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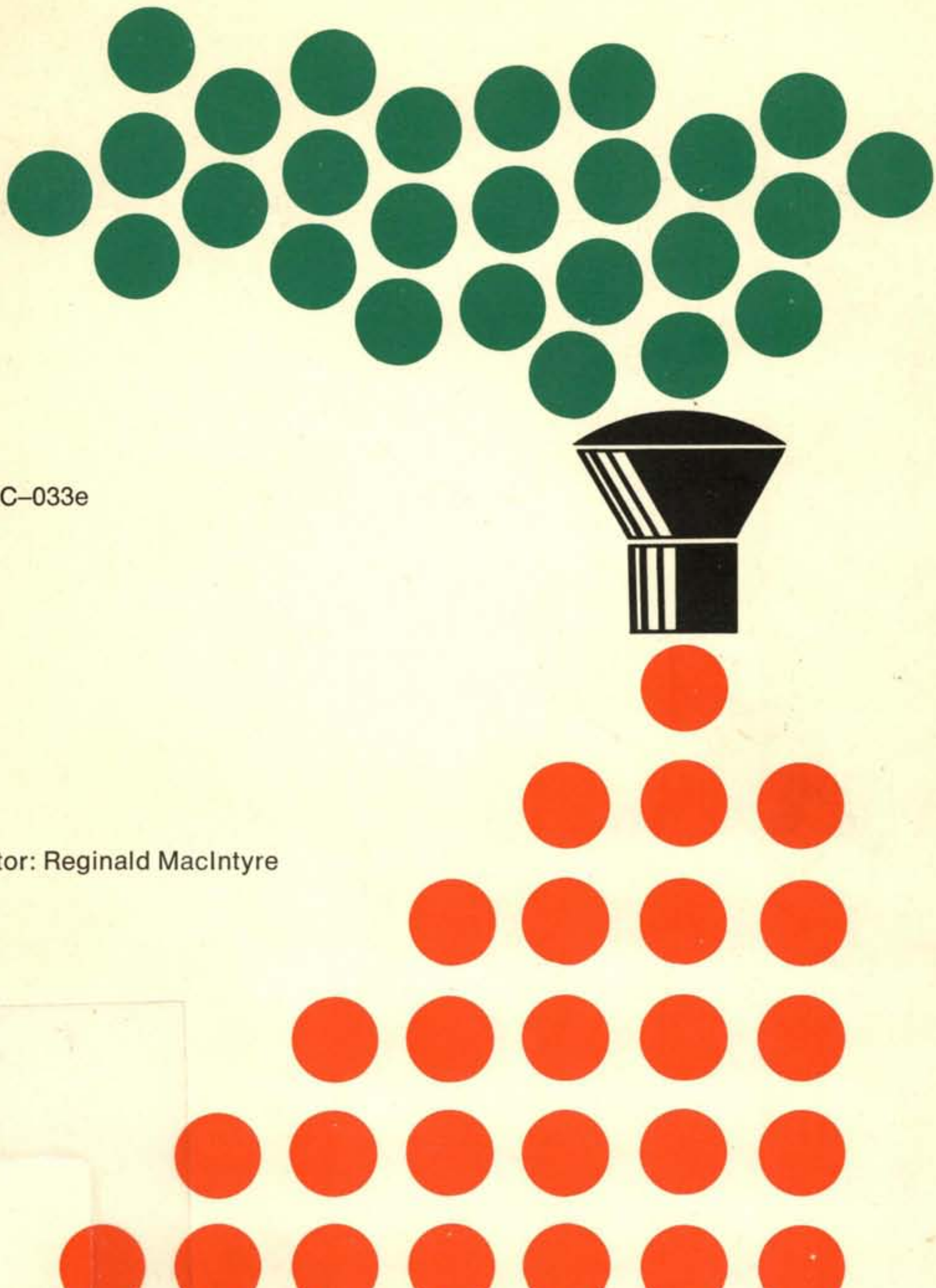
Singapore, 22-24 February 1974



IDRC–033e

Editor: Reginald MacIntyre

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Contents

Current Programs of the International Rice Research Institute

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Abstract IR8, the first variety named by the International Rice Research Institute (IRRI) represented a new plant type; it has a short and stiff straw, erect leaves, and the capacity to tiller heavily. Since the release of IR8 in 1966, a series of new varieties have been named: IR20, IR22, IR24, and IR26. These combine the IR8 plant type and its responsiveness to fertilizer with higher grain quality. IR26 is resistant to major diseases and insects. Twenty-six IRRI breeding lines have been named as local varieties and released for commercial cultivation by nations in Asia, Africa, and Latin America. Some countries have developed and released their own varieties through national breeding programs. Average yields in several countries are steadily rising as more farmers plant modern semi-dwarf varieties.

The modern varieties will reach their yield potentials only if farmers use improved cultural practices, including optimum application of fertilizer, water and weed control, and protection of crops from pests.

Nitrogen, phosphorus, and potassium (NPK) are the major nutrients used by rice. Other soil deficiencies, however, may greatly reduce the yield response to N, P, and K. IRRI scientists showed that rice grew poorly in certain areas, and did not respond to NPK, because of zinc deficiency. Fertilizer response is also dependent on good water control.

The payoff from good weed control increases sharply when farmers adopt high yielding varieties. The Institute identified several cheap herbicides for weed control. The low-cost herbicide 2, 4-D effectively controls weeds if applied 4 days after transplanting rice. Butachlor controls weeds in direct-seeded and upland rice.

IRRI has evaluated hundreds of insecticides. In early work, granular insecticides applied to paddy water were far more effective than foliar sprays. Recently, insecticides placed in the root zones proved even more effective than paddy water application. Engineers and entomologists are developing a practical method for root zone application.

Improved varieties and intensive cropping have increased the economic advantage of rice mechanization. The Institute engineering program emphasizes the design and development of machines for small-scale farmers. A simple power tiller was developed which can be easily fabricated in the developing countries. The Institute also designed and released other machines including the axial flow thresher, the batch drier, and the multihopper seeder.

