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THE EVOLUTIONARY NATURE OF THE NEW RICE TECHNOLOGY†

The development and dissemination of the so-called high-yielding varieties of rice has been widely discussed. The new, short, stiff-strawed *indica* varieties are highly fertilizer-responsive. Thus, Johnston refers to the new technology as the "seed-fertilizer revolution" (*16*). However, in reading the literature of the green revolution and in talking to my colleagues in the social sciences, I find considerable confusion about the new technology as it relates to factors other than seed and fertilizer, factors such as the requirements for water, pesticides, and mechanization. Furthermore, many writers appear to believe that the technological change begins and ends with the introduction of the new rice varieties.

Actually, the technological advance in rice is not a once-and-for-all change but rather is evolutionary in nature. The so-called package of inputs (including the seed itself) is still very much in the development stage. A major effort is being made to tailor the new technology to fit the inadequate irrigation facilities and the small amount of capital resources found on most Asian farms. At the International Rice Research Institute, for example, the direction of research has changed significantly since the release of the first high-yielding rice varieties in 1966. Before discussing technological changes, now in the research stage, I would like to clarify some of the questions surrounding the inputs associated with today's technology.

THE CURRENT PACKAGE OF INPUTS

A highly complementary package of inputs is associated with the new rice varieties. This package includes irrigation and water control, fertilizer, and methods to control weeds, diseases, and pests (insects, rats, and birds). Use of these inputs allows the new varieties to express their yield potential. Without these inputs the grower cannot expect a good yield. The difference between the high-yielding varieties and traditional varieties is their response to inputs.

Even at present, it is difficult to describe a precise set of environmental conditions or a package of inputs associated with the high-yielding varieties. As illus-

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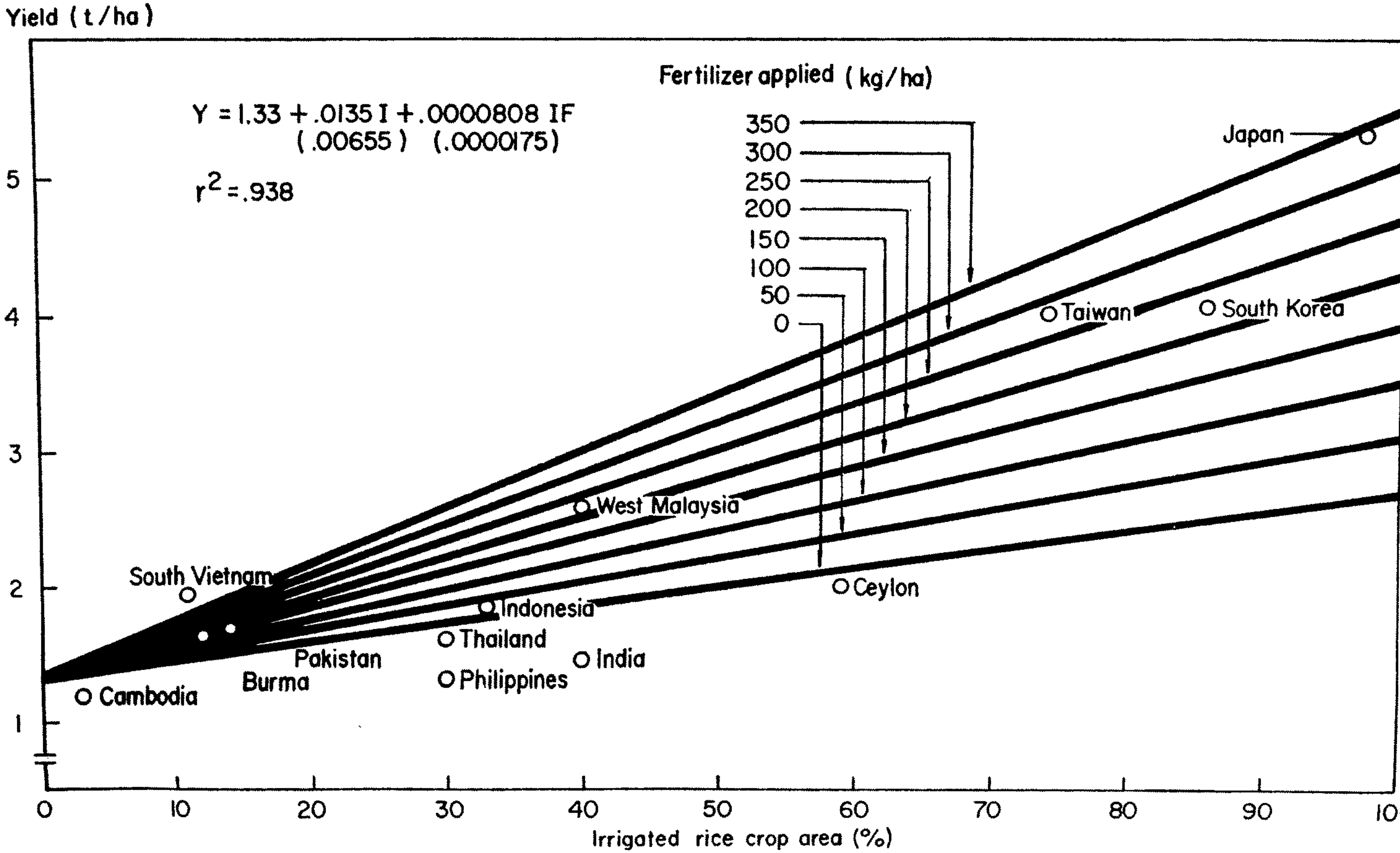
† An earlier version of this paper was prepared for a Conference on Agriculture and Economic Development, sponsored by the Japan Economic Research Center, held at Tokyo and Hakone, September 6–10, 1971. I am indebted to D. S. Athwal, T. T. Chang, B. Duff, and W. H. Meyers for their constructive comments.

