects of the root-soak and the root-coat treatments appeared to be exhausted in later observations, but the effects of the root-zone application persisted and this method was also more effective.

The root-soak treatment was further investigated in a greenhouse experiment in which we soaked the roots of seedlings, before transplanting, in 1,000 ppm of carbofuran for 1, 4, 8, 12, 24, or 48 hours. The seedlings were transplanted individually in 15-cm diameter clay pots and the insecticidal effects of the various treatments were bioassayed by caging green leafhopper adults on them.

The 48-hour root-soak treatment was phytotoxic as manifested by leaftip burn. The tip burn



2. Concentration of chlordimeform and its metabolites in rice shoots as influenced by different methods of application.

Table 19. Effect of different methods of carbofuran application on rice insect pest control in relation to number of seedlings planted per hill. Variety Taichung Native 1. IRRI, 1973 dry season.

Seedlings (no./hill)	Application rate[a] (kg/ha a.i.)	Whorl maggot damage[b]			Virus (%)			Dead hearts (%)
		20 DT	32 DT	41 DT	40 DT	60 DT	84 DT	40 DT
Root-soak (1000 ppm carbofuran)								
1	0.062	2.0 a	3.5 bcd	3.5 cd	4 bcd	37 d	72 b	6 b
2	0.083	2.2 a	3.2 bc	3.2 bcd	2 ab	35 d	71 b	8 b
4	0.107	1.7 a	3.7 bcd	3.0 bc	2 ab	21 ab	69 b	4 b
Root-coat (1000 ppm carbofuran + 2% methyl cellulose)								
1	0.170	2.2 a	4.0 cd	3.7 d	7 d	32 cd	69 b	5 b
2	0.204	2.5 a	3.2 bc	3.5 cd	4 bcd	30 cd	66 b	3 ab
4	0.229	1.7 a	3.0 b	2.7 b	1 a	25 bc	67 b	3 ab
Root-zone application								
2	1.00[c]	1.7 a	0.7 a	0.0 a	3 bc	16 a	52 a	0 a
Untreated control								
2	—	3.7 b	4.2 d	3.7 d	6 cd	48 e	91 c	5 b

[a]Calculated on the basis of the quantity of the carbofuran solution absorbed by the seedlings in 24 h. Whether the carbofuran concentration in this solution declined was not ascertained. [b]On a scale 0 to 5. Lower number represents lesser damage. [c]Applied in paper capsules at 6.25 mg/hill at 3 DT.

later spread down the leaves and about 50 percent of the treated plants died. No phytotoxicity was recorded in any of the other treatments. Soaking seedling roots even for only 1 hour caused high mortality among green leafhoppers caged on seedlings at 5 days after transplanting (Table 20). In general longer soaking provided longer insecticidal protection to the plants. These and the results presented in Table 19 indicate the possibility of developing the seedling root-soak or root-coat treatment as a practical method of insect control provided the availability of the insecticide can be increased without phytotoxic effects.

Furrow placement of insecticides for upland rice. We studied placement of insecticides in the furrows at about 2 to 3 cm below the seed as an alternative to seed treatment with insecticides against seedling pests of upland rice (1971 and 1972 Annual Reports).

Although the incidences of the rice whorl maggot, the stem borers, and virus diseases were low during this experiment and did not differ significantly among treatments, brown planthoppers and green leafhoppers were numerous. Carbofuran, aprocarb, AC 64, 475, triazophos, and Terracur were highly effective against the green leafhopper up to 50 days after the treatment, but only a few of the insecticides were effective against the brown planthopper at 50 days after seeding (Table 21). Another treatment made by side-dressing the various insecticides along the rows of the plants shows that all test compounds were effective against the green leafhopper but only carbofuran and lindane + MTMC were effective against the brown planthopper. Carbofuran was also effective against the rice leaf folder.

Cooperative insecticide trials. In the wet season we evaluated the concept of placing

Table 20. Effect of seedling root-soak treatment for different durations in 1000 ppm of carbofuran on *Nephotettix virescens*. Variety Taichung Native 1. IRRI, 1973.

Duration of soaking	Mortality[a] (%)				
	5 DT	10 DT	20 DT	30 DT	40 DT
1 h	92 b	25 e	22 c	6 b	0 b
4 h	97 ab	50 d	36 bc	6 b	0 b
8 h	94 b	87 bc	70 a	21 b	5 ab
overnight (12 h)	99 a	96 ab	49 abc	10 b	8 ab
1 night + 1 day	100 a	100 a	56 ab	11 b	1 ab
2 nights + 2 days[b]	99 a	71 c	75 a	48 a	23 a

[a]24 h after insects were caged on the plants. Avg of 10 replications each consisting of 10 insects caged on a plant. Mortality values adjusted using Abbott's formula. [b]Values for 20 DT are from eight replications, values from 30 and 40 DT are from six replications. Other plants were killed due to the phytotoxic effect of the root-soak treatment.

Table 21. Effect of placing insecticides (2 kg/ha a.i.) in the furrows at about 2 to 3 cm below the seed on insect control in upland rice (variety IR442-2-58) 35 to 66 days after seeding (DS). IRRI, 1973 wet season.

Chemical	Green leafhoppers (no./10 sweeps)			Brown planthoppers (no./meter-row)					Hopper-burned area (%)
				Nymphs				Adults	
	36 DS	50 DS	57 DS[a]	35 DS	50 DS	58 DS[b]	62 DS[b]	62 DS[b]	66 DS[b]
Carbofuran	0*	0**	0**	2	48*	147**	203**	3**	1**
Aprocarb	1	3**	0**	5	86	700	785	27	65
AC 64,475	2	2**	0**	4	54	520	695	36	41*
Triazophos	2	5**	2**	6	66	686	885	44	51
Lindane + MTMC	3	9	0**	5	52	139**	481	15	4**
BPMC	5	12	1**	6	52	462	644	38	36**
JF 4089	5	10	3**	8	60	780	721	18	87
Formetanate	6	14	2**	9	32**	562	1112	32	72
Chlordimeform	2	8	3**	6	43*	301	507	10	26**
Terracur	1	2**	0**	8	64	826	1005	18	84
Acephate	9	16	2**	9	52	430	386	7*	20**
Untreated control	4	12	9	6	103	532	1484	36	93

[a]A side dressing of each insecticide at 2 kg/ha a.i. was made at 55 DS.

insecticides in capsules into the root zone of transplanted IR22 plants at three locations in the Philippines. Six chemicals applied as capsules were compared with the routine application of carbofuran granules or no chemical treatment at all.

At the Visayas station, phytotoxicity symptoms were noticed in plots treated with Cytrolane or, occasionally, cartap. Carbofuran and Cytrolane capsules controlled the whorl maggot very well at the Maligaya station where infestation was high (Table 22), and also at Bicol under a moderate infestation. Unfortunately for this experiment, other pests were minor, and we recorded very few large differences in the number of insects and the damage level. A little tungro virus occurred at Bicol, and all treatments reduced the incidence.

At Maligaya all insecticide treatments raised the yield over the untreated control and, except for diazinon, all capsule treatments yielded better than carbofuran applied to the paddy water five times (Table 22). It is remarkable that one-capsule application was better than five paddy-water applications. Except for BPMC and chlordimeform at Bicol, and Cytrolane and diazinon at Visayas, capsules increased the yield over the control. At both the Bicol and Visayas stations, the best yields from capsule treatments were not significantly different from those obtained by paddy-water application with carbofuran. Insect problems were minor at Visayas, for increases in yield by the best treatments were small.

Only carbofuran and cartap capsules gave a consistently good performance at all locations, and were as good as, or better than, five paddy-water applications of carbofuran.

BIOLOGICAL CONTROL OF INSECTS

Pathogens. In the field leafhoppers and planthoppers are periodically killed by a fungus infection caused by either *Entomophthora coronata* (Costantin) Kevorkian or *Hirsutella* sp. The infection usually occurs near the end of a

Table 22. Effect of placing insecticide capsules into the root zone of IR22 plants at transplanting. Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, 1973 wet season.

Chemical[a]	Whorl maggot leaf damage[b]	Grain yield (t/ha) Maligaya station	Bicol station[c]	Visayas station
Cartap	9 b	4.0 a	3.6 ab	5.3 ab
Carbofuran	0 d	3.8 ab	3.9 a	5.4 a
Cytrolane	1 d	3.8 ab	3.0 bc	5.1 abc
BPMC	5 c	3.8 ab	2.8 cd	5.5 a
Chlordimeform	10 b	3.7 b	2.7 cd	5.5 a
Diazinon	5 c	3.6 bc	3.1 bc	4.9 bc
Treated control[d]	21 a	3.3 c	3.7 ab	5.5 a
Untreated control	24 a	2.8 d	2.2 d	4.6 c

[a]Capsules applied at 3 DT at 2 kg/ha a.i. Seedlings for the whole experiment were protected in the seedbed with carbofuran granules. [b]At the Maligaya station leaves graded as 0, 10, 20, or 30 at 31 DT, with larger number indicating greater damage. [c]Two typhoons occurred while the crop was maturing, and many plots lodged. [d]Carbofuran granules applied to paddy water at 2 kg/ha a.i. at 3, 23, 43, 63, and 83 DT.

Table 23. Mortality of *Nilaparvata lugens* and *Nephotettix virescens* 2 days after each species was caged separately with 20 adult predators *(Cyrtorhinus lividipennis)*.

Prey	Prey mortality (%)	
	N. lugens	*N. virescens*
20 1st-instar nymphs	78	100
20 3rd-instar nymphs	53	72
20 adults	35	35
10 1st-instar nymphs + 10 adults	—	100 + 66
10 3rd-instar nymphs + 10 adults	—	91 + 45

cropping season, but affects only a few insects. We have attempted to augment the mortality of *N. lugens* caused by one fungus, *E. coronata*, by artificially introducing its spores in a spray of water. In this cooperative study with the University of the Philippines at Los Baños, we manipulated various environmental factors to increase the pathogenicity of the fungus. In one greenhouse trial we were able to infect up to 73 percent of the insects. In most greenhouse experiments and in a field trial, however, we could not adequately control the pest population even though the pathogen caused some mortality.

Predation and parasitism. *Cyrtorhinus lividipennis* is an effective predator of *Nephotettix virescens* and *Nilaparvata lugens* (1972 Annual Report). To determine the feeding rate of the adult predators on *N. lugens*, we caged 20 predators and 20 planthoppers for 1 day, and then for each of the next 5 days, added 20 more planthoppers until we had added 120 planthoppers to the constant number of 20 predators. The number of young planthoppers killed per day per predator ranged from 0.6 to 0.9 for the first 5 days, and was 0.4 on the sixth day.

Table 24. Mortality of nymphs of *Nilaparvata lugens* and *Nephotettix virescens*, caged separately or together in various proportions, caused by 20 adult predators *(Cyrtorhinus lividipennis)*.

Initial prey number at caging		Prey mortality (%) 1 day after caging	
N. lugens	*N. virescens*	*N. lugens*	*N. virescens*
20	0	67	—
15	5	49	100
10	10	44	100
5	15	36	100
0	20	—	100

Therefore a predator is capable of killing 0.6 or more planthoppers per day for at least 5 days. On days when no new planthoppers were added and only the few from the day before were left, the feeding rate dropped off markedly to 0.1 or less. Perhaps the searching capacity of the predator is not adequate to maintain a high percentage kill when the *N. lugens* density is comparatively low.

In a similar experiment with *N. virescens*, about 50 leafhopper nymphs were killed per predator per day for at least 4 days. Such a feeding rate, if maintained in the field, would be most beneficial in controlling the pests.

We observed that *C. lividipennis* killed more nymphs than adults, especially young nymphs, of both *N. lugens* and *N. virescens* (Table 23). In field control, the most damaging portion of each generation probably is when young nymphs are abundant.

When prey species were caged separately, *C. lividipennis* killed more *N. virescens* than *N. lugens* per unit time (1972 Annual Report). When caged together, the predator appeared to prefer *N. virescens* (Table 24). This may partly explain why *N. virescens* is sometimes much more scarce than *N. lugens* in the field.

All our previous studies on *C. lividipennis* dealt with adult predators. To confirm our expectation that *C. lividipennis* nymphs were also predatory on *N. lugens*, we caged adult *N. lugens* with either adult or nymphal predators. We could not detect any difference in predatory behavior between the nymphs and adults of *C. lividipennis*.

Because of the difficulty of importing and establishing exotic parasites of stem borers, we are instead studying natural field parasitism of borers with a view toward augmenting, or at least conserving, it.

Parasitism has been relatively low in borer larvae and pupae in the past 18 months, varying from 0 to 18 percent. The peaks in parasitism occurred in May-June and in January-February, the second peak being higher than the first. The most common parasites were *Apanteles schoenobii* Wilkinson, *Xanthopimpla stemmator* (Thunberg), and *Tetrastichus* sp.

In borer eggs and egg masses, parasitism

Table 25. Grain yield of IR20 and IR22 as affected by simple integrated pest control practices in farmers' fields (locations grouped by homogeneous response to treatments). Luzon, Philippines, 1972 wet season.

Treatment				Yield[d] (t/ha)				
				IR20		IR22		
Seedbed treated[a]	Root coat[b]	Roguing[c]	Paddy water application	San Rafael Urdaneta Rosario Bacnotan	Santa Cruz Santa Barbara	Urdaneta[e] Santa Barbara[e]	Santa Cruz Bacnotan	San Rafael Rosario
√	√	√	√[f]	3.7	3.1*	1.5	4.0*	4.4*
√	√	√	√[g]	3.8	3.0*	1.4	3.8*	3.6
√	√	√	—	3.5	2.4	1.4	3.0	3.4
Untreated control				3.3	2.2	1.4	2.5	3.1

[a]Carbofuran granules applied to seedbed 3 and 13 DS at 2 kg/ha a.i. of seedbed area. [b]Seedling roots coated with solution of carbofuran (1000 ppm) and methyl cellulose (2%). [c]Hills showing virus symptoms were rogued and replaced with healthy seedlings at 10 and 20 DT. [d]Mean of locations. [e]Yields low due to tungro virus and drought. [f]Carbofuran granules applied at 1 kg/ha a.i. at 40 and 65 DT. [g]Lindane granules applied at 1 kg/ha a.i. 65 DT.

ranged from 0 to 80 percent. Again there were two peaks in parasitism, one in about May and the other near the end of the year. The most common egg parasites were *Tetrastichus schoenobii* Ferriere and *Telenomus rowani* (Gahan).

INTEGRATED CONTROL

Insecticides and varietal resistance. Previously we described an experiment on the control of insects and tungro virus combining simple insecticide treatments, roguing, and the varieties IR20 and IR22 (1972 Annual Report). The best combination was IR20 and the use of either early protection alone or early protection plus two granular applications of carbofuran, depending on the location. In the same season of 1972, in cooperation with the IRRI's office of rice production training and research, we ran virtually the same experiment on six farmers' fields in various provinces of Luzon, Philippines.

On farmers' fields, the performance of IR22 was variable. Where the tungro virus infection was serious, no treatment increased the yield significantly although a slight reduction in infection was achieved with insecticide (Table 25). In other cases early protection, plus one or two granular applications to the paddy water, was needed to raise the yield. The best way to grow IR20 was with either no protection at all, or early protection plus one granular application of lindane. Probably stem borers required control where granular treatments were advantageous. Summarizing the experiment at all locations, no variety-treatment combination consistently gave the highest yield. This points out the need for regional trials over time to determine the best combination.

In the dry season, we tested several treatments (Table 26) on IR22 and on IR20, a variety with some insect and virus disease resistance. The treatments included prophylactic applications

Table 26. Value of different integrated pest control treatments on IR20 and IR22. IRRI, 1973 dry season.

Type[a]	Insecticide applications (no.)		Cost[b] (P/ha)		Grain yield (t/ha)		Net return[c] (P/ha)	
	IR20	IR22	IR20	IR22	IR20	IR22	IR20	IR22
Proph.	7	7	1124	1124	6.5 a	5.3 a	2570 ab	1890 bcd
Proph.	5	5	266	312	4.3 c	3.6 c	2150 b	1700 d
Proph.	2	3	130	185	5.1 b	3.6 c	2780 a	1840 cd
Proph. + thresh.	4	5	279	333	5.7 b	4.5 b	2980 a	2230 abc
Thresh.	2	2	152	151	5.5 b	4.5 b	2970 a	2400 a
Control	0	0	0	0	5.1 b	4.0 bc	2920 a	2290 ab

[a]Proph. = prophylactic application of insecticide; thresh. application of insecticide when the estimated economic threshold for a given insect is reached. [b]Of insecticide and application. [c]Value of rough rice minus treatment cost. Rice price: P568/t.

of various costs, applications on the basis of estimated economic thresholds, or both. The thresholds were estimated somewhat arbitrarily: tungro virus, 0.5 to 1 (IR22) or 2 to 5 (IR20) adult green leafhoppers per hill plus a nearby virus source; whorl maggot, 10 percent hills have youngest opened leaf of any tiller severely damaged; stem borers, 10 percent dead heart tillers or one borer per 100 tillers soon after panicle initiation; leafhoppers, 20 insects per hill; planthoppers, two young nymphs per tiller; rice bug, two insects per 10 hills; others, one damaging insect per hill. When a threshold was reached, insecticide was applied immediately to reduce the population and subsequent damage level.