The Institute is trying to determine exactly why yields are lower on farmers' fields than on experiment stations. Some constraints to production are environmental; others are due to poor management. Farmers can appreciably increase their yields by using a package of practices which includes fertilizer, water management, and pest and weed control. In one area in the Philippines, insect control alone accounted for two-thirds of the yield differences between recommended practices and farmers' actual practices.

Several production constraints can be removed or their adverse effects minimized through genetic improvement of varieties. Small-scale tropical farmers are generally unwilling to take risks and to invest in inputs. Scientists have identified varieties in the world collection that are resistant or tolerant to insects, diseases, drought, deep water, low temperatures, and adverse soil conditions. IRRI is currently concentrating research to develop varieties with built-in resistance to these adverse conditions in order to lower the costs and reduce the risks of producing high yields.

The Institute shares new information and material generated by its research with national rice programs. Through cooperative projects, the Institute helps national programs enhance their capacities for rice research.

Résumé La première variété de riz à laquelle l'Institut International de Recherches sur le Riz (IRRI) ait donné un nom, l'IR8, représente effectivement un nouveau type de ce végétal; il a une tige courte et solide, des feuilles érigées et possède des capacités de tallage élevées. Une série de nouvelles variétés a vu le jour depuis que l'IR8 a été mis en circulation en 1966: IR20, IR22, IR24 et IR26. Ces variétés combinent une meilleure qualité du grain aux caractères végétaux de l'IR8 et à ses facultés de réponse à la fumure. L'IR26 est résistant aux maladies et aux insectes principaux. L'IRRI a donné une appellation à 26 lignées sélectionnées à titre de variétés locales et mises en circulation pour la production commerciale en Asie, en Afrique et en Amérique latine. Un certain nombre de pays ont créé et ont mis en circulation des variétés qui leur sont propres et ce, grâce à des programmes nationaux de sélection. Dans plusieurs pays, les rendements moyens sont en augmentation constante du fait que les agriculteurs utilisent de plus en plus des variétés modernes demi-naines.

Les rendements potentiels de ces variétés modernes ne pourront être atteints que si les agriculteurs ont recours à des méthodes culturales meilleures: épandages d'engrais optimaux, désherbage, maîtrise de l'eau, protection des cultures contre les parasites.

Les principaux éléments nutritifs utilisés par le riz sont l'azote, le phosphore et la potasse (NPK), mais des carences du sol en d'autres éléments peuvent limiter dans une grande mesure les augmentations de rendement répondant à l'utilisation de N, P et K. Les spécialistes de l'IRRI ont démontré que le riz végétait fort mal dans certaines régions, et ne répondait pas à NPK et ce, du fait d'une carence en zinc. La réaction du riz à la fumure dépend également de la qualité de la maîtrise de l'eau.

Les bénéfices dus à un désherbage de bonne qualité augmentent nettement lorsque les exploitants adoptent des variétés à rendement élevé. L'Institut a identifié dans ce domaine plusieurs herbicides peu onéreux. Le 2.4-D, qui n'est pas coûteux, est un désherbant efficace si les épandages sont faits 4 jours après le repiquage. Le Butachlore convient bien aux semis en place et à la riziculture de montagne.

L'IRRI a égalément testé des centaines d'insecticides et a constaté que les insecticides granulaires épandus précocement dans les eaux de rizières étaient infiniment supérieurs aux pulvérisations foliaires. On a constaté récemment que l'épandage d'insecticides dans la zone des racines était encore plus efficace que l'épandage dans l'eau de rizière. Techniciens et entomologistes sont en voie de mettre au point une méthode pratique d'épandage dans la zone des racines.

L'amélioration des variétés et l'intensification du mode de culture ont accru les avantages économiques de la mécanisation de la riziculture. Le programme du génie rural de l'Institut s'est penché sur la conception et sur la mise au point de machines convenant à la petite exploitation. Il a permis de mettre au point un motocultivateur pouvant facilement être construit dans les pays en voie de développement. L'Institut a également conçu

et mis en circulation d'autres machines agricoles dont une batteuse à écoulement axial, un séchoir discontinu et un semoir à trémies multiples.

L'Institut tente de déterminer exactement pour quelles raisons les rendements des agriculteurs sont inférieurs à ceux des stations expérimentales. Un certain nombre des contraintes pesant sur la production sont d'ordre écologique, d'autres sont dues au manque de qualité des gestionnaires des exploitations agricoles. Les agriculteurs ont la possibilité d'accroître considérablement leurs rendements en mettant en oeuvre un ensemble de techniques dont l'emploi d'engrais, l'utilisation rationnelle de l'eau et la lutte contre les parasites et les adventices. Dans une région des Philippines, les traitements antiparasitaires ont donné lieu à eux seuls aux deux tiers des augmentations de rendements dues à l'emploi des techniques recommandées de préférence aux méthodes traditionnelles.

Il est possible de se libérer de plusieurs de ces contraintes de la production ou d'en minimiser les effets et ce, grâce à l'amélioration génétique des variétés. Les petits agriculteurs des tropiques sont en général très réticents lorsqu'il s'agit de prendre des risques ou d'investir dans des facteurs de production. Les spécialistes ont identifié, parmi le matériel génétique mondial, des variétés résistantes ou tolérantes aux insectes, aux maladies, à la sécheresse, aux excès d'eau, aux basses températures et à la mauvaise qualité des sols. L'IRRI concentre actuellement ses recherches sur la création de variétés autorésistantes à ces conditions défavorables et ce, afin d'abaisser les coûts et de réduire les risques inhérents aux rendements élevés.

L'Institut fait bénéficier les programmes nationaux des renseignements et du matériel végétal nouveaux émanant de ses recherches ayant trait à des programmes nationaux sur le riz. Grâce à des projets communs, il permet aux programmes nationaux de développer leurs moyens sur le plan des recherches consacrées au riz.