Chart 1.—Proportion of Area Planted to High-Yielding Varieties of Yield and Input Use for All Varieties by Land Type for the Wet Season, Gapan, Nueva Ecija



trated by Chart 1, in the Philippines the new varieties are being grown under a whole continuum of conditions. The results shown in this chart are based on a sample of 513 farmers surveyed by F. S. Liu in the town of Gapan in central Luzon.

On double-cropped irrigated land, inputs have increased sharply, and the yield response has been good. On the rainfed land (bunded areas which depend on rainfall) input levels have remained low. Because of uncertain water supply little difference exists in the performance of the high-yielding and local varieties. On the irrigated land the number of farmers using insecticides and herbicides has increased rapidly since the introduction of high-yielding varieties about 1966. In spite of the increase in number of adopters of insecticides and herbicides shown in Chart 1, the total expenditure per hectare remains very low. Although a higher level of fertilizer use tends to increase problems with weeds, diseases, and pests, farmers consider the high levels of insecticide and herbicide inputs being applied or tested at IRRI to be too costly for their purposes.

The yield gains, in spite of the increased use of inputs, are disappointingly low even on the double-cropped irrigated farms. We need to identify more precisely why the current yield levels in areas such as Gapan are so far below what appears to be the farmer's potential, and we hope to be able to do this through further analysis of our Gapan data. We are also undertaking a cooperative study to investigate these types of problems in about 15 villages throughout South and Southeast Asia. One question to be explored is the importance of physical or technological constraints as contrasted with human constraints. Socio-economic constraints can involve a wide range of factors, including institutional rigidities.

Let us look at five factors in more detail—water requirements, fertilizer requirements, weed control, insecticide use, and mechanization.