The pest problem was minor except for brown planthoppers. As a result the differences among treatments in pest numbers and damage were few. However the high-cost treatment always gave the best control, and led to a significant yield increase over the untreated control. Nevertheless this treatment was too expensive for the benefits obtained, and no treatment gave a cash return significantly greater than the control. This experiment demonstrates that IR20, and even IR22, can sometimes be grown profitably without any insecticide. Nevertheless, the high yield of the high-cost treatment indicates that sub-threshold levels of several insects cause significant damage which at the moment can only be controlled by an expensive prophylactic treatment. Using lower thresholds may be one solution.

Essentially the same experiment was conducted at the same time at three other locations in the Philippines. Pest problems at these stations were greater than at IRRI, and the yields of several treatments including, usually, the highest cost treatment, were higher than the yields of the untreated control (Tables 27 and 28). Occasionally, the low-cost treatments gave a yield increase. The differences among locations were no doubt related to different pest conditions

Table 27. Grain yield from integrated pest control treatments on IR20 and IR22. Maligaya Rice Research and Training Center (M), Bicol Rice and Corn Experiment Station (B), and Visayas Rice Experiment Station (V), 1973 dry season.

Treatment			Yield (t/ha)					
Type	Insecticide applications[a] (no.)		IR20			IR22		
	IR20	IR22	M	B	V	M	B	V
Proph.	7	7	4.9 a	5.8 a	4.7 ab	3.7 ab	5.7 a	5.0 a
Proph.	5	5	4.1 b	5.2 ab	4.1 bc	4.0 a	4.8 b	4.7 ab
Proph.	1	2	4.4 ab	4.7 bc	5.2 a	4.1 a	4.9 b	4.3 bc
Proph. + thresh.	2	3	4.0 b	4.6 bc	4.9 a	3.8 ab	3.8 c	4.6 ab
Thresh.	2	2	3.9 b	4.8 bc	4.7 ab	3.8 ab	4.0 c	3.9 c
Control	0	0	4.2 b	4.0 c	3.9 c	3.3 b	3.5 c	3.9 c

[a]Avg of three locations.

Table 28. Net return from integrated pest control treatments on IR20 and IR22. Maligaya Rice Research and Training Center (M), Bicol Rice and Corn Experiment Station (B), and Visayas Rice Experiment Station (V), 1973 dry season.

Treatment			Net return[b] (P/ha)					
Type	Cost[a] (P/ha)		IR20			IR22		
	IR20	IR22	M	B	V	M	B	V
Proph.	1010	1010	1760 c	2300 ab	1640 c	1110 c	2220 ab	1860 c
Proph.	199	250	2150 ab	2740 a	2140 b	2030 ab	2500 a	2400 ab
Proph.	46	96	2460 a	2630 ab	2900 a	2210 a	2670 a	2320 ab
Proph. + thresh.	105	140	2200 ab	2520 ab	2610 a	2050 ab	1980 b	2450 ab
Thresh.	77	68	2190 b	2640 ab	2570 a	2090 ab	2210 ab	2140 bc
Control	0	0	2380 ab	2290 b	2210 b	1900 b	2000 b	2190 ab

[a] Cost of insecticide and application; avg of three locations. [b]Value of rough rice minus treatment cost. Rice price: P 568/t.

Table 29. Grain yield of different integrated pest control treatments on IR20 and IR22. Maligaya Rice Research and Training Center (M), Bicol Rice and Corn Experiment Station (B), and Visayas Rice Experiment Station (V), 1973 wet season.

Treatment: Type	Insecticide applications[a] (no.): Granule IR20	Granule IR22	Spray IR20	Spray IR22	Yield (t/ha) IR20 M	IR20 B[b]	IR20 V	IR22 M	IR22 B	IR22 V
Proph.[c]	5	5	3	3	3.6 a	2.7 a	4.6 a	3.2 a	3.6 a	5.1 a
Proph. + thresh.										
1[d]	4	4	1	1	3.0 b	2.7 a	3.7 b	2.8 ab	2.7 b	3.1 b
2[e]	2	2	0	1	2.7 b	2.4 a	3.1 c	2.7 bc	2.7 b	3.5 b
3[f]	2	2	1	1	2.7 b	2.5 a	3.4 bc	2.9 ab	3.0 b	3.8 b
4[g]	1	1	0	1	2.6 b	2.8 a	3.5 bc	2.6 bc	2.8 b	3.4 b
Control	0	0	0	0	2.6 b	2.7 a	3.6 bc	2.4 c	2.7 b	3.6 b

[a]Avg of three locations. [b]Typhoons caused lodging of some plots before maturity. [c]Carbofuran granules applied at 2 kg/ha a.i. to field at 3, 23, 43, 63, and 83 DT and to seedbed twice; monocrotophos applied three times. [d]Diazinon granules at 1 kg/ha a.i. at 3, 25, 45 DT, lindane granules at 1.5 kg/ha a.i. at 70 DT; methyl parathion for rice bugs and caseworms, or MIPC for brown planthoppers, or both. [e]Lindane granules at 1 kg/ha a.i. at 50 DT, possibly at 30 DT, and at 1.5 kg/ha a.i. at 75 DT; methyl parathion or MIPC or both. [f]Lindane granules at 1 kg/ha a.i. at 5 DT, and possibly at 50 DT (1.5 kg/ha a.i.); methyl parathion or MIPC or both. [g]Lindane granules at 75 DT and possibly at 30 DT; methyl parathion.

Table 30. Net return from integrated pest control treatments on IR20 and IR22. Maligaya Rice Research and Training Center (M), Bicol Rice and Corn Experiment Station (B), and Visayas Rice Experiment Station (V), 1973 wet season.

Treatment: Type	Insecticide cost[a] (P/ha) IR20	IR22	Net return[b] (P/ha) IR20 M	IR20 B	IR20 V	IR22 M	IR22 B	IR22 V
Proph.	1860	1860	1080 b	340 b	1860 b	720 b	1070 b	2210 b
Proph. + thresh.								
1	267	277	2140 a	1910 a	2720 a	2000 a	1910 a	2220 b
2	99	115	2100 a	1820 a	2410 a	2070 a	2060 a	2660 ab
3	83	87	2150 a	1950 a	2670 a	2230 a	2360 a	2950 a
4	66	70	2020 a	2160 a	2870 a	2030 a	2150 a	2660 ab
Control	0	0	2070 a	2130 a	2870 a	1910 a	2160 a	2880 a

[a]Avg of three locations. [b]Value of rough rice minus insecticide cost. Rice price: P805/t.

prevailing at the stations. At the Visayas station, the threshold treatment on IR20 gave a yield increase partly because it controlled stem borers and rice bugs. In general, the threshold treatment needs improvement to achieve effective pest control.

The variable yield results depending on variety and location make it difficult to select the best overall pest control practice. Based on cash returns (Table 28), at Maligaya it was most economical to grow IR20 without insecticide or IR22 with a low-cost, prophylactic treatment. In the other two locations where pests were more troublesome, these varieties usually benefited from medium-cost or low-cost treatments. Therefore a low-cost treatment to IR20 was, in general, a reliable scheme for integrated pest control at Bicol and Visayas. At Maligaya and IRRI the best choice was IR20 without any insecticide.

In the wet season we tested a series of pest control practices integrating variety, prophylactic insecticide applications, and remedial applications when estimated economic thresholds are reached (Tables 29 and 30). The insecticide treatments represent extremes from no insecticide to very frequent and expensive applications. In between, the treatments represent a gradation of prophylactic and remedial applications, and include the insect control recommendations for the 1973 wet season "Masagana 99" program in the Philippines, a program encouraging farmers to practice improved rice technology. The estimated thresholds use: tungro virus (IR22 only), two adult green leafhoppers per square meter plus a nearby tungro source; stem borers, 10 dead hearts per square meter at 30 days after transplanting, or 10 percent dead hearts at 50 days or two larvae per 100 tillers soon after panicle initiation; planthoppers, 25 insects per hill; rice bug, two insects per square meter; others, one damaging insect per hill.

Insect and virus disease problems were minor, except white heads on IR20 at Maligaya where control was achieved by the treatments with four or five granular applications. At Visayas brown planthoppers were numerous after heading.

The yield gain due to insecticide was largely confined to the entirely prophylactic treatment (Table 29). Only at Maligaya did other treatments show a yield gain on IR22. We could not determine exactly why the prophylactic treatment increased yield significantly. Probably the accumulated benefit from protection against several minor pests did add up in the end. But based on monetary returns (Table 30), no treatment at any location was significantly advantageous. These results imply that, at these locations, insect control for IR20 or IR22 was not advisable. Under the conditions of prices and control technology available at the time, it was not economically advantageous to aim for the highest yield possible

A similar experiment, but with the addition of the variety C4-63(G), was conducted on a farmer's field near IRRI. Due to a severe infestation of brown planthoppers, we could not assess the effect of the treatments on the control of other insect pests. Other pests were generally not important, however. Over a long period, planthoppers flew into the field in very large numbers from neighboring areas where rice was being hopperburned. Despite heavy use of either prophylactic or remedial insecticide treatments based on estimated economic thresholds, or both, we were unable to keep the pest population down to acceptable levels. As early as 35 days after transplanting the level reached 700 or more insects (mostly nymphs) per hill in many plots, and the control plots suffered hopperburn shortly thereafter.

As a result of the planthopper damage and a typhoon that struck just before harvest, the yields were low in all treatments (Table 31). No insecticide treatment adequately controlled the planthoppers; even the granular insecticides did not add much to the control of the brown planthopper under these circumstances. The treatment costing P812/ha gave relatively good yields, and as a result, gave about the same gross return minus insecticide cost as the other treatments, or better. When growing brown planthopper-susceptible varieties during an epidemic of this pest, planting IR20 and spraying whenever needed may be the most economical way to save the crop. But considering the low gross return minus insecticide cost we obtained, abandoning the crop early and growing a variety resistant to the brown planthopper instead would be better than trying to protect a susceptible variety.

In cooperation with the Philippine Bureau of Plant Industry we evaluated, on farmers' fields, the pest control recommendations of "Masagana 99" for C4-63(G) and C4-137 in Laguna province. Our data so far show that many farmers had difficulty in controlling the brown planthopper, and consequently obtained low yields. The recommended package of practices could not actually be carefully assessed because of the overwhelming problem with planthoppers. Even if farmers sprayed their crop weekly when there were 25 or more planthoppers per hill (the currently recommended threshold), good control was not achieved under the epidemic conditions. But usually some yield gain was achieved over an untreated area as a result of the pest control activities.

Insecticides and predation. The placing of insecticides in the root zone of plants could be a way of killing some of the pests without interfering with the effect of natural predation. We monitored the predator populations during the growth of a crop of Taichung Native 1, to whose root zone capsules of carbofuran, cartap, chlordimeform, or diazinon had been applied. Spiders and *Cyrtorhinus lividipennis* apparently were not affected directly by the treatments since the number of predators corresponded

Table 31. Grain yield and net return from different integrated pest control treatments on C4-63(G), IR20, and IR22. Farmer's field in Laguna, Philippines, 1973 wet season.

Treatment: Insecticide applications[a] (no.) For brown planthoppers: Foliar	Granular	Granular, for other insects	Insecticide cost[a] (P/ha)	Yield (t/ha) C4-63(G)	Yield IR20	Yield IR22	Net return[b] (P/ha) C4-63(G)	Net return IR20	Net return IR22
9	5	0	2040	2.2 a	2.8 a	2.1 a	−280 c	220 bc	−360 c
14	2	4	1031	1.6 b	2.0 ab	1.9 a	330 ab	660 b	310 ab
14	1	2	905	1.6 b	1.6 b	1.6 a	320 ab	380 bc	450 a
12	1	1	812	1.7 ab	2.7 a	2.0 a	540 a	1360 a	810 a
Control[c]			0	0 c	0 c	0 b	0 bc	0 c	0 bc

[a]Avg of three varieties. [b]Value of rough rice minus insecticide cost. Rice price: P805/t. [c]Completely hopperburned about 45 DT.

roughly to the number of brown planthoppers surviving the pesticide treatments. This application technique should therefore be compatible with maintaining natural predation in the field.

Economic injury by whorl maggot. We conducted several experiments to determine the economic-injury levels of major pests, that is, the lowest pest population density or damage level that would cause economic yield loss. Economic yield loss is the amount of loss which will justify the cost of artificial control measures. If we can predict population growth or damage occurrence, then we can determine the economic threshold, the density or damage level at which to initiate control measures to prevent yield loss.

We attempted to measure yield loss due to the rice whorl maggot. Undamaged hills, and hills with several grades of visible leaf damage, were removed from field plots 35 days after transplanting. The plants were put into pots in the greenhouse, grouped into four damage categories (Table 32), and grown to maturity with insect protection. There were 20 replications of each of the four categories.

The damage resulted in stunting of the plants during the vegetative phase, reduction in tiller number, and lower grain yield (Table 32). Even light damage caused large yield loss. Although the ideal growing conditions in the greenhouse may have accentuated the effect of damage, these data illustrate that this insect could be an important pest. In this experiment the economic-injury level would be an average leaf damage grade of something less than two. It may not be possible to use such a damage grade as an economic threshold for the whorl maggot. The damage occurs rather suddenly and does not persist for long. We will probably have to use prophylactic treatments in localities where the insect does cause yield loss.

Since the potential yield loss from the whorl maggot could be great according to this greenhouse test, in the dry season we conducted two experiments to measure yield loss caused by damage during early growth. This is the period when the whorl maggot is the main pest, and

Table 32. Effect of rice whorl maggot damage on plant growth and grain yield of IR20. Plants were grown and infested in the field until 35 days after transplanting (DT), then grown in the greenhouse under insect protection until maturity. IRRI, 1973 dry season.

Damage category	Leaf damage grade[a] 37 DT	Plant ht (cm) 39 DT	Tillers (no./hill) 37 DT	Tillers (no./hill) 57 DT	Yield (g/hill)	Yield loss (%)
None	0 d	64	22	40 a	62 a	—
Light	2 c	58	22	37 b	51 b	18
Moderate	5 b	51	22	34 c	43 c	31
Severe	12 a	46	22	31 d	41 c	34

[a]Leaves graded as 0, 10, 20, or 30. Larger number indicates greater damage. All leaves were included in grading procedure.

during which the insect damages the plants. We compared, for IR20 and IR22, the effect of no protection with that of granules (carbofuran, lindane, or diazinon) applied right after transplanting, or a seed and seedling root soak with carbofuran. Half of each plot was regularly protected with carbofuran granules after 20 days. We obtained indications that several treatments were reducing the pest problem. Only diazinon appeared to improve the yield of IR22 if plants were protected beyond 20 days, but this increase was not significant.

In the same season we measured yield loss in IR20 caused by lack of insect protection during the first 20, first 40, and second 20 days after transplanting. Half the plots were protected regularly after 40 days, the rest not at all. We assumed that, since we used lindane during the first 40 days, the benefit from protection would be due only to the absence of whorl maggot damage. The other important pest that lindane controls during this period at IRRI is the stem borers, which caused low crop damage.

We substantially reduced, but did not eliminate, visible maggot damage for about 20 days after an application of lindane (Table 33). Two applications were needed to cover the first 40 days after transplanting. Only a little recent damage was visible at 40 days. As expected, a higher yield was obtained by applying insecticide beyond 41 days, probably because we thereby controlled stem borers and brown planthoppers. Virus infection was very low. The reduction in whorl maggot damage increased yield by about

Table 33. Effect of rice whorl maggot damage on IR20. IRRI, 1973 dry season.

	Treatment			Whorl maggot visual damage[a]					
	Lindane 2 kg/ha a.i.		Carbofuran 2 kg/ha a.i.	Youngest leaf/tiller			All leaves	Grain yield	Yield difference
	1 DT	21 DT	41, 61, 81 DT	13 DT	20 DT	40 DT	30 DT	(t/ha)	(%)
1	√	√	√	3	4	2	1	4.4 ab	—
2	√	—	√	3	4	2	4	4.8 a	−10[c]
3		√	√	8	8	2	2	3.4[b] bcd	+22[c]
4	—	—	√	9	8	2	4	4.0 abc	+ 8[c]
5	√	√	—	3	4	1	1	3.1 cd	—
6	√	—	—	3	4	3	4	3.4 bcd	−10[d]
7		√	—	7	6	2	2	3.0 cd	+ 1[d]
8	—	—	—	8	7	3	5	2.7 d	+11[d]

[a]On a scale of 0 to 30. Larger number indicates greater damage. [b]Low yield due to rat infestation. [c]Compared with treatment 1. [d]Compared with treatment 5.

Table 34. Grain yield response of IR22 in the greenhouse to direct damage by various densities of green leafhopper *(Nephotettix virescens)* nymphs caged for 2 weeks on plants of different ages. IRRI, 1973.

Insects caged[a] (no./tiller)	Yield (g/hill)						
	28-41 DS[b]	42-55 DS	56-69 DS	70-83 DS	84-97 DS	98-111 DS	112-125 DS
0.0 (control)	8	28	16	12	15	11	12
0.1	10	16*	12	16	16	10	14
0.2	8	23	17	15	8*	12	12
0.5	8	24	13	15	10*	9	12
1	10	20*	16	12	10	8	14
2	8	19*	12	8	9*	8	14
5	10	21*	13	7	10	8	15
10	9	23	10	8	10	8	14
25	4	13*	8	10	7*	8	12
50	3	4*	5*	8	4*	9	14
100	0*	1*	1*	6	3*	8	8

[a]Where number is less than one, one insect per tiller was caged for a fraction of 2 weeks, e.g. one insect per tiller for 1.4 days (0.1 × 14). [b]Age of plant (days after seeding) during infestation. Each plant was infested for not more than 2 weeks throughout its entire growth.