RICE yields are low in tropical Asia, where more than 70% of the world's rice is grown and consumed. Although several Asian nations have conducted research on rice since the beginning of this century, improvements in yields of traditional varieties were only marginal. In fact, high-yielding varieties offered little advantage in traditional rice culture, in which little or no fertilizer was used. During the same period, however, Japan and other temperate countries had markedly increased national yields through the combined use of high-yielding varieties, fertilizers, and other inputs.

During the last two decades rice-growing nations have recognized that available land in Asia for extending rice cultivation is limited, so much of the additional rice required must be obtained by increasing yields per unit area. Some national programs started the development of varieties that respond well to fertilizer and are resistant to lodging (falling over). In 1962, the International Rice Research Institute began concentrated research to develop new rice varieties and the associated technology to increase yields. I will only talk about research oriented to major rice production problems, significant contributions that have already been made, and the current emphasis to overcome constraints to increased productivity on farmers' fields. I will primarily deal with results obtained by IRRI scientists, but I will also refer to cooperative work in different countries.

Modern Rice Varieties

The traditional tropical varieties of rice are tall and leafy. Their yielding capacity is limited because when fertilized, they grow excessively tall and fall over. The Japanese rice breeders developed fertilizer-responsive varieties that are relatively short, have stiff straws, and narrow, erect leaves. The "japonica" or temperate zone varieties, are not generally adapted to the tropics.

The first semi-dwarf fertilizer-responsive "indicata", or tropical rice variety, Taichung Native 1, was developed in 1956 in Taiwan. But Taichung Native 1 was not fully evaluated in other rice-growing countries nor were its merits as a variety responsive to fertilizer clearly recognized outside Taiwan, until 1962 when IRRI began to critically test this variety.

In 1964, trials at the Institute showed Taichung Native 1 to be one of the highest yielding varieties. Taichung Native 1 was grown commercially in India beginning in 1966 but it attracted little attention in other countries, primarily because it was susceptible to diseases.

The Institute's breeding program started with the clear objective of developing tropical varieties with improved plant type that would make efficient use of soil nutrients, solar radiation, and other inputs. Taichung Native 1 and two other semi-dwarfs from Taiwan were crossed with tropical varieties; less than 4 years later, in 1966, the Institute named its first semi-dwarf variety, IR8. The new rice was an improvement over Taichung Native 1 not only because it was more responsive to applied nitrogen (Fig. 1) but also because it was more resistant to diseases. IR8 rapidly spread throughout Asia, particularly in India, Pakistan, the Philippines, Bangladesh, and Vietnam (Athwal 1971).

IR8 represented a new plant type with short and stiff straw, erect leaves, and capacity to tiller heavily. This plant type essentially doubled the yield potential of the rice plant. IR8 was also non-sensitive to daylength, so it could be grown at any time of the year. IR8 was deficient, however, in grain quality. Its grains are bold and chalky. They cook dry and fluffy. Although people in the Indian subcontinent prefer rice which cooks dry, those in the Philippines, Indonesia, and some other countries prefer rice which has a soft texture. Another variety, IR5, was named in 1967. Its grain quality is similar to that of IR8.

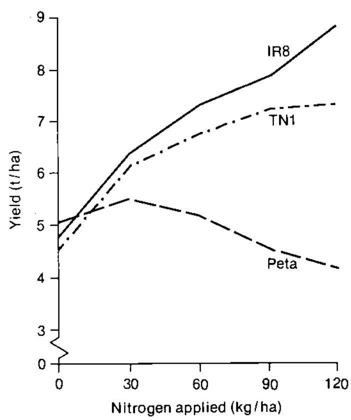

FIG. 1. Effect of plant type on nitrogen response (3-yr dry season average).

After demonstrating that rice varieties with high yield potential can be developed for the tropics, the Institute concentrated on improving the grain quality. Since then, a series of new varieties have been released which combine the high yield potential of IR8 with good grain quality. Grains which are long or medium-long, slender, clear, and transluscent are preferred by consumers in tropical Asia. The cooking quality of rice depends primarily on the amylose content of the grain. Rices with low and intermediate amylose content are soft-textured on cooking, but those with high amylose content cook dry and fluffy. All of the new varieties, IR20, IR22, IR24, have clear, transluscent and attractive grains; IR20 and IR22 have high amylose content whereas IR24 has low amylose content. The grains of IR20 are medium-long and slender, whereas those of IR22 and IR24 are long and slender.

Although IR22 and IR24 have high yield potential and excellent grain quality, farmers' acceptance has been limited because they are susceptible to some diseases and insects. On the other hand, IR20, which has a somewhat lower yield potential but a broad spectrum of disease and insect resistance, rapidly spread to many new countries. Today it is the most popular variety in the Philippines, South Vietnam, and Bangladesh. This demonstrates that disease and insect resistance is an indispensable characteristic which must be incorporated in new varieties to ensure their widespread dissemination.

In November 1973, the Institute named a new variety, IR26, (IRRI 1974). IR26 is resistant or moderately resistant to the major insects and diseases of rice in tropical Asia (Table 1). This resistance should be especially helpful to farmers who cannot buy extra pesticides to combat outbreaks of insects. IR26 is resistant to brown planthoppers and green leafhoppers, and moderately resistant to stem borers. IR26 is the first IRRI variety to be highly resistant to the brown planthopper, which causes severe damage in the Philippines,

TABLE 1. Reactions of IRRI varieties to major diseases and insects.

Variety	Blast	Bacterial blight	Bacterial streak	Grassy stunt	Tungro	Green leaf-hopper	Brown plant-hopper	Stem borer
IR8	MR[a]	S	S	S	S	R	S	MS
IR5	S	S	MS	S	S	R	S	S
IR20	MR	R	MR	S	R	R	S	MS
IR22	S	R	MS	S	S	S	S	S
IR24	S	S	MR	S	MR	R	S	S
IR26	MR	R	MR	MR	R	R	R	MR

[a]R, resistant; MR, moderately resistant; S, susceptible.