Table 35. Grain yield response of IR22 in the greenhouse to direct damage by various densities of brown planthopper nymphs caged for 2 weeks on plants of different ages. IRRI, 1972-73.

Insects caged[a] (no./tiller)	Yield (g/hill)							
	26-39 DS[b]	40-53 DS	54-67 DS	68-81 DS	82-95 DS	96-109 DS	110-123 DS	124-137 DS
0.0 (Control)	34	21	20	15	14	16	14	14
0.1	21*	22	20	18	17	13	11	12
0.2	29	20	17	12	12	8*	9	14
0.5	20*	24	17	15	12	16	13	14
1	21*	15	16	11	14	16	11	14
2	21*	21	15	14	13	16	13	15
5	5*	20	16	13	10	13	14	14
10	0*	21	21	12	10*	13	13	12
25	0*	6*	20	11	10*	13	9	16
50	0*	0*	15	11	5*	10	11	16

[a]Where number is less than one, one insect per tiller was caged for a fraction of 2 weeks, e.g. one insect per tiller for 2.8 days (0.2 × 14). [b]Age of plant (days after seeding) during infestation. Each plant was infested for not more than 2 weeks throughout its entire growth.

400 kg/ha, but this increase was not statistically significant. Again we were not able to detect a reliable yield increase due to early protection or protection from the whorl maggot specifically. Therefore, recognizing that we did not actually eliminate damage, it appears that field trials cannot demonstrate convincingly that the rice whorl maggot can by itself cause a yield loss comparable to that found in the greenhouse study.

Economic injury by leafhoppers and planthoppers. Previously we measured the damage from leafhopper and planthopper populations that were fluctuating over time (1972 Annual Report). To more clearly define the relationship between the number of insects and damage to the susceptible variety IR22, we held the number of nymphs per tiller constant throughout a 2-week period. We subjected plants to infestation for 2 weeks only, some plants at one age, some at another. The difference in effect among plants of different ages reflects the capacity of a tiller to tolerate insect feeding.

The plants were most sensitive to damage by the green leafhopper, *Nephotettix virescens*, during the active tillering and at late booting stages (Table 34). Loss in yield was correlated with fewer tillers and panicles. Very little irreparable damage was done by 2-week densities of 10 nymphs or less per tiller. The economic-injury level tends to be between 10 and 100 nymphs per tiller for 2 weeks. Such a population rarely occurs in the field. Unless cumulative damage is critical, controlling this insect to prevent direct damage is of minor importance in the Philippines.

The brown planthopper nymphs (Table 35) caused the greatest damage to plants at 26 to 39 days after seeding. They also caused some damage during active tillering and at the booting-to-flowering period. Early damage reduced the number of tillers and the eventual panicle number. For most of the growing period, the plants could tolerate 5 or 10 nymphs per tiller for 2 weeks. This economic-injury level represents approximately 100 to 200 nymphs per hill for a 2-week period. It is clearly related to crop age, and the plants beyond 40 days after seeding can tolerate large densities for a short time.

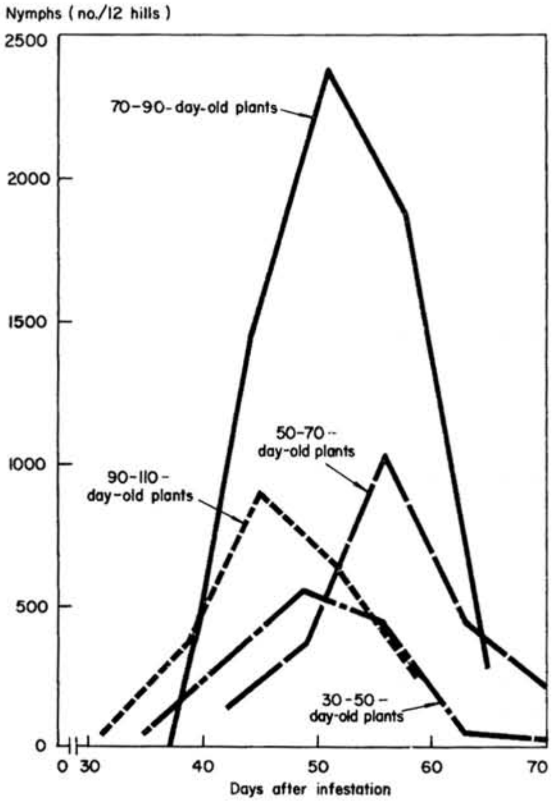
Such population densities of the brown planthopper do occur in the Philippines. But the density is not constant over time; small and large numbers are found for much more than 2 weeks per crop. Therefore we must investigate cumulative damage caused by varying densities over time. Because of the many possible combinations of plant age, duration of infestation, and pest density, we tried simply to determine the economic-injury level by setting various arbitrary pest population maxima in the field. We maintained these density limits by spraying an insecticide when the predetermined maximum was reached. Unfortunately the yield data obtained are not very useful because all yields were low, probably due to climatic conditions (Table 36). Nevertheless there was a

Table 36. Determination of an economic-injury level for the brown planthopper on IR1917-3-17 in the field. IRRI, 1973 wet season.

Max insects that occurred[a]		Approx. insect-days per 90-day period	Insecticide applications	Grain yield
No./tiller	No./hill[b]	(no.)	(no.)	(t/ha)
2 (control)	45	60	15	1.9
5	115	115	2	1.8
13	300	210	1	1.9
30	690	310	1	1.8
22	505	370	0	0.9*[c]

[a]Population density was monitored twice a week and, if desired, suppressed by spraying MIPC. [b]Approximately based on 23 tillers per hill, the avg between 60 and 110 days after seeding. [c]Hopperburned after flowering.

significant yield loss when, in addition to an earlier infestation, the population at 106 days after seeding reached 22 insects per tiller and remained above 13 insects per tiller for 10 days. Even if a higher maximum was reached, if control measures reduced the population immediately, no loss in yield was evident. It appears that a simple field economic-injury level could be a certain number of young nymphs per hill at a certain crop age. Thus, under usual circumstances, the critical time for surveillance would be when nymphs are hatching. This will probably occur only three times per crop period.



3. Density of the second generation of *Nilaparvata lugens* on IR22 plants of different age ranges in an insectary experiment.

ECOLOGY OF RICE INSECTS

Fluctuations in density. Light trap collections at IRRI showed that the green leafhoppers this year were, in general, as abundant as last year, but the highest peak occurred in March rather than July. The brown planthopper, which in recent years has been increasing in number with each passing year, reached even higher levels in 1973. We caught about six times as many insects this year as last. The catches were large from February to October, with peaks in March-April and August-September. The pest was very difficult to control in localities surrounding IRRI, and it caused severe crop losses. We believe the large catches in light traps occur when insects abandon plants that are dying or maturing and search for new hosts. In 1973 we started using sticky boards placed upright around rice fields to monitor flying planthoppers. Most are caught in the early evening hours.

Population dynamics of ***N. virescens*****.** In the insectary we observed the effects on population growth of various mixtures of resistant and susceptible varieties. IR8 (resistant) and IR22 (susceptible) were grown together in cages in ratios of 10:0, 9:1, 5:5, 1:9, and 0:10. By changing plants periodically, we maintained plant age at about 80 days. Starting from an initial density of five pairs of adults in each cage, the eventual population size after four, five, and six generations was roughly in proportion to the number of susceptible plants present in the cage: the more susceptible plants there were, the more insects. Where only IR8 was present, the insects all died. We could detect no tendency in insects to multiply more on resistant plants if susceptible ones were present than if susceptible plants were absent. These data suggest that even if an area is only partially planted to resistant plants, these plants would reduce the total insect population in the area.

Population dynamics of ***N. lugens*****.** To determine if plant age affects the growth of a population of the brown planthopper, we caged five pairs of adults on IR22 plants of various ages. We changed the plants at least every 20 days, and if they showed signs of insect damage, we changed them immediately to prevent the quantity of food from becoming limiting. By the second generation there were distinct differences in insect population size among the age groups. Judged by the population size, the most suitable plant age for growth of the insect population was 70 to 90 days after seeding (fig. 3). The third generation showed a similar relationship. The population on 10- to 30-day-old plants never exceeded 200 throughout the experiment. When brown planthoppers were reared on plants increasing in age from 10 to 110 days old, the third generation was only one-half the size of that of insects reared on plants in the reproductive stage. It appears that this pest is often abundant on crops in later stages of plant growth, not only because it takes time for the insect population to increase, but also because the plants, just before or at this time, are in some way suitable for them. In a similar experiment last year with *Nephotettix virescens*, the maximum density reached was only a little higher than that for *N. lugens* this year. Thus the capacity of these species to multiply on IR22 appears to be about the same.

We compared three methods of planting to determine if the differences in plant growth affect the brown planthopper population. We broadcast seeds in some plots, row-seeded in others, and 18 days later, transplanted seedlings in the remaining plots. We monitored the planthopper incidence throughout the crop period. No one planting method was clearly different from the others in its effect on the insects. Apparently the pests were not sensitive to the differences in environment that may have existed among the plots.

We also measured the planthopper population size in plots differing in weed density. We artificially maintained weed differences by hand weeding and by applying herbicides. The major weed species present were *Leptochloa chinensis* (L.) Nees and *Fimbristylis miliacea* (L.) Vahl. Again no obvious differences in pest number could be detected among the plots. But near crop maturity, the weedy plots contained slightly more planthoppers per square meter than the weeded plots, even though weedy plots probably contained fewer tillers of rice than weeded plots. Therefore planthoppers may tend to be a greater pest problem in weedy than in weeded fields, possibly because the dense vegetation of weedy fields provides a suitable environment for them.

Upland rice insects. In cooperation with the multiple cropping department, we observed the insects present in several upland rice fields of the variety Dagge in Batangas province. We found the usual pests of lowland rice, and also termites and mole crickets. The most numerous species was *Sogatella furcifera* (Horvath). Insects were present throughout the crop period, but distinct peaks in density occurred. The largest count of *S. furcifera* was obtained about 70 days after seeding when at one location we found 110 insects per linear meter row. Some predators were regularly found in the rice environment.

Rice production training and research

TRAINING PROGRAMS

Training activities increased in intensity during 1973: In addition to the ninth annual 6-month "train the trainer" rice production course, 604 extension workers were trained in eight 2-week courses to prepare for the launching of the Philippine government's "Masagana 99" rice production program. Two additional 2-week courses held in November and December were attended by 57 persons.

Six-month course. Thirty trainees from 11 countries attended the 6-month rice production course. IRRI has graduated 277 trainees from 25 different countries since the first course in 1964.

As in past years, the 1973 6-month trainees differed greatly in educational background. One held a Ph.D, two held master's degrees, and 11 held B.S.A. degrees. Ten were diploma holders, one was a junior in college, and five were high school graduates. Such variation in educational background, experience, and interest represents a challenge to the trainers. Training was improved through frequent evaluations and special assignments. The overall performance of the class was excellent. Eleven earned certificates with distinction; 19 earned certificates indicating satisfactory completion of the course.

The average score on the practical examination at the start of the course was 34 percent with a range of 1 to 88 percent. On the written test it was 40 percent with a range of 11 to 70 percent. The average on the final practical test was 91 percent and on the written, 78 percent.

The use of small tape recorders and recorded lectures helped overcome the communication problem encountered with the 6-month trainees. Trainees are permitted to check out the tape recorders and tapes to take to their rooms at night. This activity has been extremely helpful in improving the performance of trainees with language problems.

The 6-month trainees established and managed 10 applied research plots, four production plots with selected IRRI varieties and the growth-stages plots. They developed written plans, prepared the required materials and grew their projects, performing all the operations required under the supervision of the course instructors. These "learning by doing" experiences develop the self-confidence, skills, and know-how required by the trainees to enable them to teach the new rice technology to others.

The trainees are required to collect field data on factors being investigated. They harvest yield samples, process, and analyze the data. They perform analysis of variance and tests to determine the significance of differences using their own data. The objective of this training is to enable the trainees to develop the knowledge and skills required to design and manage applied research projects in their own countries to adapt the new rice technology to local conditions.

Short courses. Ten short courses in rice production were conducted during 1973. The first eight 2-week courses were held from January to May. Over 600 Filipino rice extension workers were trained to assist with the implementation of the Philippine government's "Masagana 99" rice production program. The ninth course held in November was organized and conducted by the 6-month rice production trainees. This course was designed to provide the 6-month trainees with experience in planning and conducting a short course in rice production. Fifteen persons attended this course: two private farmers, one physician, three IRRI employees, and nine employees of the National Irrigation Administration. The tenth course was held in December, with 42 in attendance: 24 persons from the irrigation management project of the East-West Center (U.S.A.), five IRRI employees, four U.S. Peace Corps Volunteers, three industry representatives, two Filipino vocational agricultural teachers, and one person each from Japan and Korea, one bank technician, and one person from the German-Philippine rodent control project. The 2-week rice production trainees perform all the operations in producing a rice crop through use of the growth-stages plots where rice is planted every 2 weeks and all stages of the rice plant are present at any one time.

APPLIED RESEARCH TRIALS

While the major portion of our research effort has been centered in four municipalities of Bulacan province and in Gapan municipality of Nueva Ecija province, the IRRI-based staff, in cooperation with various Philippine agencies, conduct a number of applied research trials on farmers' fields. The activities for 1973 were concentrated on the Farmers Evaluation of New Selections Applied Research Trial (FENSART), conducted in cooperation with the Bureau of Plant Industry and University of the Philippines at Los Baños (UPLB) College of Agriculture, and the IRRI New Selections Applied Research Trial (INSART), conducted in cooperation with IRRI plant breeding department.

New selections. The results for the wet-season FENSART are not available for inclusion in the report for the year in which the trials are conducted, so they are reported in the succeeding year. Data for the 1972 dry season appear in the report for the 1972 Annual Report. A total of 39 FENSART kits were distributed to 28 provinces during the 1972 wet season. BPI seed inspectors received 24 kits; Bureau of Agricultural Extension, various government schools, private institutions, and farmers each received five kits. Two IRRI selections, IR1529-680-3 and IR1541-76-3, produced higher mean yields than IR20 and C4-63G, the check varieties (Table 1). IR24 gave the highest mean yield, 4.3 t/ha.

Thirty-eight FENSART kits were distributed to 26 provinces for the 1973 dry season. BPI received 34 kits and various agricultural schools, four kits. Reports were received from only 13 locations in 12 provinces (Table 2). Average yields of all 12 entries were between 4 and 5 t/ha. IR1529-680-3 and IR1541-76-3 gave the highest yields.

We conducted INSART on farmers' fields with and without application of insecticides. During the 1973 dry season, 12 plots were established in six provinces. Due to rat and bird damage and the breakdown of irrigation pump units, complete data were obtained from only eight locations in five provinces (Table 3). IR8 produced the highest yield under protected conditions and IR1514A-E666 under unprotected conditions.

During the 1973 wet season, only six projects were established in four provinces because the

Table 1. Grain yield of 14 varieties or selections at 18 locations in the Philippines. 1972 wet season.

Province	Yield (t/ha)													
	C 168-134	C4-63-G	C4-137	C12	BPI 121-407	Fortuna × MA3-26	IR8	IR20	IR24	IR665-8-3	IR1006-20-5	IR1541-76-3	IR1529-680-3	IR833-6-2
Batangas	5.3	5.1	4.5	4.3	5.2	4.4	5.3	5.1	5.7	4.9	5.9	5.3	5.4	4.0
Bohol	6.4	5.1	4.7	4.6	4.6	4.1	5.3	4.7	3.8	3.5	4.0	4.6	5.4	3.2
Bukidnon[a]	1.8	1.7	1.7	1.3	1.4	1.4	1.2	2.0	1.7	1.5	1.9	2.0	1.9	1.0
Cagayan	3.7	4.9	3.6	3.1	6.1	3.4	2.7	5.4	4.6	2.9	2.7	4.8	3.8	3.9
Camarines Sur	3.1	3.8	3.4	4.0	2.9	3.6	1.8	3.4	3.8	4.2	3.2	4.2	3.5	2.7
Ilocos Norte	4.1	3.9	4.4	4.5	4.3	4.5	3.4	4.4	4.3	3.2	3.5	4.6	3.3	4.6
Ilocos Sur	3.6	3.1	2.9	3.5	1.7	3.6	2.6	3.4	3.5	3.0	2.2	2.0	2.5	2.5
Isabela	2.1	2.3	2.0	2.0	2.1	1.9	2.1	2.2	2.3	2.3	2.4	2.1	2.1	1.9
Kalinga-Apayao	4.9	5.3	5.7	4.5	5.5	5.0	5.8	5.3	5.9	5.7	5.3	3.6	5.5	4.5
Laguna (IRRI)	3.1	3.7	3.8	2.2	5.1	2.1	3.3	4.2	3.9	5.7	3.5	5.3	5.6	4.4
Laguna (Santa Cruz)	4.0	4.5	4.7	4.6	4.6	4.1	5.3	4.7	3.8	3.5	4.0	4.6	5.4	3.2
La Union	6.0	6.0	5.6	6.9	5.4	5.6	5.6	4.4	6.8	6.0	6.0	6.0	5.8	4.4
Leyte del Norte	4.5	5.3	4.5	5.5	5.0	4.8	4.2	5.4	5.1	5.5	4.2	4.2	4.6	4.4
Mindoro Oriental	3.6	5.3	4.3	4.6	4.1	3.7	3.2	4.4	4.7	5.4	3.2	5.4	5.1	5.2
Nueva Ecija	3.1	2.8	3.3	2.7	2.0	2.8	3.0	2.3	4.4	3.4	3.2	2.9	2.5	2.6
Pangasinan	1.4	3.4	3.2	4.0	3.4	3.5	—	3.7	2.9	3.0	1.8	4.1	3.5	1.4
Sorsogon	4.0	4.5	4.7	4.6	4.6	4.1	5.3	4.7	3.8	3.5	4.0	4.6	5.4	3.2
Surigao del Norte	3.2	3.6	3.8	3.1	3.8	3.8	3.7	2.7	3.9	3.2	3.1	3.2	2.6	1.5
Mean	3.8	4.1	3.9	3.9	4.0	3.8	3.8	4.1	4.3	4.0	3.7	4.2	4.2	3.4

[a]Low yields due to soil problem.

Table 2. Grain yield of 12 varieties or selections at 13 locations in the Philippines, 1973 dry season.

Province	Yield (t/ha)											
	C 168-134	C4-63G	BPI 121-407	Fortuna × MA3-2b	PARC 2-3	IR8	IR20	IR665-8-3	IR1006-20-5	IR1541-76-3	IR1529-680-3	IR833-6-2
Agusan del Sur	4.7	3.8	3.6	3.5	3.9	4.2	4.3	4.2	4.3	4.3	4.5	3.1
Batangas	5.9	6.5	5.3	5.9	4.9	5.6	4.9	5.6	5.7	6.0	5.4	5.5
Camarines Sur (BRCES)	6.3	6.0	5.8	6.3	5.9	6.4	4.9	5.4	6.3	4.2	7.4	6.5
Camarines Sur (Pili)	4.6	3.5	3.5	3.1	4.3	3.1	3.4	4.3	4.7	4.7	3.5	3.5
Cotabato North	3.6	3.8	2.7	3.6	2.8	2.3	3.4	3.0	3.7	4.3	3.3	3.2
Ilocos Norte	2.3	3.1	3.5	3.2	2.4	2.4	3.7	3.2	2.8	3.1	3.4	3.0
Iloilo	3.5	3.4	2.6	4.2	2.5	2.0	3.6	1.9	3.5	3.5	4.4	3.4
Kalinga-Apayao	4.9	4.9	4.7	5.0	5.3	5.3	5.5	5.2	5.3	3.8	5.5	5.1
Leyte del Norte	4.7	4.5	4.9	5.0	5.1	5.3	4.7	5.3	5.2	5.1	6.1	3.8
Negros Oriental	4.0	3.6	3.8	3.6	4.1	4.2	4.2	3.2	3.1	4.2	3.5	3.4
Nueva Ecija	5.9	6.4	4.8	5.7	5.5	6.5	5.7	6.4	6.3	6.6	6.9	6.2
Sorsogon	4.4	4.5	4.3	5.0	4.8	4.9	5.2	4.1	4.2	6.2	4.1	5.6
Surigao del Norte	3.1	4.1	3.1	3.8	5.4	2.3	5.1	2.3	3.8	3.8	3.8	3.5
Mean	4.5	4.5	4.0	4.5	4.4	4.2	4.5	4.2	4.5	4.6	4.8	4.3

quantity of seeds available of the new selections was small (Table 4). Yields were low in all locations in Laguna (Santa Rosa, Pila, and IRRI) and in Tiaong, Quezon, because of the heavy infestation of brown planthoppers. At Pila and the IRRI farm, infestations were so severe that IR20, IR1529-680-3, and IR442-2-58 were completely killed in both unprotected and protected plots. IR26 produced the highest yields in both the protected and unprotected plots.

RAINFED AND UPLAND RICE PROJECT

In 1971, the International Rice Research Institute and the National Food and Agriculture Council of the Philippines established a 3- to 5-year comprehensive applied research project in the rainfed and upland areas of Bulacan and Nueva Ecija. The project is aimed at investigating the various factors affecting rice yields under rainfed and upland conditions and at developing an extension program to effect wide-scale adoption of worthwhile findings resulting from such research (1972 and 1973 Annual Reports).

To obtain additional data on rainfed and upland rice and on other crops planted before and after the rice crops, 118 projects were established in 1973 in five municipalities--Santa Maria, San Rafael, San Ildefonso, and San Miguel in Bulacan province, and Gapan in Nueva Ecija.

The workload this year doubled with the addition of the maximum grain yield trial in which rice selections with different lengths of

Table 3. Grain yield of varieties or promising selections grown with protection and without at eight locations in Luzon, Philippines, 1973 dry season.

Designation	Yield[a] (t/ha)																	
	Santa Rosa		Victoria		Pila		San Juan		Tiaong		Candelaria		Muñoz		Pila		Mean	
	P[b]	U[c]	P	U	P	U	P	U	P	U	P	U	P	U	P	U	P	U
IR8	5.7	4.7	5.7	5.1	5.5	4.6	5.8	5.7	6.7	5.1	6.5	5.5	6.7	5.9	6.7	5.8	6.2	5.3
IR20	6.9	6.6	5.7	4.5	5.8	5.0	5.5	5.5	6.6	6.2	5.9	3.7	5.2	5.9	6.7	6.2	6.1	5.4
IR1529-680-3	5.7	4.7	4.9	4.1	5.2	4.5	5.2	5.1	7.0	5.2	6.2	4.8	6.2	6.7	7.3	5.3	5.9	5.1
IR1541-76-3	7.3	6.6	4.6	4.7	4.9	4.4	5.0	5.1	7.1	6.0	4.7	3.9	6.8	5.6	6.4	5.8	5.8	5.3
IR1514A-E666	7.7	7.2	5.5	5.5	5.8	4.8	6.1	5.9	6.5	6.0	5.5	5.4	5.4	5.0	5.9	6.0	6.0	5.7
IR1561-228-3	5.9	3.8[d]	5.7	4.7	5.3	4.9	6.1	4.6	6.7	6.3	4.1	5.1	5.6	5.2	7.2	6.4	5.8	5.3
IR1480-116-3	6.3	5.7	5.4	3.8[d]	4.7	4.9	5.1	4.8	6.1	5.1	4.2	4.1	5.3	4.9	6.8	6.2	5.4	5.1
C168-134	6.6	6.3	5.2	5.0	5.8	4.8	5.3	5.4	6.9	5.8	5.7	5.5	6.4	6.2	6.7	5.8	6.1	5.6

[a] Mean of two replications. [b] Protected—seed and seedling soak in carbofuran; lindane granules applied at 1 kg/ha a.i. 5 days after transplanting (DT); carbofuran applied at 0.5 kg/ha a.i. 20 and 40 DT; MIPC (0.05% toxicant) sprayed 80 to 86 DT. [c] Unprotected—no insecticide applied. [d] Rat/bird damage.

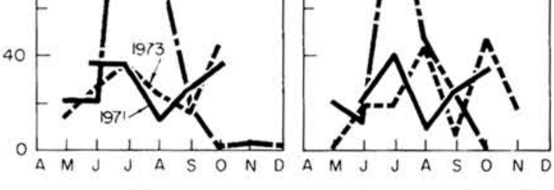
Table 4. Grain yield of promising varieties or selections grown with protection and without at six locations, Luzon, Philippines, 1973 wet season.

Designation	Yield[a] (t/ha)													
	Batangas		Nueva Ecija		Santa Rosa		Tiaong[b]		Pila[b]		IRRI		Mean	
	P[c]	U[d]	P	U	P	U	P	U	P	U	P	U	P	U
IR20[e]	4.8	3.8	5.0	4.0	3.6	2.5	3.0	2.7	0	0	0	0	3.0	2.2
IR1529 680 3[e]	4.9	4.2	5.0	4.1	3.8	2.7	3.3	1.4	0	0	0	0	3.0	2.1
IR442 2 58[e]	3.9	3.5	3.6	3.5	3.0	1.7	1.2	0.9	0	0	0	0	2.1	1.6
IR1514A-E597-2	4.2	3.3	4.8	3.4	4.8	4.3	3.2	2.8	2.3	2.9	3.9	2.7	3.9	3.3
IR1541-76-3	4.2	4.3	3.5	3.4	3.8	3.7	2.4	3.4	1.8	1.6	2.2	1.4	3.0	3.0
IR26	5.0	4.4	4.8	4.2	5.7	5.0	4.4	3.5	3.1	2.9	3.9	3.5	4.5	3.9
IR1561-228-3	5.5	5.0	4.8	3.9	3.5	3.0	4.5	3.5	4.3	3.2	3.6	2.3	4.4	3.5
IR2061-213-2	3.1	2.3	3.2	2.2	4.1	3.4	3.2	2.1	1.5	2.3	3.5	1.7	3.1	2.3
464-5	4.7	3.8	4.5	4.4	3.3	2.6	4.6	3.6	3.2	2.0	4.6	3.5	4.1	3.3

[a] Mean of two replications (three replications at IRRI). [b]All selections lodged due to typhoons. [c]Protected—seed and seedling soak in carbofuran; lindane granules applied at 1 kg/ha a.i. 5 days after transplanting (DT); carbofuran granules at 0.05 kg/ha a.i. 5 DT; Dolmix at 1 kg/ha a.i. 35 and 60 DT; MIPC (0.05% toxicant) sprayed at 70 DT. [d]Unprotected—no insecticide applied. [e]Completely killed by brown planthoppers at Pila and IRRI.

growing seasons were directly seeded in various combinations in an attempt to produce two crops during the normal rainfed period. The pilot extension program conducted in Bulacan province was likewise expanded, doubling the number of barrios covered. Ten extension technicians added to the extension project increased the total number to 21.

Some technicians working in Bulacan were asked to assist with training activities. Twenty persons working with the Bulacan project were requested by the Secretary of Agriculture to visit other provinces to train extension personnel to assist with the implementation of the "Masagana 99" program. The coordinators of the project were involved with the national "Masagana 99"



1. Monthly rainfall, Bulacan and Nueva Ecija, 1971, 1972, 1973.

production program. They helped select more than 600 technicians from 43 provinces to be trained at IRRI and at the UPLB College of Agriculture. They also assisted the rice program officers in the 43 "Masagana 99" provinces in initiating the program in those provinces, and the "Masagana 99" management committee in "trouble shooting" throughout the country. A significant contribution of the project management was the development of a plan which the National Food and Agricultural Council used as a model in developing its nation-wide "Masagana 99" program.

The rainfall distribution in 1973 differed greatly from that in 1971 and 1972 (fig. 1). In 1971, the rain was heavy in June and July permitting early planting of the rice crop, but it stopped raining during August when the rice crop was at the panicle initiation stage. In 1972, the rain was again heavy from June to the middle of August. It stopped raining in mid-September when most of the rainfed rice was at the booting to flowering stages. In 1973, the rain was light from June to mid-July. There was not sufficient rain to flood the fields in Bulacan, so the land could not be puddled and transplanted until the third week of July. It was the first week of August before it was possible to transplant in Gapan. Rainfall was evenly distributed over the entire project area from mid-July to December.

Three successive typhoons hit Central Luzon when the crops were at the flowering stage. They reduced the yields of most plots. The yields from the best performing varieties averaged 4 to 4.5 t/ha compared with 4 to 6 t/ha in 1971 and 1972.

Rainfed variety trial. In 1973 four varieties and 11 new selections were tested in rainfed paddies in 22 locations. Most entries yielded over 4 t/ha (Table 5). The highest mean yield, 4.5 t/ha, was obtained with IR1529-680-3; the lowest mean yield, 3.6 t/ha, with IR665-8-3. IR1529-72-5 produced the highest yield, 6.5 t/ha, in the Buenavista sandy loam, while IR442-2-58 produced the lowest, 2.3 t/ha, on the same soil type. Higher yields would have been obtained had not three typhoons passed through the area when the crops were in the flowering stage.

The incidences of bacterial and virus diseases were low this season. Fungus diseases were widespread. The most common fungus diseases were Cercospora leaf spot, false smut, neck rot, leaf smut, sheath blight, and an unidentified disease which caused a blackish discoloration of the rice hulls. All test entries were infected by Cercospora leaf spot. The most seriously damaged was IR20 whose leaves completely dried in some locations. Neck rot, observed in most locations, caused slight damage to IR1529-680-3, IR26, C4-63, IR665-8-3, IR1529-72-5, IR1480-116-3, and IR1539-823-1. It caused serious damage to IR442-2-58. Some leaf smut damage was observed on IR26 and IR1529 lines. All the test entries were infected by false smut, but IR1480-116-3, IR1541-76-3, and IR26 were damaged more than the other entries. Sheath blight, observed on all entries, caused severe damage in some locations on the IR1529 lines, IR5, and IR26.

While IR26 has shown some susceptibility to Cercospora leaf spot, false smut, and neck rot, it yielded well, over 4 t/ha, in nine out of the 17 test sites. In four locations where no fungus diseases were observed, it yielded 4.8, 5.0, 4.4, and 5 t/ha. But in three locations where false smut, sheath blight, and leaf smut diseases were severe, it gave yields of 3.0, 3.5, and 3.4 t/ha. IR1529-680-3, the best yielder under drought conditions in 1972, performed consistently well, producing an average yield of 4.5 t/ha.

Rainfed fertilizer trial. To determine the most profitable level of nitrogen, phosphorus, and potassium on the five different soil types in the project area, tests were conducted with 0, 60, 90, and 120 kg/ha of N; 0, 30, and 60 kg/ha P_2O_5; and 0, 30, and 60 kg/ha K_2O.

Table 5. Grain yield of 15 varieties or selections in rainfed paddies at 22 locations. Bulacan and Nueva Ecija, 1973 wet season.

Designation	Yield (t/ha)	
	Mean	Range
IR1529-680-3	4.5	3.3 to 5.2
IR5	4.4	2.7 to 5.8
IR20	4.4	3.0 to 5.7
IR1108-3-5	4.4	3.2 to 6.3
IR1721-11-6	4.3	3.4 to 4.9
IR1539-823	4.2	2.8 to 5.2
IR1529-677-2	4.2	3.5 to 5.3
IR26	4.2	3.0 to 5.2
IR1541-76-3	4.2	2.5 to 5.7
IR1529-72-5	4.2	3.3 to 6.5
C4-63 G	4.1	3.2 to 4.7
IR442 2 58	4.1	2.3 to 5.8
IR148-116-3	4.0	2.8 to 5.3
IR1721 14 6	3.9	3.0 to 5.0
IR665-8-3	3.6	3.0 to 4 6

Results from 18 locations indicate a yield response to nitrogen up to 120 kg/ha N, but the differences in yields above 60 kg/ha N was not significant (Table 6). Significant yield response was observed in eight locations. The application of 60 kg/ha N increased the yield by 1 t/ha in the Prensa clay soil, by 0.8 t/ha in the Buenavista silt loam, by 1.3 t/ha in the Buenavista sandy loam, by 0.5 t/ha in the Sibul clay, and by 0.7 t/ha in the Bantog clay soil. No significant response to nitrogen was observed at 10 locations. Farmers in these locations had used chicken manure to fertilize their fields.

In locations where nitrogen applications increased yields significantly, the average response (rough rice) obtained per kilogram of nitrogen applied was 17 kg at the rate of 60 kg/ha, 12 kg at 90 kg/ha, and 10 kg at 120 kg/ha. Based on the current cost of nitrogen and price of palay, an increase of 2 kg rice would pay for 1 kg of nitrogen.

The highest net profit of P434 was obtained with the application of 90 kg/ha N in the Buenavista sandy loam soils (Table 7).

Response to phosphorus was observed in most of the test sites during the early tillering stage. The plots without phosphorus application had two to three less tillers per hill. The difference in yield, however, was significant only in two plots on the Buenavista silt loam soils

Table 6. Nitrogen response of IR1529-680-3 with 60 kg/ha P_2O_5 and 60 kg-ha K_2O under rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Soil type	Location	Grain yield (t/ha)			
		0 kg/ha N (control)	60 kg/ha N	90 kg/ha N	120 kg/ha N
Prensa clay	a	3.6	4.6**	4.7**	4.6**
	b	4.7	5.2	5.0	5.4
	c	3.7	3.5	3.7	4.1
Buenavista silt loam	a	3.4	4.2*	4.6*	4.2*
	b	3.5	4.4**	4.8**	4.9**
	c	4.1	4.4	4.5	4.1
	d	4.2	4.1	4.0	4.1
	e	4.3	4.9	5.0	5.0
	f	4.6	4.4	4.4	4.9
Buenavista sandy loam	a	3.4	4.6**	4.8**	4.9**
	b	3.3	4.8**	4.9**	4.8**
	c	4.8	4.8	4.7	4.8
	d	4.8	4.9	5.2	4.9
Sibul clay	a	4.0	4.5	4.7*	4.3
Bantog clay	a	4.3	4.9*	4.8*	5.3
	b	3.2	4.1**	4.3**	4.5**
	c	4.4	4.9	4.8	5.2
	d	3.5	3.9	4.2	3.8
Mean		4.0	4.5	4.6	4.7

(Table 8). The plots without phosphorus in other locations were able to recover. The favorable rainfall distribution this year could have influenced the crop response to phosphorus. The data suggest that the soil phosphorus became available to the crop after the soil was continuously flooded.