South Vietnam, India, and Sri Lanka. It is also resistant to tungro and bacterial blight, widespread diseases in Asia. It is moderately resistant to grassy stunt virus and rice blast diseases. IR26 has a slightly higher yield potential than IR20 because of its stronger stems, which resist lodging. Its grains are clear, slender, and medium in length, comparable to those of IR20. For tropical Asian tastes, its eating quality should be slightly better than that of IR20 and substantially better than that of IR8.

The new semi-dwarf varieties, with modern management practices, have consistently achieved yield levels very much higher than those of traditional and tall varieties. The IRRI varieties have been accepted over wide areas in several countries. But even more important has been the introduction into national research programs of genetic material with improved characteristics. Since 1965, the Institute has supplied 80,000 seed packets of improved genetic lines to more than 100 rice-growing countries and territories. To date, at least 26 of the IRRI lines have been released for commercial cultivation in Asia, Africa, and Latin America. National programs in India, Indonesia, Sri Lanka, Philippines, and Bangladesh have also developed and released their own semi-dwarf varieties for cultivation.

In 1971–72, an estimated 12 million or more hectares in tropical countries of South and Southeast Asia (15% of the total rice area) were planted to modern rice varieties. About 0.6 million hectares out of the total rice area of 6.5 million hectares in Latin America are planted to varieties developed from the genetic material supplied by IRRI. Average rice yields in several Asian countries are now rising.

Country	Yield (*kg/ha, approx.*)	
	1961–64	1971
Pakistan	1400	2400
India	1520	1710
Indonesia	1800	2200
Philippines	1240	1720
South Vietnam	1860	2280

A large part of the yield increases can be attributed to the cultivation of modern rice varieties and the use of fertilizers. The adoption of new varieties and the associated technology must, however, be greatly increased to have a real impact on production.

The cereal protein of rice is of good quality because it has a relatively high lysine content (4%). But rice has a low level of protein. The protein content of milled rice averages about 7%. Increasing the protein content of modern varieties is a major objective of the Institute's varietal development program. The protein content is markedly influenced by environment, but Institute scientists have gathered evidence to indicate that the protein content of high-yielding varieties can be genetically increased by at least one-fourth. If high protein varieties are to be accepted by farmers, however, they must yield as well as the ones they would replace, and should be equally acceptable to consumers. Studies on the nutritive values of rices with varying protein contents have shown that the net utilization of protein increases as protein content in milled rice increases, up to 10% protein. An increase in the protein content of the rice grain would not adversely affect its cooking and eating qualities. IRRI scientists have identified an experimental line IR480-5-9, which combines the improved plant type with a protein content of 9-10%. It has not been released for commercial production (except in Fiji), however, because it is susceptible to some diseases and insects. Improved lines that have a protein content and yield potential comparable to IR480-5-9, and that also are resistant to several diseases and insects, are now undergoing preliminary evaluation.

Cultural Practices

Improved cultural practices must be used to enable the new varieties to express their full yield potential. Such practices as land preparation, time of planting, and spacing are generally well understood. Recent research has been concentrated on fertilizer application, water use, and weed control.

Nitrogen, phosphorus, and potassium (N, P, and K) are the major elements needed for plant growth. A crop of rice that yields 5 t/ha removes about 100 kg of N, 20 kg of P, and 120 kg of K from the soil. Most rice soils contain adequate potassium for crop growth; the potassium supply is continuously replenished in many soils by the incorporation of rice straw, and the use of irrigation water, which has a high potassium content. Nitrogen is the most important nutrient that limits rice production, although phosphorus must also be added in many areas. Long-term fertility experiments conducted by Institute agronomists indicate that soils that continuously receive nitrogen may become deficient in phosphorus as well as in potassium under intensive cropping.

Commercial fertilizers offer a large potential for increasing rice production in the developing countries. But fertilizers are costly, particularly since the world oil crisis has caused their scarcity. Current research in IRRI's soil chemistry and agronomy departments is focussing on increasing the efficiency of nitrogen utilization. Water management markedly influences the nutrient balance in the soil. Nitrogen is often lost through denitrification, particularly when flooded rice land dries during the growing season. We now know that continuous soil submergence minimizes denitrification. Under rainfed conditions or with poor water management, a split application of nitrogen has been found to be more beneficial than a basal application (IRRI 1974).

Plants may fail to respond to fertilizer in some soils because of a deficiency of micronutrients. Institute soil chemists found that zinc deficiency limits yields on thousands of hectares of alluvial soils in two provinces of the Philippines that are well supplied with major nutrients and water. Field experiments at six rice farms in this region showed that, in the absence of zinc application, NPK fertilizer either had no effect or depressed the grain yield (IRRI 1973). Averaged for all levels of nitrogen, phosphorus, and potassium, response to zinc was as high as 2.4 t/ha, the minimum yield for the zinc-only treatment for the six locations was 4.47 t/ha. The zinc treatment costs less than $2 per hectare. It consists of dipping the seedlings in a 2% suspension of zinc oxide in water just before transplanting. Experiments were also conducted on abandoned land that is topographically well suited to rice cultivation to determine whether these lands, which have a dense growth of weeds, could be made productive by the application of zinc. The application of NPK fertilizer did not increase yields. Zinc alone, however, increased the yield of IR20 by 3 t/ha — from 2.4 t/ha without zinc to 5.4 t/ha with zinc.

The lack of adequate water is an important yield-limiting factor. Institute agronomists have demonstrated that continual flooding is not essential for high grain yield. As long as the soil remains well saturated with water, optimum yields can be obtained. However, standing water helps control weeds. If irrigation water is available, 5–7 cm of water is sufficient on most soils for weed and insect control with granular chemicals, for high nutrient availability, and for minimum losses of nutrients from fertilizer and soil. Greater water depth may reduce tillering and induce lodging. Moisture stress at any growth stage will lower yields.