No significant response to potassium was observed in any of the test sites (Table 9). In 1972, the application of potassium in the Sibul clay soils increased yield significantly. Farmers claim they get better yields when they use a complete fertilizer. It is important that more tests be conducted in the area to determine the extent of potassium deficiency.

Table 7. Net return from the application of nitrogen on transplanted IR1529-680-3 under rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Soil type	Return[a] (P/ha)		
	60 kg/ha N	90 kg/ha N	120 kg/ha N
Prensa	196	224	322
Buenavista silt loam	196	224	252
Buenavista sandy loam	406	434	392
Sibul clay	266	364	42
Bantog clay	336	294	392
Mean	280	308	280

[a]Palay, P700/t; nitrogen, P1.40/kg.

Rainfed insecticide trials. Insecticide trials were established in 10 locations to determine the effect of different insecticide applications on the yield of IR20 and IR22.

Tungro infection was insignificant on IR20 in all locations (Table 10). Tungro virus, however, was observed on the susceptible variety IR22. Only treatments 3, 4, and 5 effectively protected IR22 from tungro virus. The incidence of white head was insignificant. Yield data indicate IR20 will produce satisfactory yields with only one application of Dolmix at the flowering stage which provides protection from late stem borer attack. IR20 outyielded IR22 in all treatments. The average response obtained with the application of insecticides was 0.4 t/ha and 0.3 t/ha on IR22. The slight response to insecticide treatments this year indicates the low level of insect pests and disease incidence. White heads were insignificant in all treatments.

Rainfed management. To determine the most profitable level of management for IR1529-680-3, 12 trials were established in Bulacan and Nueva Ecija. Three trials were abandoned due to damage from three typhoons which hit Central Luzon. Except in the Prensa clay loam where the weed and insect populations were very

Table 8. Phosphorus response of IR1529-680-3 with 90 kg/ha N and 60 kg/ha K_2O under rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Locations (no.)	Soil type	Yield (t/ha)		
		0 kg/ha P_2O_5	30 kg/ha P_2O_5	60 kg/ha P_2O_5
3	Prensa clay	4.4	4.6	4.5
6	Buenavista silt loam	4.4	4.4	4.6
4	Buenavista sandy loam	4.7	4.9	4.9
1	Sibul clay	5.0	4.5	4.7
4	Bantog clay	4.1	4.4	4.5

Table 9. Potassium response of IR1529-680-3 with 90 kg/ha N and 60 kg/ha P_2O_5 under rainfed conditions. Bulacan and Nueva Ecija. 1973 wet season.

Locations (no.)	Soil type	Yield (t/ha)		
		0 kg/ha K_2O	30 kg/ha K_2O	60 kg/ha K_2O
3	Prensa clay	4.5	4.6	4.5
6	Buenavista silt loam	4.6	4.4	4.6
4	Buenavista sandy loam	4.7	4.8	4.9
1	Sibul clay	4.7	4.6	4.7
4	Bantog clay	4.4	4.6	4.5

low, results indicate significant yield differences between the treated and untreated plots. Yield differed by as much as 1 to 2 t/ha between the treated and untreated plots (Table 11). No significant difference was observed between the application of foliar and granular insecticides.

The average response obtained with the application of insecticide and herbicide was 0.5 t/ha, while nitrogen application increased yield by 1.2 t/ha. In the Bantog clay soils where insect and weed populations were high, the application of insecticide and herbicide alone increased yield by 1.1 t/ha.

Direct seeding in unpuddled soil. Growing rainfed rice by the traditional transplanting method is difficult. The difficulty lies in timing operations such as land preparation, seedbed preparations, transplanting, and application of fertilizer. The optimum time for these operations depends on the amount and frequency of rainfall, a factor beyond human control. For example, this year in Central Luzon, the monsoon rains which usually come in late June and July were delayed. As a result, farmers were not able to transplant until the last week of July. In Gapan, farmers were transplanting as late as the middle of September. Many had to use 50- to 55-day-old seedings. When it did rain, farmers were in a hurry to plant their fields and did not prepare the soil well. Some fields were transplanted 2 to 3 days after plowing, which reduced yields. Trials in 1971 and 1972 indicated that this problem could be avoided by seeding on unpuddled soil in bunded fields. Yields over 4 t/ha were obtained with IR5 in 1971, and with an IR1561 line and IR20 in 1972. Work on

Table 10. Effect of various insecticide combinations on two rice varieties under rainfed conditions at nine locations. Bulacan and Nueva Ecija, 1973 wet season.

Treatment	Seed and seedling soak[a]	Post-transplanting treatment		Whorl maggot damage[b]		Dead hearts[c] (%)		Tungro virus[c] (%)		Yield (t/ha)	
		Chemical	Applied (DT)	IR20	IR22	IR20	IR22	IR20	IR22	IR20	IR22
1		—	—	1.5	1.9	0.3	0.1	0	4	3.5	3.1
2	√		—	0.8	1.6	0.4	0.5	0	3	3.6	3.3
3	√	Carbofuran[d]	20								
		BHC[e]	40								
		Azodrin[d]	70	0.4	0.8	0.1	0.1	0	1	4.1	3.8
4	—	Dolmix[e]	5, 25								
		Hostathion[d]	50, 70	0.5	0.5	0.1	0.1	0	1	4.0	3.7
5	—	Gusathion[d]	5, 20, 40, 70	0.2	0.4	0.1	0.2	0	0	3.9	3.4
6	—	Dolmix[f]	60	1.2	1.8	0.3	0.2	0	12	3.8	2.9
7	—	Dolmix[e]	40								
		Dolmix[f]	70	1.2	1.4	0.3	0.2	0	6	3.8	3.6
8	√	Dolmix[e]	40								
		Dolmix[f]	70	1.3	1.8	0.5	0.2	0	2	4.0	3.2

[a]Carbofuran solution. [b]Scale 0 to 5: 0 = no damage, 5 = severe damage. [c]30 DT. [d]0.05%. [e]1 kg/ha a.i. [f]1.5 kg/ha a.i.

Table 11. Effects of different levels of management on grain yield of IR1529-680-3 under rainfed conditions. Bulacan and Nueva Ecija. 1973 wet season.

Soil type	Sites (no.)	Yield (t/ha) 0 kg/ha N	45 kg/ha N	90 kg/ha N
		No weed or insect control		
Prensa clay	2	3.1	3.5	3.7
Buenavista silt loam	2	1.5	3.4	3.2
Buenavista sandy loam	3	2.0	3.4	3.6
Bantog clay	2	0.8	2.6	2.4
Mean		1.9	3.2	3.2
		Weed control[a] and insect control[b]		
Prensa clay	2	2.8	3.3	3.5
Buenavista silt loam	2	2.7	3.4	3.7
Buenavista sandy loam	3	2.1	3.4	4.1
Bantog clay	2	1.4	2.7	3.3
Mean		2.3	3.2	3.7
		Weed control[a] and insect control[c]		
Prensa clay	2	3.1	3.3	3.8
Buenavista silt loam	2	2.2	3.7	3.5
Buenavista sandy loam	2	2.8	3.8	4.0
Bantog clay	2	1.9	3.0	3.6
Mean		2.5	3.5	3.7

[a]2,4-D applied 4 DT. [b]MIPC spray on seedbed and at 15 DT, Gusathion spray at 30 and 50 DT. [c]Seed and seedling treatment; carbofuran at 20 DT; Gusathion spray at 40 DT and lindane at 55 DT.

direct seeding was expanded this year to further explore the potential of this method in rainfed areas. Eight observational plots, each measuring 1,000 sq m, were established on four different soil types. The soil in three locations was rotovated in March; five locations were rotovated after it rained in June. Before the final rotovation, 30-30-30 kg/ha N, P_2O_5, K_2O, and 0.5 kg/ha a.i. carbofuran were applied. A *lithao* was passed over the field to make shallow furrows. Seeds of IR1529-680-3 were soaked in carbofuran, dried, then broadcast uniformly over the entire area at the rate of 70 kg/ha. A comb harrow was passed over the field to cover the seeds.

Butachlor was sprayed 2 to 5 days after seeding to control germinating weeds. The crop was topdressed with ammonium sulfate 40 to 60 days after rice emergence. Half of the plot received a total of 90 kg/ha N and the other half, 120 kg/ha N. Three field applications of insecticide were made to control insects.

Table 12. Performance of direct-seeded IR1529-680-3 in bunded dry and puddled soil under rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Trial no.	Grain yield (t/ha) 90 kg/ha N	120 kg/ha N
	Unpuddled soil	
1	4.7	7.1
2	4.3	4.1
3	[a]	5.0
4	5.8	6.1
5	5.6	5.8
6	5.2	5.0
7	5.3	4.6
8	4.7	6.2
Mean	5.1	5.5
	Puddled soil[b]	
1	2.8	3.3
2	1.4	1.8
Mean	2.1	2.6

[a]Farmer-cooperator applied additional fertilizer. [b]Crop damaged by typhoon during flowering stage.

Results of the trial were impressive. An average of 5.1 t/ha was obtained with 90 kg/ha N and 5.5 t/ha with 120 kg/ha N (Table 12). Figure 2 shows the amount of rainfall before seeding and during the various growth stages of the crop in San Rafael, Bulacan. The plot in San Ildefonso, on Buenavista sandy loam soil, received only 12 cm of rain during the first 30 days after seeding and 14 cm from flowering to harvest. Yet, it produced yield of 6 t/ha. The exposure of the crops to moisture stress during the first 30 days apparently did not affect the yield.

In the Bulacan area, the rains started to intensify during the third week of July when more than 30 cm of rain was received. Only then could the farmers plow their fields and transplant their crop. Transplanting was spread over 2 months. Some farmers transplanted their crops as late as September 15. By this date, the direct-seeded crops, planted in May, were almost ready for harvest. IR1529-680-3 matured in about 120 days from seeding. If a 100-day variety had been used, the crop could have been harvested by the time many farmers were transplanting their crops. This would have permitted a second crop to be grown.

Two observational plots were direct-seeded in puddled soil during the last week of July. Butachlor was applied 7 days after seeding. Insecticide and fertilizer rates were identical to those in the direct seeding done on dry soil. The crops were hit by three successive typhoons during the flowering stage. Yields obtained were low (Table 12).

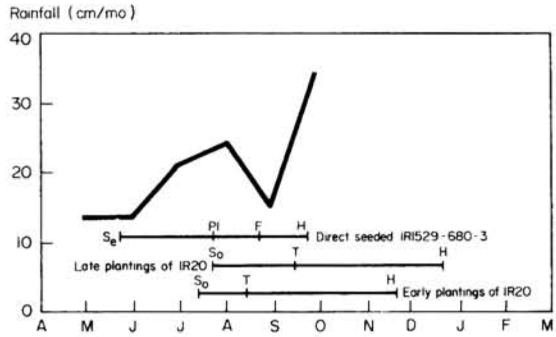
Maximum grain production. Maximum grain yield trials were organized to explore the possibility of growing two crops of rice in rainfed paddies or a crop of rice and a crop of sorghum or corn using early and medium maturing rices.

The first rice crop was directly seeded on unpuddled soil and the second rice crop was transplanted. An attempt was made to grow a sorghum and corn crop after the rice crop and also to grow a rice crop after a corn crop.

The early maturing rice selections were IR1561-228-3, IR1712-217-2, and IR1712-195-1. The medium maturing rice selections used in the first planting were IR1529-680-3, IR1541-76-3, and IR577-24-1. In the second planting, IR577-24-1 was replaced with IR1721-15-6 due to its susceptibility to blast. Three sorghum varieties, IS314, Darso, and Cosor-2 and three corn varieties, Hawaiian 68 sweet, UPCA-1, and DMR-2, were tested following the first rice crop.

Nine trials were established in five soil types. In five locations the trials were grown in elevated paddies, and in four locations they were established in low-lying areas. A tenth location, a low-lying area, had been planned but was abandoned because early heavy rainfall made it impossible to prepare the soil for seeding the crop.

Land preparation and seeding methods were similar to those used for upland rice. Most of the areas were rotovated during the dry season before the monsoon rains. A basal application of 30-30-30 kg/ha N, P_2O_5, K_2O was made and carbofuran was broadcast on the trial areas at 1 kg/ha a.i. A *lithao* was used to form furrows 25 cm wide. Seeds were soaked in carbofuran for 24 hours and sun-dried before being directly seeded in the furrows at the rate of 70 kg/ha. The seeds were covered with soil by means of a spike tooth harrow. Butachlor was sprayed 2 to 4 days after seeding at 2 kg/ha a.i. to control weeds. The crop was topdressed with 30 kg/ha N as ammonium sulfate at 20 to 25 days after the rice emerged and with 30 kg/ha N again at



2. Time of seeding and harvesting of direct-seeded IR1529-680-3 and transplanting of IR20 in relation to the amount of rainfall. San Rafael, Bulacan, 1973 wet season.

panicle initiation. At 25 days after rice emergence (DARE) 0.5 kg/ha a.i. carbofuran was applied and 10 days after panicle initiation 1.5 kg/ha a.i. lindane was applied.

The first plot was established May 18 and the last on June 15. Seven trials were directly seeded on dry soil and two trials on moist soil. In one location the seeds were in the soil 8 days before it rained. All locations had excellent stands except one which suffered from herbicide toxicity.

Many farmers in Central Luzon in 1973 sowed their seedbeds between July 1 and July 17 and transplanted between August 18 and September 1. Seedlings were invariably older than 30 days at the time of transplanting. In the very late plantings, seedlings in the booting stage were transplanted. In some of the upper paddies, farmers were unable to plant their rice crop because of insufficient moisture.

Because this year's rainy season began late, most of the early development of the direct-seeded crop was under restricted moisture in the upper paddies. Only after heavy rains in the middle of July was there standing water. In the low-lying areas, the soil was either saturated or had standing water continuously after rain showers in early June, so these crops did not suffer from lack of water.

Wherever butachlor was applied on moist, well-prepared soil, before the grasses had reached the three-leaf stage, weeds were satisfactorily controlled. Where butachlor was not applied under the right conditions or was applied too late, weeds were a problem. The most serious weeds were the perennial grasses

Table 13. Performance of early and medium maturing rice when direct seeded on dry soil under rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Location	Grain yield (t/ha)					
	Early maturing rice[a]			Medium maturing rice[b]		
	IR1561-228-3	IR1712-217-2	IR1712-195-1	IR1529-680-3	IR1541-76-3	IR577-24-1
Santa Maria—Parada	5.8	3.1	1.9	6.0	5.4	6.1
San Rafael—Cruz na Daan	5.1	3.8	3.9	6.1	5.3	5.3
San Rafael—Diliman	4.0	2.5	2.2	3.8	3.8	4.0
San Ildefonso—San Juan	5.6	3.0	4.4	6.2	5.8	6.0
San Ildefonso—Pinaod	5.0	4.3	3.6	5.0	4.3	4.8
San Miguel—Santa Ines I	5.6	4.0	4.2	5.6	4.8	5.6
San Miguel—Santa Ines II	5.8	5.0	4.6	4.6	4.4	4.2
Gapan—Kapalangan I	5.7	3.3	3.6	5.8	4.5	5.3
Gapan—Kapalangan II	5.4	3.8	3.5	5.1	4.8	4.6

[a]Each location mean is avg of six observations. [b]Each location mean is avg of 12 observations.

Cynodon dactylon, and several *Paspalum* species, which are not controlled by butachlor. The annual *Echinochloa colonum* was another major weed pest.

In San Ildefonso, Bulacan, we harvested the first plots of early maturing rice on August 19. At that time 40 percent of the rice paddies on the upper portions of slopes in the area had not been transplanted for lack of sufficient rainfall to permit plowing and puddling of the soil. When the last of our early maturing rices were being harvested on September 7, some farmers were just transplanting their crop.

Rats, whorl maggots, rice bugs, and leaf folders were the major pest problems encountered. False smut was the most serious disease affecting the crop. In Gapan and Santa Maria, some of the IR577-24-1 plots suffered hopperburn.

The IR1712 lines matured between 83 and 101 days after emergence, the IR1561 line matured between 97 and 110 days, depending on the amount of soil moisture available. The IR577 line matured in 105 to 130 days, the IR1529 line in 112 to 123 days, and the IR1541 line in 112 to 131 days.

Among the early maturing lines, IR1561-228-3 significantly outyielded the two IR1712 lines and produced an average of 5.3 t/ha for the nine locations (Table 13). Among the medium maturing selections, IR1529-680-3 produced 5.4 t/ha, IR1541-76-3 produced 4.8 t/ha, and IR577-24-2 produced 5.1 t/ha. Yield differences among the locations were fairly large.

The low-lying paddies produced higher yields than did the upper paddies (Table 14). IR577-24-1 appeared least affected by the differences in moisture because of differences in topography.

Seedbeds for the second planting were prepared 2.5 weeks before the anticipated date of harvest of the first crop. The soil was plowed and puddled as quickly as conditions permitted. Three to four harrowings were usually required to prepare the land for transplanting. Ten to 15 days were needed to prepare the land properly. The second crop was being harvested at the end of 1973. Some of the early maturing lines were harvested on November 28, when many of the neighboring farmers were still harvesting their first and only crop of rice.

Table 14. Grain yield of early and medium maturing lines as affected by paddy location, direct-seeded, rainfed conditions. Bulacan and Nueva Ecija, 1973 wet season.

Designation	Yield (t/ha)		
	Lower paddies[a]	Upper paddies[b]	Mean
	Early		
IR1561-228-3	5.5	5.1	5.3
IR1712-217-2	3.9	3.3	3.6
-195-1	4.1	2.8	3.5
	Medium		
IR1529-680-3	5.5	5.1	5.3
IR1541-76-3	5.0	4.5	4.8
IR577-24-1	5.1	5.0	5.1

[a]Avg of 30 and 60 observations for early and medium maturing lines, respectively. [b]Avg of 24 and 48 observations for early and medium maturing lines, respectively.

Table 15. Performance of 15 varieties or selections under upland conditions at seven locations. Bulacan and Nueva Ecija, 1973 wet season.

Designation	Yield (t/ha)		Maturity (days)	
	Mean	Range	Mean	Range
IR5	2.3	0.9–4.4	140	130–146
IR8	2.7	1.4–3.4	130	120–140
IR272-4-1	2.0	0.4–3.3	119	113–126
IR442-2-58	1.7	1.0–2.8	119	113–125
IR577-24-1	2.8	1.6–4.4	127	120–133
IR1480-116-3	1.9	1.2–3.5	126	122–133
IR1529-680-3	2.8	1.7–3.8	126	122–133
-949-3	2.2	0.7–4.3	124	120–133
IR1539-823-1	2.1	0.8–4.1	128	120–133
IR1721-11-6	1.8	0.8–2.8	125	118–133
-14-6	2.0	0.9–3.1	122	113–133
C4-63 G	1.6	0.2–3.2	126	120–133
C22-51	2.4	1.4–4.0	122	113–127
BPI 1-48	1.8	0.3–3.0	119	112–133
MRC 3-2b	1.5	0.2–2.8	126	120–133

The corn-rice combination was not successful. Inspite of planting of beds, drainage was a problem. In many of the upper slope locations, the depth of the soil is only 25 to 30 cm. Heavy rains in the middle of July saturated the soil when the corn crop was near tasseling and caused serious damage. Some lodging occurred. Stem borers, cutworms, earworms, and corn silk beetles were prevalent and caused significant damage. After the corn was harvested, removing the corn stubble so that the land could be prepared for planting the rice crop required large amounts of labor. Corn followed by rice does not appear to be a practical cropping sequence in rainfed rice paddies.

In two of the upper bunded areas, sorghum and maize were planted after the medium maturing rice. In one location both sorghum and corn were destroyed as a result of heavy rains several days after seeding. In the other locations, heavy rains waterclogged the soil for several days, retarding severely the growth of corn and to a lesser degree the sorghum which completely recovered.

Although all of the second crops have not been harvested, indications are that two crops of rice can be grown in the low-lying paddies and in most of the upper paddies. Where the paddies do not hold water well, it is possible to grow other grain crops, such as sorghum. The multiple cropping trials now under way should determine which crops can be grown in the rainfed bunded paddies where a second rice crop is not possible.

Upland variety trial. Three varieties and 13 selections were tested at eight locations this year to determine which varieties and selections perform better than IR5, the standard variety for upland culture. IR577-24-1 and IR1529-680-3 produced the highest mean yields, 2.8 t/ha (Table 15). IR577-24-1 also performed well in 1972. Low yields were obtained in two locations with IR5 due to bird and animal damage since the trials were the only standing plots in the area after the other varieties were harvested. C22-51, a selection from the UPLB College of Agriculture, produced high yields in two locations, 4.0 t/ha and 3.9 t/ha, but it performed poorly in two other locations where it produced only 1.4 t/ha.

Rice blast attacked crops at the early vegetative stage in five test sites. IR442-2-58, C4-63G, MRC-3-2b, BPI 1-48, C22-51, IR1529-949-3, and IR5 were damaged severely but they recovered and produced good stand. IR272-4-1 and IR1721-14-6 were the only entries resistant to rice blast.

Upland herbicide trial. Weeds are a serious problem under upland conditions. Previous trials show that upland rice yields seldom exceed 1 t/ha when weeds are not controlled. Six herbicides were compared with two hand-weedings in five locations in 1973 to determine their performance as pre-emergence treatments.

All chemicals were sprayed at 2 kg/ha a.i.

Table 16. Effects of herbicides (2 kg/ha a.i.) and of hand weeding on grain yield of IR5 under upland conditions at five locations. Bulacan and Nueva Ecija, 1973 wet season.

Treatment	Yield (t/ha)	
	Mean	Range
Benthiocarb	1.86	1.1–3.1
Butachlor	2.31	1.7–3.2
C-288	3.01	2.3–4.0
Preforan	1.79	0.7–2.9
A-820	2.56	1.6–4.3
USB 3153	2.26	1.5–3.8
Hand weeding (twice)	2.44	1.6–3.7
Control	1.31	0.7–2.3

Table 17. Nitrogen response of direct-seeded IR5 under upland conditions. Bulacan and Nueva Ecija, 1973 wet season.

Soil type	Grain yield (t/ha)			
	0 kg/ha N (control)	60 kg/ha N	90 kg/ha N	120 kg/ha N
Buenavista silt loam	1.33	2.53**	3.27**	3.31**
Buenavista silt loam	1.92	4.05**	3.23**	3.96**
Buenavista sandy loam	0.77	1.54**	1.71**	1.55**
Sibul clay loam	1.97	2.76**	3.12**	3.96**
Bantog clay loam	2.91	2.66	2.76	2.18
Bantog clay loam	1.59	2.02	1.99	2.23
Mean	1.75	2.59	2.68	2.87

Table 18. Phosphorus response of direct-seeded IR5 with 90 kg/ha N and 60 kg/ha K_2O under upland conditions. Bulacan and Nueva Ecija, 1973 wet season.

Soil type	Grain yield (t/ha)		
	0 kg/ha P_2O_5 (control)	30 kg/ha P_2O_5	60 kg/ha P_2O_5
Buenavista silt loam	1.08	2.70**	3.27**
Buenavista silt loam	1.84	2.55	3.23
Buenavista sandy loam	1.55	2.30	1.71
Sibul clay loam	2.76	3.20	3.12
Bantog clay loam	2.38	2.09	2.76
Bantog clay loam	2.08	2.10	1.99

Table 19. Potassium response of direct-seeded IR5 with 90 kg/ha N and 60kg/ha K_2O under upland conditions. Bulacan and Nueva Ecija, 1973 wet season.

Soil type	Grain yield (t/ha)		
	0 kg/ha K_2O (control)	30 kg/ha K_2O	60 kg/ha K_2O
Buenavista silt loam	3.22	2.88	3.27
Buenavista silt loam	2.93	3.97	3.23
Buenavista sandy loam	1.56	1.69	1.71
Sibul clay loam	3.97	3.68	3.12
Bantog clay loam	2.03	2.80	2.76
Bantog clay loam	1.42	1.25	1.99

A 3-m boom sprayer was used to apply the chemicals. The soil was moist at the time of application in all locations. The following weeds are common in the area: *Digitaria sanguinalis, Echinochloa colonum, Ludwigia octovalvis* spp. *sessiliflora, Cyperus rotundus, Eleusine indica, Ageratum conyzoides, Celosea argentea*, and *Ipomeaea triloba*.

The best performing herbicides in the trial were C-288 and A-820. C-288 gave the best control of grasses. sedges, and broadleaved weeds (Table 16). All C-288 treated plots were completely free of weeds. At two locations the C-288 treated plots produced from 2.5 to 3.0 t/ha more than did the control plots which were heavily infested with weeds. A-820 controlled grasses well, but did not effectively control the broadleaved weeds and sedges.

Butachlor and benthiocarb prevented weed growth during the first 30 days after spraying, but grassy weeds grew again at about 35 to 40 days after spraying. Preforan did not perform as well this year as in the past 2 years. In one location, the chemical formed a precipitate as soon as it was mixed with the water. The water in the area is rather hard.

C-288 and USB 3153 were toxic at 2 kg/ha a.i. Both caused severe burning and yellowing of the leaves and stunting of growth. At two locations, the toxic effects of the chemicals were visible up to 45 days after seeding, but the crop recovered and produced 1 to 2 t/ha more than plots treated with other test chemicals. At a third location plots treated with C-288 and USB 3153 were burned so badly the crop never recovered. No toxicity was observed on the plots treated with butachlor, benthiocarb, or Preforan.

Upland fertilizer trial. Fertilizer plots were established in six locations on four soil types to determine the response to nitrogen, phosphorus, and potassium under upland conditions.

On Buenavista silt loam, Buenavista sandy loam, and Sibul clay loam soil yield increased significantly by 1 to 2 t/ha in response to nitrogen application up to 60 kg/ha N (Table 17). No response was obtained on the Bantog clay loam soil.

Phosphorus response was observed only on the Buenavista silt loam soils (Table 18), where the yields increased by 1.7 t/ha with the application of 30 kg/ha P_2O_5. Response was also observed during the early vegetative growth on the Buenavista sandy loam and on the Sibul clay loam soils but the crops in these plots recovered.

No response to potassium was observed on any of the soils (Table 19).

Training programs

IRRI's training programs are integral parts of both its core research program and of its international cooperative efforts. The individuals selected for training are staff members of government agencies and institutions involved in research and extension in rice-producing countries. The long-range objectives of the training program are to improve the technical proficiency of national research and extension staffs and to encourage multi-disciplinary research production programs.

IRRI continues to offer opportunities for rice scientists to participate in degree or non-degree research programs, and for extension workers to participate in 6-month or 2-week rice production courses. We are launching a 5-month multiple cropping training program in 1974.

During 1973, 126 scholars, fellows, and 6-month rice production trainees from 24 countries were trained at IRRI. Ninety-two were in research-oriented programs, 30 were in the 6-month rice production course, and 4 were in research support areas.

All research departments provided research training during the year: plant breeding trained 17 persons; entomology and pathology trained 11 each; and agronomy, 10 (Table 1). Forty-three of the research participants completed training in 1973; 10 earned M.S. degrees from the University of the Philippines at Los Baños.

Thirty persons from 11 countries participated in the 6-month rice production course from June to December. As part of the "train the trainer" program, they planned and conducted a 2-week rice production course and held an applied research field day in November.

Fifty-seven others attended the two 2-week rice production courses. As in the past, participants in these 2-week courses had diverse backgrounds: rice farmers; U.S. Peace Corps Volunteers; rural bank technicians; chemical company representatives; farm technicians of the Philippine National Irrigation Administration; irrigation engineers from Thailand, Korea, Philippines, Indonesia, and Malaysia who participated in the East-West Center's water management course; and IRRI research aides, scholars, and assistants.

Six hundred and four farm management technicians were trained in a series of 2-week rice production courses from January to April, at the request of, and financed by, the Philippine government. The technicians were prepared for the government's Masagana 99 rice production program, which was launched in May.

In 1973, 23 individuals studied in the U.S., the U.K., and India under IRRI scholarships provided by its different country programs: 9 were from Sri Lanka, 6 from Indonesia, 6 from Bangladesh, 1 from Egypt, and 1 from the Philippines. Most are graduate students working for Ph.D. degrees.

Twenty-four countries participated in the training programs during 1973; five countries provided more than half of the trainees. India sent 12 participants; Korea, 14; the Philippines,

Table 1. Categories and numbers of research trainees among departments.

Department	Number			
	Research scholar	Post-MS fellow	Post-doctoral fellow	Total
Agricultural economics	6	2	—	8
Agricultural engineering	1	3	—	4
Agronomy	6	2	2	10
Chemistry	—	3	1	4
Entomology	9	1	1	11
Multiple cropping	4	1	1	6
Plant pathology	5	6	—	11
Plant physiology	1	1	—	2
Rice production training and research	4	1	—	5
Soil chemistry	1	2	2	5
Soil microbiology	3	2	2	7
Statistics	2	—	—	2
Plant breeding	10	6	1	17
Total	52	30	10	92

Table 2. Countries which sent training participants to IRRI in 1973.

Country	Number of trainees					Total	Equivalent man-years training
	Research oriented			Production oriented[a]	Others[b]		
	Scholars	Post-M.S. fellows	Post-doctoral fellows				
Bangladesh	2	3	2	2		9	3.81
Burma	2			2		4	2.12
Colombia	2				1	3	1.16
Egypt		2		1		3	1.33
England		1				1	0.75
Guyana	1					1	0.37
India	1	9	2			12	7.52
Indonesia	1	2		4		7	2.49
Ivory Coast		1				1	0.50
Japan	1	3	1			5	2.02
Khmer Republic				2		2	1.00
Korea	7	3	1	2	1	14	6.80
Laos	4	1				5	2.91
Liberia	1					1	0.50
Malaysia	2			1		3	1.50
Nigeria	3					3	2.12
Philippines	7	1	3	3		14	9.84
Senegal	1					1	1.00
Sri Lanka	2			7	2	11	6.08
Taiwan	5	2				7	2.73
Thailand	9	1		4		14	6.98
USA	1					1	0.79
Vietnam		1		2		3	1.91
West Germany			1			1	0.70
Total	52	30	10	30	4	126	66.93

[a] 6 months rice production course. [b] Participated in training program for research support maintenance/repair of laboratory equipment, management of research farm, and library.

14; Sri Lanka, 11; and Thailand, 14. IRRI provided the equivalent of 67 man-years of training in 1973 (Table 2).

We received a preliminary report on an evaluation of IRRI's training programs. Seventy-six percent of the trainees responded to a mailed questionnaire. Both research- and production-oriented trainees evaluated their training experiences at IRRI in a positive manner. The final report will be available in 1974.

The names, countries, and research project areas of persons who completed their training during the year are given below. An asterisk (*) indicates individuals who completed the M.S. degree during the year.

RESEARCH SCHOLARS

Agricultural Economics

*Jerachone Sriswasdilek**. Thailand. The new high yielding dwarf rice varieties: advantage and adoption in Don Chedi, Suphan Buri, Thailand.

Jung Hwa Yang, Korea. Economics of farm size with special reference to mechanization of rice farms in the Philippines and Korea.

Agronomy

Isaac Trokon Guar, Liberia. Yield potential of high protein rices.

*Francois Faye**, Senegal. Differential responses of rice varieties and lines to controlled moisture stress condition at vegetative and reproductive stages.

*Lewis Okafor**, Nigeria. Weed control in upland rice.

Entomology

*E. Akinsola**, Nigeria. Resistance of rice varieties to the yellow borer, *Tryporyza incertulas*.

Bounthern Naovarangsy, Laos. Different methods of pesticide application on insect control in rice.

Ho Savongdy, Laos. a) Comparison of methods of insecticidal protection on a young crop; b) Relation of whorl maggot damage to yield loss; c) Predation by *Cyrtorhinus lividipennis* on *Nilaparvata lugens*.

Multiple Cropping

Nathy Viengrouthasane, Laos. Field techniques for applied research in multiple cropping.

Sisavath Manxunvong, Laos. Field techniques for applied research in multiple cropping.

Plant Pathology

*Wu-hsiung Tsai**, Taiwan. Pathogenic variability of *Pyricularia oryzae*.

Chin Khoon Min, Malaysia. Testing varietal resistance to viral, bacterial, and fungus diseases with special reference to sheath blight.

Panee Suworakul, Thailand. Methods of screening for varietal resistance to sheath blight, blast, and bacterial blight.

Rice Production Training & Research

*Eddie Chu**, Philippines. High yielding varieties at the crossroad: three post-trial alternative decisions among farmers.

Soil Chemistry

*Reynaldo Gaballo**, Philippines. Association of soil factors with paddy yield on some lowland rice soils in the Philippines.

*Kang Han Wan**, Korea. Application of radioisotopes to the transformation of zinc, sulphur, and phosphorus in submerged rice soils.

Statistics

*Saowanee Pisithpun**, Thailand. Nitrogen response of rice.

Plant Breeding

*A. V. E. Chin**, Guyana. Genetic behavior of certain quantitative characters in rice.

Rareun Boondaung, Thailand. Maintenance of genetic stocks of rice.

Chin Thian Hon, Malaysia. General rice breeding program and germplasm conservation.

Byung Tae Jun, Korea. Training in rice breeding methods and procedures.

RESEARCH FELLOWS

Post-M.S.

V. K. Agarwal, India. Design and development of water measurement techniques for open canals.

Masakazu Nagaki, Japan. Biological production, function, and identification of constraints of farm rice yields.

Yong Kook Lee, Korea. Optimization of IRRI stripper harvester design.

Siene Saphangthong, Laos. Varietal response to nitrogen and insecticide.

A. A. El-Shirbeeny, Egypt. Effects of salinity of irrigation water on quality characteristics of Egyptian rice.

Jagtap Shivaji Malharrao, India. Grain properties of indica and japonica mutants which differ in grain shape.

Rogelio Cuyno, Philippines. Case study of the institutional linkage strategy set up for increasing rice productivity through applied research and non-formal education activities.

Clement Boka Kra, Ivory Coast. The interactions of iron and manganese in the growth of rice on two flooded soils.

Koji Yoshida, Japan. Microbial mineral transformation in rice rhizospheres and soils.

Masaaki Suzuki, Japan. Ethylene formation in submerged soil and ethylene degradation by rice roots.

Milad Azer Maximos, Egypt. General breeding program.

Soo Yean Cho, Korea. General breeding program.

Post-doctoral

Wilfredo David, Philippines. Rice response to moisture stress: research approach.