Nearly half of the world's rice is grown without irrigation, under lowland rainfed conditions. Institute rice production specialists have conducted experiments on farmers' fields under rainfed conditions. They have demonstrated that rice that is direct-seeded, rather than transplanted, at the beginning of the rainy season uses rain water more efficiently. The monsoon rains in the Philippines usually begin in May but farmers seldom have enough rain water to prepare the land for transplanting until July or August. Transplanting itself is often delayed until August. Seedlings in the nursery, or seedbed, may pass the optimum age for transplanting. But experiments on farmers' fields have shown that the crop can be directly seeded at the beginning of the rainy season. Yields of 4 t/ha can be obtained on the unpuddled soils. Using short-season rice varieties, two rice crops can be grown under rainfed conditions (Fig. 2), or a crop of rice can be followed by other crops that require less water.

The experimental plots were established on farmers' fields at nine different sites in Central Luzon, Philippines, from mid-May until mid-June 1973 (IRRI 1974). The first plots of early maturing varieties were harvested during the second half of August, when about 40% of the paddies in the area had not even been transplanted. Not enough rain had fallen for farmers to plow and puddle the soil. An early maturing selection, IR1561-228-3, averaged 5.33 t/ha at nine locations. Seedbeds for the second planting were prepared 2½ weeks before the anticipated date of harvest of the first crop. The soil was plowed and puddled and rice was transplanted as quickly as conditions permitted. The second crop was harvested at about the time that local farmers were harvesting their first (and only) crop. Direct seeding of early maturing rice, followed by a second

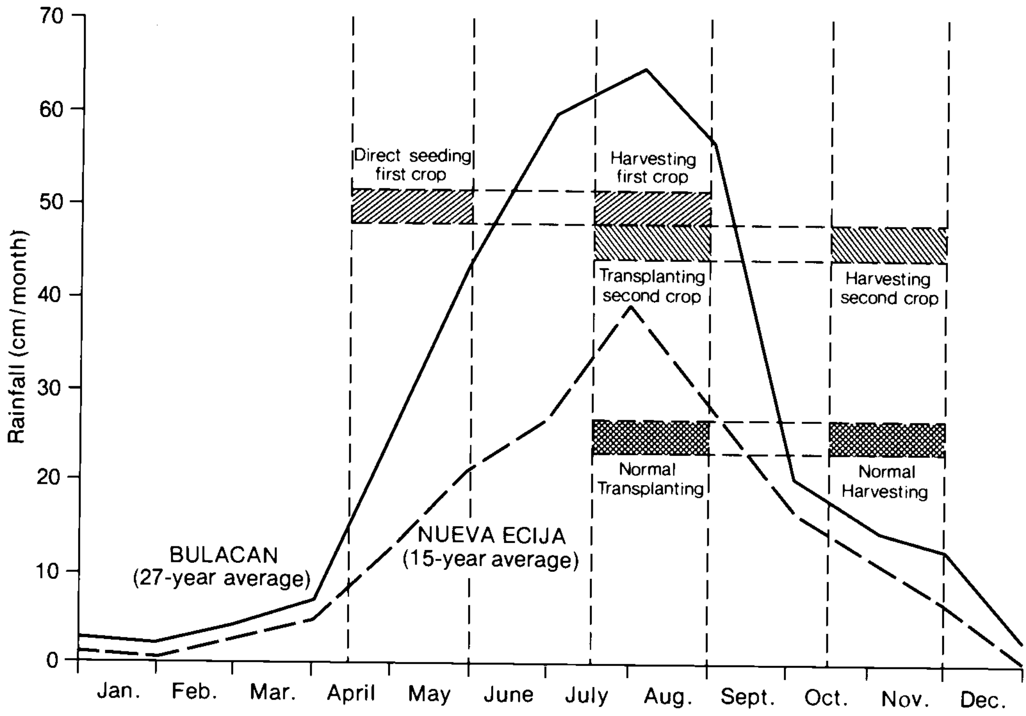

FIG. 2. Monthly rainfall in Bulacan and Nueva Ecija, Central Luzon, Philippines, with planting and harvesting periods shown for the normal transplanted crop and the two crop system.

crop of rice, corn, or grain legume, promises to become a commercial practice that will use available rain water more efficiently.

The payoff from good weed control increases sharply when farmers adopt high-yielding varieties. Handweeding is very laborious and time consuming. Even on farms as small as 2–3 ha, a farm family has difficulty adequately controlling weeds by hand. A survey of Philippine farmers conducted by Institute economists showed that labour for weeding increased with adoption of high-yielding varieties. These analyses suggest that mechanical and chemical weed control is likely to increase output rather than displace labour, except in areas where wages are very low and farms are extremely small.

The recent success of Institute experiments in chemical weed control may bring a dramatic change in the weed control practices in tropical Asia. The 2,4-D results were most interesting. When applied 4 days after transplanting this low-cost herbicide adequately controls grasses, broadleaved weeds, and sedges. In the past, 2,4-D was known to effectively control only broadleaved weeds and annual sedges. The time of application is the key factor in control of grasses with 2,4-D. When applied after transplanting but before weeds emerge, it kills grasses as well as annual weeds. Institute agronomists recommend using 800 g (active ingredient) of 2,4-D to control weeds in 1 ha of paddy. The cost of treating 1 ha with the granular herbicide is only $6, compared with $12 for handweeding.

Weed control is more critical and more difficult in direct-seeded rice than in transplanted rice. When rice is direct-seeded, the weeds and rice emerge simultaneously and the weeds are highly competitive. Because the weeds cannot easily be distinguished from rice seedlings of the same age, labourers invariably damage the rice plants in direct-seeded rice. Experiments conducted by IRRI agronomists have shown that 1.5 kg/ha (active ingredient) of butachlor or of benthiocarb applied 6–8 days after seeding successfully controls weeds in direct-seeded rice. The cost per hectare of either chemical is about the same as that of hiring labour to handweed transplanted rice. Either of these chemicals applied at lower rates can also control weeds in transplanted rice. Weed control in upland rice is even more difficult than in direct-seeded rice. Butachlor in liquid form at 2 kg/ha active ingredient controls all annual weeds in upland rice.