Md. Erfan Ali, Bangladesh. New method of studying aluminum toxicity in rice.

RICE PRODUCTION TRAINEES

M. R. M. Abeyratne, agricultural instructor, District Agricultural Office, Galle, Sri Lanka.

Morakot Augsornsward, second grade officer, Technical Division, Department of Agriculture, Bangkhen, Bangkok, Thailand.

Orabi Ali Bastawesy, research assistant, Sakha Research Station, Kafr-Elshekh, Egypt.

Nurul Islam Bhuiyan, scientific officer, soil chemistry division, Bangladesh Rice Research Institute, Dacca, Bangladesh.

Prak Chhay, controller of agriculture, development of rice production, Directorate of Agriculture, Phnom Penh, Khmer Republic.

Pyung Kwan Chung, rice researcher, Experiments Crop Station, Office of Rural Development, Chunnam, Kwangju City, Korea.

P. Ganeshamoorthy, agricultural instructor, District Agricultural Office, Amparai, Sri Lanka.

Arnawa Anom Idabagus, head, Kampar Agriculture Service Extension Office, Badulla, Sri Lanka.

P. Kariyawasam, agricultural instructor, District Agricultural Office, Badulla, Sri Lanka.

K. Kunaratnam, agricultural instructor, District Agricultural Office, Vavuniya, Sri Lanka.

Francisco Manipon, plant propagator, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines.

U Soe Myint, township manager, Agricultural Corporation, Rangoon, Burma.

L. Nanayakkara, agricultural instructor, In-Service Training Institute, Gannoruwa, Peradeniya, Sri Lanka.

Muhammad Nasiruddin, senior scientific officer, breeding division, Bangladesh Rice Research Institute, Dacca, Bangladesh.

Abdul Latief Nazar, head, planning and evaluation section, Riau Province Agriculture Office, Pekanbaru, Riau, Indonesia.

Ngo Van Giao, program manager, Rice Service, General Directorate of Agriculture, Saigon, South Vietnam.

Ekachai O'Charoen, second grade officer, Agricultural Extension Office, Korat, Thailand.

Asyari Rahim, head, Agriculture Service of Pekanbaru Municipality, Pekanbaru, Riau, Indonesia.

Nakorn Sang Plung, second grade officer, Rayong Agricultural Extension Office, Rayong, Thailand.

Lim Chow Shiun, agricultural instructor, Natural Resources Training Center, Semongkok, Kuching, Sarawak, East Malaysia.

U Kyaw Soe, township manager, Agricultural Corporation, Rangoon, Burma.

B. W. Somapala, agricultural instructor, District Agricultural Office, Kegalla, Sri Lanka.

Apolinario Sotomil, farm management technician, Bureau of Agricultural Extension, San Fernando, La Union, Philippines.

S. Subramaniam, agricultural instructor, In-Service Training Institute, Maha-Illuppallama, Sri Lanka.

Eun Soo Shin, extension specialist, Office of Rural Development, Whang-Chang Dong, Dong-gu, Taegu, Korea.

Mai Ngoc Thach, agricultural controller, Rice Service, General Directorate of Agriculture, Saigon, South Vietnam.

Chuankasem Thanomsak, second grade officer, Agricultural Extension Office, Nakornnanyok, Thailand.

Sun Heang Thay, controller of agriculture, development of rice production, Directorate of Agriculture, Phnom Penh, Khmer Republic.

Noemi Yapit, farm management technician, Bureau of Agricultural Extension, San Fernando, La Union, Philippines.

Ansar Zainuddin, head, production section, Agriculture Extension Service, Pekanbaru, Riau, Indonesia.

SHORT-TERM OBSERVERS AND TRAINEES

Karunaratna Banda, Sri Lanka, 3 months. Operation and management of a research farm.

Daniel Camacho, Colombia, 2 months. Maintenance and repair of electronic research instruments.

Ching-Chung Chen, Taiwan, 2 months. Mass rearing of and screening for varietal resistance to the green leafhopper.

Md. Nurul Choudhury, Bangladesh, 2 months. Rice breeding methods and procedures.

A. Hsueh Wen Kao, Taiwan, 2 months. Mass rearing of and screening for varietal resistance to the brown planthopper.

Jayasingha A. Jayaratna, Sri Lanka, 4 months. Maintenance and repair of electronic scientific instruments.

Charoen Khaoporisuthi, Thailand, 1 month. Rice production training and research.

Nichai Thaipanichaya, Thailand, 1 month. Rice production training and research.

International activities

The term international program refers to all of IRRI's off-campus activities, including integral parts of IRRI's core program, such as international testing and regional projects. The major component of IRRI's international program is the outreach service, which is specifically meant to assist national programs.

International testing

Our international testing programs, coordinated by IRRI scientists, expanded both in types of nurseries and in number of test locations. Genetic material was screened for resistance to diseases and insects, and promising selections were evaluated under a range of environmental conditions. Rice scientists in national programs nominated many entries for the disease and yield nurseries. We multiplied the entries at IRRI and dispatched seeds to cooperating countries. We obtained promising herbicides from various companies and sent them to cooperating centers in many countries for weed control evaluation. Details of our cooperative testing programs can be found in departmental sections of this annual report.

The International Blast Nursery continued for the 11th year, distributing test material to 26 countries. The International Bacterial Blight Nursery was tested for the second year at 18 locations in nine Asian countries. IRRI initiated the International Sheath Blight Nursery by sending 60 varieties with varying degrees of resistance to nine Asian countries. The first International Rice Yield Nursery, with 34 entries nominated by 13 countries and IRRI, was distributed to 16 countries in Asia, Africa, and Latin America.

IRRI agronomists developed herbicide trials and distributed herbicides for 142 experiments in 15 Asian countries. The experiments were conducted under transplanted, direct-seeded, flooded, and upland conditions. We also sent herbicides to the West Africa Rice Development Association (WARDA) for trials.

IRRI-designed machines were evaluated in India, Indonesia, Korea, Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam. The machines included the drum thresher, the table thresher, the single hopper seeder, the multi-hopper seeder, the grain cleaner, the power tiller, the bellows pump, and the batch drier.

Regional projects

A regional project for the collection and preservation of rice germ plasm in South and Southeast Asia was continued. IRRI staff members participated in field collection programs in Bangladesh, Burma, Indonesia, and the Khmer Republic. More than 3,000 rice samples were collected.

The agricultural economics department coordinated a regional study of the changes in production, farm income, and employment that have followed the introduction of modern rice varieties. Twenty-five social scientists in six countries participated in the project.

IRRI continued to cooperate in regional rice research with the International Institute of Tropical Agriculture (IITA) and WARDA in Africa, and with the Centro Internacional de Agricultura Tropical (CIAT) in South America.

Outreach service

Through our outreach programs, IRRI cooperated with or directly assisted rice improvement programs in developing countries by supplying improved genetic material, training rice scientists, exchanging visits and information, and providing scientists to work in national programs. For example, IRRI sent 7,600 seed packets of promising selections to 45 different countries. In 1973, six IRRI lines were named as varieties in these countries.

Our 11 cooperative country projects are intensified efforts to assist national programs in seven countries: Bangladesh, Egypt, India, Indonesia, Philippines, Sri Lanka, and Vietnam. Twenty senior IRRI scientists lived in these countries and worked together with local scientists as members of national teams to solve local problems. The 1973 budget for these projects was almost two million dollars. Besides the resident scientists, the country projects provided funds for the services of short-term consultants, the training of local scientists, and the supply of essential equipment and library books. We are not reporting this work in detail in our annual report because IRRI's international staff members are integral parts of the respective national programs. Following is a brief and general review of national programs in which IRRI scientists participate and of the status of cooperative country projects.

Bangladesh. The Ford Foundation grant which provided one IRRI scientist to work with the Bangladesh Rice Research Institute (BRRI) terminated in June, 1973. The project had been thoroughly reviewed in late 1972 and early 1973. Senior IRRI administrators visited and consulted with the Bangladesh Ministry of Agriculture several times and jointly identified major constraints to progress in rice research. The most significant steps to remove these constraints included the establishment of the BRRI as an autonomous organization by an act of the Parliament, and the appointment of the BRRI director on a regular and long-term basis. IRRI will increase its involvement in Bangladesh. A new Ford Foundation grant approved in June, 1973, provides for three IRRI scientists (an entomologist, an agricultural engineer, and a rice production specialist) to work with BRRI. The entomologist, who is also team leader, has already been appointed. A program of training scientists both at IRRI and in U.S. has been initiated. A USAID grant has provided additional funds for training.

The government of Bangladesh is fully supporting BRRI. It provided additional funds to establish a rice production training program and to expand its research.

BRRI released a new rice variety, BRRI-3, which combines high yield potential with early maturity. It is adapted to all three of Bangladesh's rice seasons. A pilot project area of 15,000 hectares was designated to demonstrate and test new rice varieties and to accelerate the adoption of new technology. Extension methodologies developed by IRRI in its applied research and pilot extension programs in the Philippines will be tested in Bangladesh.

Because of rapidly increasing population pressures and the limited amount of land available for rice cultivation, local rice research programs must be strengthened if Bangladesh is to become self-sufficient in rice. BRRI recognized the need to develop long-range research plans to help the nation meet its rice production goals. The decision to establish a joint IRRI-BRRI study team to prepare long-range research plans and to identify research priorities was highly significant. The team will start working in January, 1974.

Egypt. Under an agreement with the Ford Foundation, IRRI has provided a project specialist to work with the Arid Lands Agricultural Development Program in Egypt. He and local rice scientists continued to evaluate the potential of growing IRRI selections with long and slender grains in Egypt, where past commercial production has been confined to japonica varieties with short and bold grains. IR22 was commercially grown on a limited area. Its dissemination will remain restricted primarily because of its prolonged growth duration and sensitivity to low temperatures at flowering. The performance of IR579-48-1 was very encouraging. It has the potential for widespread use for commercial production in Egypt.

Designation	Days to flowering	Yield (t/ha)*
IR22	130	6.0
IR24	124	5.9
IR579-48-1	114	7.4
IR1561-228-3	115	7.4
Nahda (local)	119	7.1

*average of 3 replications

In agronomic experiments, optimum cultural practices were identified for selected IRRI lines under Egyptian conditions. Preliminary data indicated that the date of sowing greatly influences their performance. When planted early, both IR22 and IR579-48-1 markedly increased yields over the standard local variety, Nahda.

Designation	Yield (t/ha)			
	Seeded Apr. 20	Seeded May 5	Seeded May 20	Seeded June 5
IR22	7.5	6.3	5.7	4.5
IR579-48-1	8.3	7.1	5.7	5.4
Nahda	5.5	5.7	6.7	5.9

As labor costs rise and as cotton increasingly competes with rice, farmers will shift from transplanting to direct seeding. This will be particularly true for indica selections with long grains which must be planted early to get high yields. Several herbicides were evaluated for direct-seeded rice in cooperative experiments. Benthiocarb and butachlor provided excellent weed control in drilled rice. Butachlor was also found equally effective for weed control in broadcast rice.

New breeding materials have been developed in the cooperative project. About 200 crosses were made, which will be grown at IRRI during the 1973–74 winter season. Selections from F_2 populations in Egypt are being grown in Sudan during the winter season to advance a generation.

India. The USAID contract which supported several IRRI scientists in India was gradually phased out during 1973. A Rockefeller Foundation scientist assigned to the All-India Coordinated Rice Improvement Project (AICRIP), however, will continue to be the IRRI representative in India. An agreement for continuing cooperation between AICRIP and IRRI is being considered for approval by concerned Indian government agencies. AICRIP has developed strong capabilities and leadership in rice research; collaboration between the two organizations is mutually beneficial. When the agreement is approved, IRRI and AICRIP will develop and implement joint research projects.

Despite the 1972 setback in production because of drought, the area planted to high-yielding varieties in India continued to expand. During the 1972–73 dry season, about 80 percent of the rice in several states was in new varieties. The proportion planted to them in the monsoon season, however, was much lower. The new varieties are now planted on 25 percent of India's rice area.

AICRIP continued its coordinated varietal yield trials and has included several hundred new selections in observational nurseries. These selections were screened without chemical protection and under various stresses at many locations to rapidly identify lines adapted to broad ranges of ecological conditions.

Two fine-grain varieties from AICRIP, Sona and Jayanti, were released. At the time of release, these varieties covered 120,000 hectares, mostly in Andhra Pradesh and Punjab. Research pathologists and entomologists have cooperated in breeding programs to develop new selections with high levels of resistance to bacterial blight and gall midge. Those which performed well during 1973 will move into extensive yield evaluation trials.

New varieties and technologies have increased the need for coordination of research and extension activities. The AICRIP headquarters will extend its area of responsibility to include a facility to provide training and current information on varieties and production practices to extension workers and organizations. The Indian Council of Agricultural Research is providing staff and capital support for this facility; Ford Foundation is providing substantial financial support.

Indonesia. The chief objective of IRRI's Indonesia program is to develop a coordinated rice research program which uses limited manpower and facilities more efficiently. One of our major goals remains to assist in the development and strengthening of the National Rice Research Program (NRRP). The foreign donors that contribute to rice research in Indonesia look to this coordinating body for guidance in determining how to best allocate their assistance.

Through a Ford Foundation grant, an IRRI scientist continued to work as joint coordinator of the NRRP. Although the NRRP was established in 1971, its first full-time local coordinator was appointed only in September, 1973. The IRRI joint coordinator spent most of his time supervising other IRRI projects in Indonesia. But with the appointment of the local coordinator, we expect NRRP to become fully effective in planning and coordinating rice research on a nationwide basis.

Under the USAID/IRRI contract, five scientists (a rice breeder, a rice agronomist, a statistician, a legume breeder, and a multiple cropping agronomist) are stationed at the Central Research Institute for Agriculture (CRIA) at Bogor. They worked closely with local counterparts to develop long-term research objectives and yearly work plans.

Tungro virus reached an epidemic level in South Sulawesi. The rice breeder organized a tungro testing and screening program with the objective of releasing a variety which is resistant to the disease. About 2,000 lines have been tested; several lines which appear resistant also seem to be acceptable to Indonesian farmers. Breeding lines were also screened for reactions to grassy stunt virus and bacterial blight. Spikelet sterility, caused by low temperatures and possibly other factors, has caused concern. Breeding lines are now being screened in low-temperature areas.

The rice agronomist helped carry out experiments on varieties, fertility levels, and cultural practices. One such experiment was designed to determine the effects of four water management regimes, three nitrogen rates, two nitrogen sources, and two times of nitrogen application. Continuously flooded rice yielded higher than did rotational or intermittently irrigated rice. Plots fertilized at 120 kg/ha N yielded 116 percent more than did the unfertilized check. Sulfur-coated urea, a slow-release nitrogen source, increased yields by 128 percent over the check when applied at transplanting. It yielded 9 percent more than urea applied at the same rate but split into three equal doses.

The legume breeder introduced new genetic material from various sources. Over 2,000 mung bean lines were introduced; 11 promising lines have been included in a preliminary yield trial. Of the 60 peanut selections introduced, some are moderately resistant to rust. Others have seed dormancy, high yield capacity, and resistance to leaf spot. Forty soybean varieties were introduced for disease and insect resistance, high yielding capacity, and other desirable agronomic characteristics. Some of the introductions yielded substantially higher than the local varieties. Several are resistant to the bean shoot fly, either because of non-preference by insects or host tolerance. More than 1,000 cassava and sweet potato lines were introduced for preliminary screening.

Multiple cropping field experiments were conducted to study mixed cropping, intercropping, and sequential planting under controlled conditions of high and low management. In one experiment, the effect of interplanting legumes and sweet potatoes on the yields of corn was studied. The data confirm results from IRRI that legumes planted in corn do not significantly reduce the yield of corn but simply add to the total grain yield and profit. About 100 participants, mostly from the Directorate of Agriculture, attended a workshop to stimulate interest in and coordination of multiple cropping, and to plan research and extensive activities.

The National Rice Research Program in Indonesia can be strengthened by the development of regional research stations. The institute helped to improve experiment station facilities and to develop research programs at two regional stations.

Under a Dutch grant, an agronomist (designated as research administration specialist) and a station development engineer worked at Maros for the second year. IRRI helped develop improved laboratory, office, greenhouse, and field facilities at Maros. The national and provincial governments provided funds, although grant funds were used to purchase some equipment. After the main laboratory and office buildings were completed in August, the research staff moved to Maros and began their rice and multiple cropping research programs. About 70 tungro-resistant rice selections were planted in preliminary yield trials for further evaluation.

Under a contract with the government of Indonesia, IRRI helped strengthen research at the Sukamandi branch station of the Central Research Institute for Agriculture. Although the major emphasis will be on rice, research will also be directed to corn and soybeans. IRRI will provide five senior scientists. The IRRI team leader, who is also corn breeder, joined in June. He has introduced promising genetic material of corn and has begun a breeding program for higher yields. The IRRI farm superintendent assisted in designing and developing land for experimental plots.

Trained scientists are acutely scarce in Indonesia. One objective of stationing several IRRI scientists in the country is to relieve promising young scientists for training abroad. Several Indonesians are now receiving training in U.S. and at IRRI. An IRRI consultant spent 6 weeks in Indonesia and prepared a report on the trained manpower requirements of the NRRP for the next 5 to 10 years. On the entire rice research staff at CRIA and its regional stations and sub-stations, only three scientists have Ph.D. degrees and nine have M.S. degrees. The report specifically recommended a long-range plan for training Indonesian scientists in different disciplines to staff research centers.