This success of chemical weed control has stimulated the use of herbicides in the Philippines and other Asian countries. Because of a shortage of labour, or an unwillingness to control weeds by hand, the use of cheap herbicide is likely to become a widespread practice. Formulations and derivations of 2,4-D, MCPA, butachlor, and benthiocarb are now being marketed in several countries.

Plant Protection

Warm temperatures and high humidity, which are typical of the tropical rice environment, are optimum for the development of organisms that are harmful to the rice plant. About 20 diseases and insects seriously damage the rice plant in the tropics; most are present in the Philippines. Institute scientists have concentrated their attention on the most widespread and damaging pests; these are blast, bacterial leaf blight, and tungro virus among the diseases and stem borers, planthoppers, and leafhoppers among the insects. Another major insect pest is the gall midge, which is not found in the Philippines. The Institute has also done considerable work on bacterial streak, sheath blight, and grassy stunt diseases and on the whorl maggot insect.

Improved management practices must include protection of the crop from diseases and insects. Chemical control of diseases has not been very successful in the tropics. Year-round rice cultivation favors rapid and frequent build-ups of pathogenic organisms that make chemical control uneconomical. The breeding of varieties resistant to diseases is the only practical method of disease control.

IRRI entomologists have evaluated hundreds of chemicals and have standardized their application methods for cheap insect control. Conventional foliar sprays and dusts do not penetrate dense foliage well and are easily washed off by rains. They must be applied repeatedly for effective control. Early work at IRRI led to the standardization of paddy water application of insecticides in granular form. Granular insecticides are convenient for paddy water application and are far more effective because they function systematically in the plant. Two granular insecticides, lindane and diazinon, were found not only to be most effective in controlling insect pests of rice but also to be the least hazardous to man. Two applications of these chemicals controlled insects better than did 8–12 foliar sprays of such potent compounds as endrin and parathion. Carbofuran, which is also available in granular form, was identified as a highly promising insecticide in recent tests. Carbofuran controls all major insects when applied to paddy water, but it is relatively expensive.

The entomologists recently focussed their attention on developing new and less expensive methods of applying insecticides. In several experiments, placing insecticides 2 cm below the soil surface at 3 days after transplanting protected the crop from insects until harvest. The effect of insecticides is prolonged because they are less exposed to heat and sunlight and aerobic degradation, and are less susceptible to volatization and loss in the paddy water. The insecticide applied in this manner is also expected to be less hazardous to the parasites and predators of rice pests. The insecticides were placed in protein gelatin capsules that dissolve in water. Two insecticide manufacturers also formulated cartap into tables of the appropriate size and chlordimeform into large granules. These formulations had to be pushed below the soil surface by hand. Institute engineers are now working on the development of a mechanical applicator for placing such insecticides in the root zone.

In a series of experiments, root zone applications of carbofuran, cartap, and chlordimeform were compared with water application of carbofuran at 2 kg/ha active ingredient applied every 20 days, which is considered the most effective method of insect control (IRRI 1974). The root zone applications were as effective as the paddy water application of carbofuran, at only a fourth of the cost. Investigations have shown that a greater proportion of insecticides is absorbed by the plant when it was applied to the root zone than when it was broadcast on the soil surface. For example, chlordimeform applied in the root zone was rapidly absorbed and translocated to the stems and leaves of the rice plants and its concentration in the plants was several times higher than that of surface application (IRRI 1974). Even 40 days after treatment the concentration of the insecticide applied to the root zone was twice as high as that applied to paddy water.

Rice Mechanization

Improved varieties and intensive cropping have increased the economic advantage and scope of rice mechanization. Farm surveys by Institute economists have shown that the new rice varieties have increased overall labour requirements. Reliable, low-cost sources of power are basic to the reorganization of small farms for increased production. In tropical Asia, a large portion of paddy land is medium-sized farms of 2–10 ha each. The Institute's agricultural engineering program is focussed primarily on the design and development of machines for such medium-sized farms, which are too large to work economically with animals, but not large enough to justify investments in large agricultural equipment imported from the industrialized countries. An integral part of the program is cooperation with agricultural equipment manufacturers to extend new machines to rice farmers.

Among the machines that the Institute has designed and released, the IRRI power tiller has made the greatest impact. The single-axle power tiller is simple and lightweight, and can be manufactured in most developing countries. It uses an imported 5- to 7-hp aircooled gasoline engine. The other tractor components are easy to fabricate locally in small shops. The number of companies that manufacture the IRRI-designed machine, or modifications of it, has increased rapidly. Since the design of the power tiller was released in 1972, 12 companies in the Philippines have received IRRI authorization to produce the machine. They are now manufacturing more than 500 tillers per month. The IRRI-designed tiller costs about half as much as an imported tiller. Farmers like it because of its simple design, ease of maintenance, and low cost. The tiller has been tested in about a dozen countries; initial manufacture has begun in Sri Lanka, Thailand, and South Vietnam.

IRRI released its design for the axial flow thresher for commercial production in late 1973. Five Philippine companies are now building production models. Two companies in Pakistan, one in Sri Lanka, and one in South Vietnam have initiated prototype fabrication. The machine can consistently thresh and clean ¾–1 ton of paddy per hour. It uses a 7-hp gasoline or kerosene engine. The engine of the power tiller is interchangeable; it can also be used on the thresher. The thresher can handle both dry and high moisture paddy efficiently.

Economical pumps are not available in the tropics for many low lift irrigation needs. A simple and low cost "bellows" pump was developed for this purpose at IRRI. It is designed for fabrication from light sheet metal, canvas, rubber, and wood, and can be built by small blacksmith shops. The pump is light and can easily be carried by one man. It can deliver 100–150 liters of water per minute and sells for approximately US $25.

The design for the IRRI batch type drier was released for commercial production late in 1972. Since its release a number of changes have been incorporated into the design to improve its performance and to reduce cost. This 1-ton drier has an underlying plenum chamber through which heated air is driven upward into the grain mass. The bin can be made of either metal or wood. Its two parts are separated by a perforated metal sheet or a screened partition. Either a kerosene burner or a simple self-feeding rice hull furnace provides heated air. A ton of grain can normally be dried in 5–6 h. Five companies in the Philippines now produce the drier. Initial investment cost is about US $550 with a metal bin, or $350 with a wooden bin.