Philippines. Under a contract with USAID, an IRRI crop production specialist has worked with the National Food and Agriculture Council (NFAC) since August, 1972. Working through an NFAC-sponsored interagency project called the Unified Rice Applied Research, Training, and Information Project (URARTIP), he assisted NFAC to incorporate research results from IRRI and other agencies into national production programs.

An interagency rice production program called "Masagana 99" (bountiful harvest) was highly successful in 1973. It involved the use of high-yielding varieties which were resistant to tungro (especially IR20), supervised farm credit, a fixed minimum support price to the farmer, and the use of recommended rates of fertilizers and insecticides. The demand for agricultural inputs greatly exceeded the available supplies. A record rice harvest, 35 percent higher than last year's, 12 percent higher than the previous best harvest of 1970–71, is estimated for 1973.

Ten thousand minikits were distributed to farmers by 3,000 extension workers as sample packs of modern technology. Each kit contained seeds of promising new rices and recommended inputs. When Laguna province was seriously infested with brown planthoppers, 2,200 1-kg seed-increase kits of resistant IR26 were distributed to farmers. Cooperative insecticide and fertilizer research trials, featuring promising rice selections, were established on 85 farm locations.

Sri Lanka. Two IRRI specialists are working with two cooperative projects in Sri Lanka: one on production aspects of rice and multiple cropping, and another on rice processing.

The rice and multiple cropping project continued to emphasize the training of extension workers and to encourage the coordination of research. The Department of Agriculture appointed a scientist as multiple cropping coordinator; he will work closely with the IRRI scientist. Sri Lanka's multiple cropping program organized a 2-month training course for 16 Indonesian officials at the Dry Zone Agricultural Center, Maha-Illuppallama.

BG11, BG34-6, and BG34-8, newly released rice varieties which were bred in Sri Lanka, are spreading rapidly. They are now grown on about 35 percent of the total rice area. Some of the most interesting and potentially useful rice research relates to genetic resistance to hostile environments, such as iron toxicity, drought, and salinity. The project attempted to bring about coordination of these studies.

Soybean and corn received special attention in the multiple cropping system. The project assisted with seed multiplication and with the distribution of production kits to accelerate the spread of improved soybean and corn varieties. As in previous years, rice production kits were also distributed.

IRRI's rice processing specialist worked closely with the Paddy Marketing Board of Sri Lanka. He specifically helped design the new storage and processing complexes and training program facilities, and helped develop the specifications for grades of paddy and milled rice. Each of the four new storage and processing complexes under construction will have a modern rice mill with a 2 t/h capacity, with supporting parboiling and storage facilities. The training center started operating about the end of the year. Managers, engineers, technicians, and operators of rice mills are being trained in modern paddy drying, storage, parboiling, and milling. Five engineers and two storage superintendents were sent abroad for training. They have returned and are now assisting in the overall development of the country program. A management training program was also developed for the PMB staff. The IRRI specialist helped improve the private milling sector. He worked with local manufacturers to stimulate the local production of modern equipment.

Vietnam. Under a USAID contract, two IRRI scientists worked with the Institute of Agricultural Research (IAR) for the second year. They helped conduct varietal yield trials, fertilizer trials, and herbicide and insecticide screening trials at four locations in South Vietnam. In September, the IRRI contract was renewed for an additional year, and additional funds were provided for another scientist in multiple cropping.

Two IRRI lines, IR1529-680-3 and IR1561-228-3, performed better than IR20, which is now the most extensively grown variety in Vietnam. The Ministry of Agriculture released both IRRI lines for general cultivation. IR1529 was named Than Nong 73-1 (TN73-1) and IR1561, TN73-2. Eight of the most promising IRRI lines from preliminary tests at IAR experiment stations during the 1972-73 dry season were entered in cooperative trials at the Rice Service, Extension Service, and University of Cantho experiment stations during the 1973 wet season.

Until November, 1973, only three Vietnamese college graduates (B.S. level) worked full time on rice research. The shortage of trained manpower limited the types and numbers of experiments. By the end of 1973, however, the Ministry of Agriculture began to intensify rice research and assigned five more technicians to the rice program. A joint IRRI-Vietnam study team determined rice research needs in Vietnam and the extent of assistance from IRRI or other agencies needed to meet these needs. The team recommended that high priority be given to adequate coordination of national rice research, and to identification of strong local scientific leadership to guide the program. The report pointed out the real potential for research to improve deep-water rice. The report, now being considered by the Vietnamese Ministry of Agriculture and the IRRI administration, will be the basis for strengthening the cooperative project.

INTERNATIONAL CONFERENCES.

Seventy-five rice scientists from 20 countries attended the International Rice Research Conference from April 23 to 27. After a brief review of the general IRRI program, the participants concentrated on recent research in pathology, soils, and agronomy. Fifty-five papers were presented by scientists from national programs and IRRI. A significant achievement of the conference was a general recognition of the need for more cooperative nurseries to identify broad-spectrum resistance to diseases and insects and for more field trials to screen promising genetic lines and to evaluate herbicides.

"The expert group meeting on the design and manufacture of wetland rice mechanization, harvesting, and threshing machinery in developing countries of Asia and the Far East region" was held at IRRI from March 12 to 17. It was jointly organized and sponsored by the United Nations Industrial Development Organization (UNIDO) and IRRI. Of the 78 participants, 59 were from 14 developing countries, 8 from industrialized countries, and 11 from international organizations. The participants explored ways to promote local manufacture of machinery for rice production in the developing countries of Asia. Fifteen technical papers were presented and discussed.

Information resources and experimental farm

Library and documentation center

International Bibliography. The 1972 Supplement to the *International Bibliography of Rice Research* was published in 1973. It contains 2,974 references to scientific rice literature, most of which appeared in journals in 1972. An additional 21 serial titles were scanned and searched in the compilation. The 1972 supplement has worldwide coverage and the citations are classified according to subject matter. The 295 pages include an author index, a manually produced keyword index, and a list of 60 rice literature translations, mostly from Japanese to English.

Reference and circulation. We received numerous requests for information and photocopying services from outside IRRI. Requests for Japanese literature on genetics and breeding outranked requests for literature on all other aspects of rice culture. Most of the requests came from India, Burma, and Malaysia. Our assistance was also sought on library organization and management, selection and acquisition of agricultural materials, and the processing of special materials such as microfilm, maps, and pamphlets. A few requests were for short bibliographies on specific subjects.

Within IRRI, the number of books and journals borrowed markedly increased: from 28,900 in 1972 to 31,297 in 1973. These figures do not include books and journals used in the library.

Library holdings. More than 2,200 books, pamphlets, and reprints were added to the library, bringing the total collection of monographs to 33,500. Over 100 serial titles were added during the year. Maps, translations, and microfilms were also added to the collection.

Other library activities. We continued to circulate photocopies of tables of contents of newly received journals. This service resulted in requests for loans of these journals and for photocopies of articles appearing in them.

We also continued the monthly listing of books, translations, reprints, and new serial titles to notify the Institute staff about the availability of new information relative to their fields of specialization and interests.

We sent copies of translations of foreign-language rice literature regularly to the National Agricultural Library, U.S. Department of Agriculture, where they are eventually listed in the Bibliography of Agriculture for the information of rice scientists.

Information services

More than 120,000 copies of *Field problems of tropical rice* in four languages were distributed during the year. In addition, 17,000 copies of other publications were distributed. Most publications go to rice scientists and libraries in Asia.

A Bengali edition of *Field problems* came off the press this year. The World Council of Churches purchased 99,000 copies for distribution in Bangladesh. In addition, a Tagalog translation was printed for the first time. *Field problems* was first printed in 1971. More than 195,000 copies are now in print in English, Vietnamese, Indonesian, Bengali, and Tagalog.

We published a four-color leaflet describing IRRI's activities and a new booklet explaining IRRI's training program. Two new research publications were also issued: *Techniques for field experiments with rice* and *A handbook of rice diseases in the tropics.*

Publications on upland rice research at IRRI and changes in rice farming in Asian villages are being processed.

The visitor's guide gave tours and explained IRRI's activities to nearly 14,000 visitors.

Experimental farm

In the wet season, we planted 7.8 hectares of the lines IR1541-76-3, IR1541-102-7, and IR1561-228-3 for seed production. IR1541-76-3 was badly damaged by tungro and grassy stunt diseases, so we plowed under several plots. The grain harvested from the remainder of this crop was milled. IR1541-102-7, on the other hand, performed quite well. The seeds that it produced were distributed for seed multiplication to the Philippine Bureau of Plant Industry, to the Bureau of Soils, to about 2,000 Laguna province farmers, to seed growers in Central Luzon and Leyte, and to the Unified Rice Applied Research Training and Information Project.

In the dry season, from March to June, we planted 5.8 hectares to IR1529-680-3, IR841, IR1480-116-3, IR443-2-58, IR1514A-E66, and IR1721-1-6. The selection IR1541-102-7 was named a new variety, IR26, so we planted it and IR1514A-E597 in farmers' field outside the IRRI farm for seed production. We also planted about a hectare to the selection at the IRRI farm. We are presently multiplying two other varieties or selections from Korea, Milyang 16 and S242, on 1.5 hectares.

The low yields of selections planted during both the wet and the dry seasons were caused mainly by outbreaks of tungro and grassy stunt. Leafhopper infestation was widespread not only on the IRRI farm, but also all over Laguna province. Many neighboring farms were heavily infested and plowed under. Since most of the farmers in these areas ran out of planting seeds, IRRI gave them seeds of IR1561-228-3. Because the crop yielded well, most farms near IRRI are now planted to this line.

When hopper infestation was heavy at the IRRI farm, insecticide was sprayed twice a week instead of once every 2 weeks. Some departments not only increased the frequency, but also doubled the rate of application. Carbofuran, MIPC, lindane, and monocrotophos were the most commonly used chemicals.

We used more ammonium sulfate and urea and less solophos and muriate of potash this year. As in previous years, 2,4-D granules and benthiocarb were used to control weeds in the experiment and production plots. Paraquat was used mainly on the levees and roadways.

This year we stopped using animal power for land preparation. We succeeded in preparing even the deep areas of the farm, where tractors previously failed, with our hand tractor by installing tubes inside its cage wheels for floatation.

We constructed bridges over the concrete culverts along the drainage ditches of every other plot at the IRRI farm to make all plots easily accessible. A big levee was built along the creek passing through one of the upland areas to protect the seedbed area of the plant breeding department from floods during typhoons.

A small seed processing room now stands adjacent to our seed cleaners. In it, seeds of promising IRRI selections and varieties are processed after drying. The LSU-type seed drier, constructed by experimental farm staff, will be in operation next harvest season. Screw conveyors built by institute mechanics greatly facilitate the unloading of dried rice from our flat bed dryers.

To conserve fuel, we converted two gasoline Vogel threshers into electrical-powered ones.

We controlled rats by poison baiting and by dusting rat burrows with cyanogas. The Rodent Research Center cooperated with us in setting up baiting stations around the farm and in changing the bait weekly. We also provided owners of neighboring farms with poisoned bait whenever rat infestation was heavy.

The farm superintendent went to Indonesia twice to help in the land development and in determination of the farm machinery and equipment needs of the Sukamandi Rice Experiment Station.

Publications and Seminars

Publications

Administration

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SEMINARS

The following topics were the subjects of seminars held at the institute during 1973. Unless otherwise stated the speakers were staff members.

Masagana 99 pilot extension program. Mr. Peter Smith, general manager, Shell Chemical Co., Makati, Rizal; Mr. Inocencio C. Bolo, assistant rice production specialist, IRRI; Atty. Ciriaco Santos, Rural Bank, Pandi, Bulacan; and Mr. Renato Capinpin, agricultural chemicals manager, Shell Chemical Co., Makati, Rizal.

IRRI's international program. Dr. Athwal.

The control of vampire bats in Central and South America. Dr. Dan Thompson, animal physiologist, Wildlife Research Center, Denver, Colorado, U.S.A.

Fertilizer industry of the Philippines. Dr. Jorge G. Davide, manager, Technical Services, Planters Products, Makati, Rizal.

The organization and operations of PCAR. Dr. Joseph C. Madamba, director-general, Philippine Council of Agricultural Research.

The operations of the Department of Local Government and Community Development. Dr. Orlando Sacay, undersecretary for cooperatives, Department of Local Government and Community Development.

The rice specialist goes to manage a commercial rice farm. Mr. Florencio Macapugay, farm manager.

NFAC's role in agricultural development with special reference to the presidential regional offices for development. Mr. Domingo Panganiban, deputy executive director, National Food and Agriculture Council.

The operations of the National Grains Authority. Mr. Jesus Tanchanco, administrator, National Grains Authority.

Communications in development. Dr. Thomas G. Flores, director, socio-economic research division, Philippine Council of Agricultural Research.

The land reform program of the Philippine Government. Mr. Benjamin Lebayen, assistant secretary, Department of Agrarian Reform.

The Philippine fruit industry. Dr. Ramon Valmayor, associate professor, department of agronomy, UPLB.

Rice milling in the Philippines. Mr. Harry van Ruiten, United Nations Food and Agriculture Organization rice milling consultant.

Spring review for small farmer credit. Dr. Dana Dalrymple, agricultural economist, U.S. Agency for International Development, Washington.

Panel discussion on integrated planning for the Bicol River project. Panel moderator: Dr. Ramon L. Nasol, chairman, department of agricultural economics, UPLB. Panel members: Mr. F. Umali, Department of Agriculture and Natural Resources; Mr. B. Gaon, UPLB; Mr. S. Pejo, Department of Agrarian Reform, Legaspi City; and Mr. J. del Rosario, National Irrigation Administration.

Farm equipment marketing in the Philippines. Mr. Edilberto Uichanco, vice president, marketing division, Gregorio Araneta Machineries, Inc., Quezon City.

Statistical program of the Asian Development Bank. Dr. Burton T. Oñate, chief statistician, Asian Development Bank.

Archaeological data on early rice in northern Thailand. Dr. Wilheim Gerhard Solheim, department of anthropology, University of Hawaii.

Outsiders can help, but insiders must do the work. Dr. R. W. Roskelly, head, Livelihood Department, International Institute for Rural Reconstruction, Cavite.

Cross-cultural relations and dimensions of influence. Dr. Obdulia Sison, professor of agricultural education, UPLB.

Public administration, an input in development. Dr. Raul P. de Guzman, dean, College of Public Administration, University of the Philippines.

The operations of the National Irrigation Administration. Mr. Cesar L. Tech, chief engineer, National Irrigation Administration.

The preparation of feasibility studies for agricultural projects, with special reference to methodology. Mr. Vicente R. Jayme, executive vice president, Private Development Corporation of the Philippines.

Program highlights—Rodent Research Center. Dr. Fernando Sanchez, head, Rodent Research Center, UPLB.

Engineering aspects and features of the IRRI phytotron. Mr. B. Gibbs, engineer, Commonwealth Scientific and Industrial Research Organization, Australia.

The interaction of irrigators and water authorities in irrigation systems. Dr. E. Walter Coward, Jr., research director, International Institute for Rural Reconstruction, Cavite.

Screening plants for aluminum tolerance, Dr. E. Ali, postdoctoral fellow, soil chemistry department, IRRI.

Phytotron, a new tool in rice research. Dr. S. Yoshida.

Philippine-German field rat control project. Mr. Juergen Schaefer, project manager, Philippine-German Field Rat Control Project.

Influence of mineral nutrition on the relationship between rhizosphere organisms and plants. Dr. Gunter Trolldenier, postdoctoral fellow, soil microbiology department, IRRI.

Integration of fodder crops with intensive cropping systems involving rice. Dr. Emil Q. Javier, associate professor of agronomy, UPLB.

Multidisciplinary approach to development. Dr. Abelardo G. Samonte, chancellor, UPLB.

Rice consumption in the Philippines. Dr. Lawrence B. Darrah, Ford Foundation, Philippines.

High protein food for children. Dr. Carmen Ll. Intengan, assistant research director, Food Nutrition Research Center, National Science Development Board.

A blueprint for the college of sciences and humanities, UPLB. Dr. Edelwina C. Legaspi, dean, College of Sciences and Humanities, UPLB.

Activities and operations of the Rice Central Pilot Project in Pagsanjan, Laguna. Mr. Ed Agravante, manager, Rice Central Project, Borromeo Corporation.

The Cyanamid Agricultural Research Foundation, Inc. Dr. Feliciano B. Calora, director, Cyanamid Agricultural Research Foundation, Inc., Laguna.

Agriculture in South Sulawesi, Indonesia. Dr. Cezar P. Mamaril, resident research administration specialist, Lembaga Penelitian Pertanian Makassar—IRRI Project, Indonesia.

Crop improvement through plant cell and tissue culture. Dr. Emerita V. de Guzman, associate professor in physioculture, UPLB.

Technology and methodology in agricultural research. Mr. Yoshiaki Ishizuka, acting director, Food and Fertilizer Technology Center, Asian and South Pacific Council, Taiwan.

Rice farming in Santa Rosa, Laguna. Mr. Abel Silva, president, Seed Growers Association of the Philippines.

The polar transport of the plant hormone indoleacetic acid. Dr. Rollo de la Fuente, associate professor, department of botany, UPLB.

Use of systems analysis in biological research. Dr. Rudy Yaptenco, ESSO, Philippines.

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