The multihopper seeder was designed to place pregerminated seeds in rows in lowland rice fields quickly and precisely. The machine is made of sheet metal and meters out seeds by simple wooden rollers. The lightweight seeder can easily be transported across fields and levees. One man can seed 1 ha in 7–8 h with the machine. About 300 multihopper seeders were sold at approximately US $50 each, in the Philippines during 1973.

Major Constraints to Production

Despite the development of high-yielding varieties and associated technology, the rate of adoption, as well as its impact on production is not as high as expected. Most farmers do not obtain yields in their fields as high as those demonstrated at experiment stations. The Institute is seeking explanations for these substantial yield differences.

The agricultural economics department participated in a cooperative regional project in which about 25 social scientists from different countries surveyed farms in 36 villages in 14 separate study areas in 6 countries during 1971–72 (IRRI 1974). The primary objective was to gather information on changes in production, income, and employment associated with the introduction of new rice technology, and on the major obstacles to further increases in rice production in these areas. Three major factors seem to explain many of the differences found among villages in the areas planted to high yielding varieties: (*i*) the availability of suitable varieties that combine high yield potential, with resistance to pests and good grain quality; (*ii*) the nature and quality of the rice-growing environment (solar radiation, water control, etc.); and (*iii*) the price relationships between improved and local varieties, and between rice and inputs such as fertilizer. Even in areas where adoption was widespread, the constraints to high yields most frequently mentioned were insects and diseases.

The Institute statisticians conducted experiments on farmers' fields in Laguna province, the Philippines, at four locations in the 1972 dry season, three locations on the 1972 wet season, and 14 locations in the 1973 wet season (IRRI 1974). All of these farms were within a radius of 25 km from the IRRI experiment station. Most farmers in Laguna province are progressive and now use fertilizers and improved cultural practices. Factors such as insect control, water management, weed control, fertilizer, seed source, and seedling management were studied in each experiment at two levels — the farmers' levels (as practiced by the concerned farmers in the sample farms), and the recommended levels (the standard practices at the IRRI experiment station).

In the dry season, improved management practices increased yields in farmers' fields by an average of 85%. Absolute yield increases ranged from 2.4 to 4.4 t/ha. At one farm the yield increased to 9.6 t/ha with improved practices. Insect control, water management, and fertilizer were most crucial in raising rice yields in the dry season.

In the wet seasons, improved practices increased average yields far less: only 0.6 t/ha (14%) in 1972, and 1.3 t/ha (63%) in 1973. Insect control was by far the most important factor contributing to yield; it accounted for more than two-thirds of the yield differences between recommended and farmers' practices. Weed control ranked second. Most farmers in the study area were already using adequate fertilizer.

The new rice technology has proved highly profitable in areas where solar radiation is high and irrigation water is adequate. For example, national yields in Pakistan increased by 50% during the 3-year period ending in 1969–70 with the adoption of modern varieties on a third of its rice area (Athwal 1971). Rice is grown in Pakistan under irrigated conditions with extremely low rainfall and high solar radiation. Modern varieties give high yields in other countries when grown during the dry season with adequate irrigation. But the existing technology is less suited to unfavourable environments, such as wet season, poor water control, low solar radiation, and high incidences of diseases and insects.

A recent Institute study in the Philippines clearly shows that poor management practices, as well as poor environments, markedly limit farm yields (IRRI 1974). To realize the full yield potential and to maximize benefits from the new technology, all factors which contribute to production must be optimized. For example, the data collected by Institute economists both in the Philippines (R. Barker, unpublished) and Thailand (IRRI 1973) emphasized the high degree of complementarity between weed control and fertilizer input for obtaining high yields and income. High levels of either one increased yield and income insignificantly. Marked increases in yields and farm income levels came only with heavy applications of fertilizer accompanied by good weed control.

Overcoming Production Constraints through Genetic Improvement

On the basis of research information now available, it appears that several of the constraints to production can be removed or at least their adverse effect minimized through genetic improvement. Perhaps water and fertilizer are the most important inputs for increasing rice yields. Inadequate water supplies, or excesses of water, limit the potential yields in some areas. After water, the most important factors that limit yields are insects, diseases, and weeds. Adverse soil conditions that affect lowland rice include salinity, alkalinity, zinc deficiency, and iron toxicity. Aluminum toxicity and iron deficiency interfere with the response of new varieties to fertilizer and other inputs in upland rice. Low temperatures prevail in many rice areas at high altitudes and in northern latitudes. An enormous potential exists for incorporating built-in resistance or tolerance to insects, diseases, drought, deep water, low temperatures, and adverse soil conditions.

IRRI maintains a "germ plasm bank," or collection of more than 25,000 varieties. Scientists have screened these varieties and identified sources of resistance or tolerance to these yield-limiting factors. Genetic materials that are almost immune to different diseases and insects are available. Some varieties in the germ plasm bank have resistance to salinity, alkalinity, or iron toxicity. The traditional varieties that are grown in areas of deep water can elongate several meters as the water rises. Studies have established that the genes responsible for elongation can be combined with the semi-dwarf plant type. Varieties may be developed that remain short under normal conditions, but that have the capacity to elongate as the water deepens. Other rices have been identified that are tolerant to drought and low temperatures.

Small-scale tropical farmers generally are not willing to take risks and are hesitant to invest in inputs. For example, farm surveys by Institute economists have shown that although farmers have increased insecticide use over the past few years, they still generally apply only low amounts. The normal farm practice is to use the chemical when damage is visible. The insect damage varies with location, season, and variety. Although it is difficult to rely on chemicals as a major insect and disease control measure, farmers quickly identify and adopt resistant varieties. Modern varieties must obviously be improved to provide genetic protection against unfavourable conditions in order to lower the costs and reduce the risks of producing high yields.

Institute scientists have made remarkable progress, through intensive cross-breeding, in transferring disease and insect resistance from different sources into improved genetic lines. Fig. 3 shows that 70% of the selections included in the 1973 replicated yield trials were resistant to at least five major diseases and insects (IRRI 1974). Only 4 years ago, less than 15% of the entries in these trials were resistant to two pest organisms, and none were resistant to three pests. Some of the experimental selections now being tested have combined resistance to blast, bacterial leaf blight, tungro virus, grassy stunt virus, green leafhoppers, brown planthoppers, white back planthoppers, and stem borers (Table 2).

The new crosses that are now being studied are designed to incorporate resistance or tolerance, not only to diseases and insects, but also to other unfavourable environmental factors, into lines that yield well and have good grain quality. The genetic recombination of all these characters into single varieties requires a massive breeding program. The Institute has expanded and accelerated its breeding program and now makes about 2000 crosses per year, compared with only 200–300 crosses in the past. The development of varieties suited to unfavourable environments is a long range program that offers a continuing challenge to rice breeders. Diseases and insects have the capacity to change and new varieties must continuously be bred to withstand these variations.

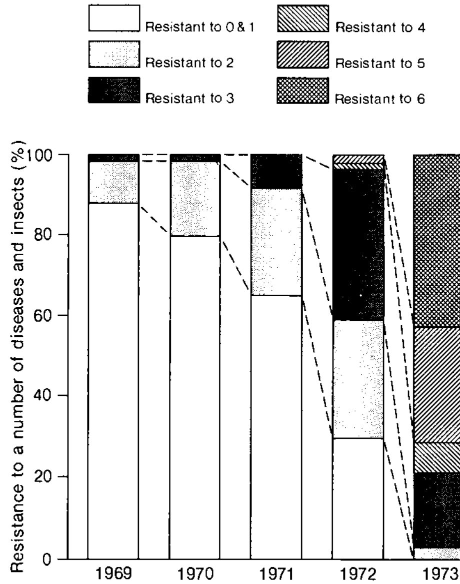

FIG. 3. Proportion of entries in replicated yield trials with multiple resistance to important diseases and insects (blast, bacterial blight, tungro, grassy stunt, brown planthopper, and green leafhopper). Each year's trials consisted of about 185 entries.

Research Utilization

The Institute orients its activities to insure that the new information and materials generated by its research are shared with national rice programs. The genetic material developed by IRRI is available to every rice-growing country for evaluation and ultimate use as varieties. IRRI has a large training program and provides about 80 man-years of training to young scientists every year. During their stay at IRRI, the scholars are encouraged to work on problems that are important in their countries. Many of the scholars take selected genetic lines from the breeding materials back with them for evaluation at their home stations. IRRI publications are distributed to the major rice research stations and libraries

TABLE 2. Reactions of named varieties and promising selections to major diseases and insects.

Variety/ selection	Blast	Bacterial blight	Bacterial streak	Tungro	Grassy stunt	Green leaf-hopper	Brown plant-hopper	White back plant-hopper	Stem borer
IR8	MR[a]	S	S	S	S	R	S	S	MS
IR26	MR	R	MR	R	MR	R	R	S	MR
IR2061-464-2	R	R	MR	R	R	R	R	S	MR
IR2071-88-10	R	R	MR	R	R	R	R	R	MR

[a]R, resistant; MR, moderately resistant; S, susceptible.

around the world. For example, the Institute sends its annual research report to about 2000 addresses, mostly rice researchers in the less developed nations. The *IRRI Reporter*, a bimonthly publication, goes to 4000 addresses, mostly scientists, extension workers, teachers, and farmers.

We recognize that most of the work for increasing rice production in any nation must be carried out by research stations of that nation. Strong national institutions are essential prerequisites to accelerated progress. The Institute is engaged in cooperative projects in the major rice-growing countries to help them improve their research capabilities. Projects in India and Pakistan have been completed; each lasted for more than 5 years. Cooperative country projects in Bangladesh, Indonesia, Sri Lanka, Vietnam, Egypt, and the Philippines are continuing.

Three parties are usually involved in the development of a cooperative country project — the national agency, IRRI, and an agency that is willing to finance IRRI's participation. A project normally provides for assignment of one or more IRRI scientists and short-term consultants, training for local scientists, and supply of essential equipment. Institute scientists employed in country projects work as members of local teams on local problems. These projects are in no way intended to be branch stations of IRRI. Not only are technical resources of the project applied to enhance the local research efforts, but also the Institute at Los Baños often incorporates into its research program supplementary investigations to help solve rice production problems in the host country. The Institute emphasizes that its efforts in a country must be a part of the national program. IRRI has also stimulated the development of coordinated national programs where they did not previously exist.

Inadequate extension programs may limit the adoption of improved technology and the achievement of production goals in some countries. Although IRRI's major focus is on research and the training of research scientists, IRRI also trains extension workers, cooperates in adaptive research on farmers' fields, and helps develop new extension techniques. The Institute has assisted some countries in accelerating the adoption of improved technology. Working cooperatively with Philippine agencies, IRRI developed the concept of "Rice minikits" to accelerate the dissemination of new varieties among farmers. Each minikit contains seeds of several new selections, fertilizers, insecticides, and herbicides to plant small plots on farmers' fields. The technique is designed for large-scale evaluation of selections prior to their release under a range of environments and to give farmers an opportunity to choose the selection that gives best performance under farm conditions. In addition to the Philippines, the rice minikit has proved a powerful extension tool for disseminating the new varieties in Sri Lanka and India.

More recently, IRRI scientists working with local Philippine agencies have developed an extension methodology that can be applied in other countries. The methodology includes the use of a "package" of practices (improved varieties, proper use of inputs, etc.), a mass informational campaign, farmers' field days, training of technicians, improving the mobility of technicians, assuring an adequate supply of inputs, and timely credit. Through its cooperative projects, IRRI will stimulate the use of this methodology in other countries, and will continue to help demonstrate the effectiveness of new technology in increasing rice yields at the farm level and in improving the living conditions of farmers.

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