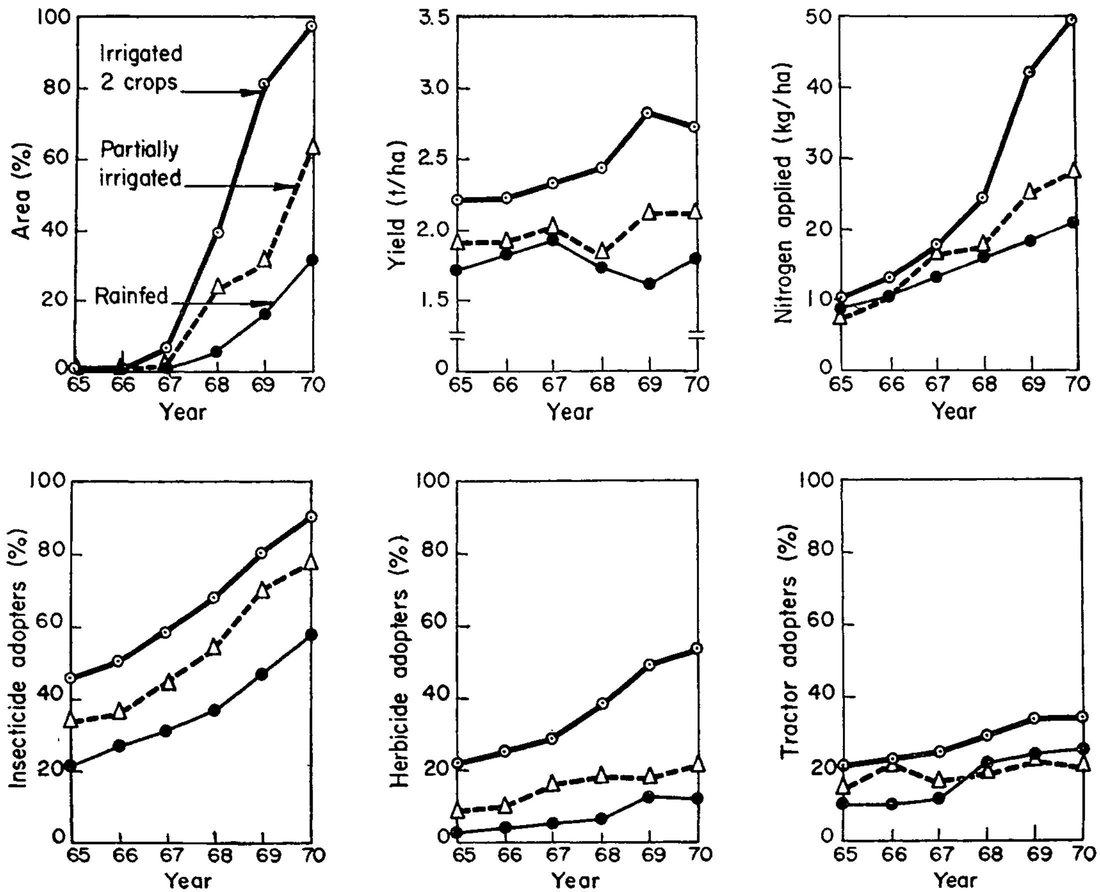
Water Requirements

The greatest production gains from the new technology have occurred in the best irrigated areas. Farmers in these areas have adopted the high-yielding varieties more rapidly and have generally used higher levels of inputs such as fertilizer, insecticide, and herbicide (Chart 1).

It is frequently stated that the high-yielding varieties require more precise water control than the local varieties. By itself, this statement has little meaning. Fukui defines what he means by "stricter water conditions" (*11*). He states that high-yielding varieties are not suited to the deep water areas found in major river basins, such as the Chao Phraya in Thailand, because of their short stature and photoperiod insensitivity.

This statement is correct when applied to the original high-yielding varieties such as IR8. These varieties were bred specifically for areas with good control of water levels. Insensitivity to photoperiod allows varieties to be planted over a fairly wide range of latitudes because their growth duration is unaffected by differences in day length. But in deep water areas varieties must be able to elongate several centimeters a day when the floods come and they must be sensitive to photoperiod so that they mature after the rains (and floods) have ended. Such varieties are being developed. The Thai Rice Department has several promising experimental lines from a cross between a Thai floating rice and an IRRI semi-

Chart 2.—Relationship Between Yield of Rough Rice (Y), Fertilizer Input (F), and Per Cent of Rice Crop Area Irrigated (I)



dwarf line that in shallow water are about the same height as semi-dwarf varieties, but in deep water can stand up to 1.3 meters. The T442 lines are highly responsive to fertilizer and weakly sensitive to photoperiod.

IRRI varieties named after IR8 are suited to different conditions. For example, IR5 is preferred in many areas of the Philippines because it is taller than IR8 (135 cm. vs. 100 cm.) and it seems to be more drought resistant than many varieties. The popularity of IR20 in East Pakistan results not only from its disease resistance but also from its weak photoperiod sensitivity. This sensitivity allows it to be harvested at the end of the rainy season.

The degree of water control has been a significant factor in the adoption of high-yielding varieties. The rice growing area can be broadly classified into three major categories based on the level of water control and the closely associated varietal adoption pattern.

(1) Approximately 20 per cent of the rice growing area is now irrigated. The introduction of the high-yielding varieties has been concentrated in this area and has resulted in significant yield increases.

(2) The rainfed rice (excluding deep water and upland) constitutes approximately 50 per cent of the rice growing area of Asia. High-yielding varieties can be grown in this area, but due to the low application of fertilizer and other inputs, yields are not likely to be significantly different from local varieties. There is no evidence to suggest that yields of the high-yielding varieties are lower than those of local varieties.

(3) The remaining area, representing 30 per cent of the total, is mainly deep water and upland rice. There are obviously soil, climatic, and deep water conditions for which the high-yielding varieties presently available would give lower yields than existing local varieties. Knowledge of the performance of high-yielding varieties under upland conditions is very limited. In some upland areas, the high-yielding varieties are reported to be superior to local varieties (*8*; *17*).

Fertilizer Requirements

As suggested earlier, and reflected in Chart 1, the level of fertilizer used is closely associated with the adequacy of irrigation. Farmers under the best irrigated situations use nearly the recommended levels of fertilizer. Most experiment station recommendations seem to assume adequate irrigation for all areas, although it is not explicitly stated. The growth in fertilizer use as well as the improvement of irrigation facilities are occurring gradually. Undoubtedly, the availability of these two highly complementary inputs largely determines the sustained rate of growth in rice production that can be achieved by any country with the existing form of the seed-fertilizer technology.

Despite high yields at experiment stations, the current level of irrigation development in most Asian countries does not permit a national yield level above about 2.5 metric tons of rice. This point is illustrated in Chart 2, constructed by using national estimates of yield and fertilizer input from FAO (average of 1964 to 1968) and estimates of the area of irrigated rice crop, taken principally from a recent Asian Development Bank survey (*2*). Yield (Y) was estimated as a function of per cent of the rice crop irrigated (I) and the interaction (IF) between per cent of the rice crop irrigated and the amount of plant nutrients (N, P, K) applied.

It was thus assumed in the model that fertilizer would be applied to the rice crop in significant amounts to cause a yield increase only on irrigated lands. The low level of national yields in many Asian countries suggests that before the introduction of the new fertilizer-responsive varieties, these countries were apparently not able to reach the production potential of their existing irrigation and drainage systems.

Insecticide Use

Every year the International Rice Research Institute conducts a six-month training program for about thirty-five participants from South and Southeast Asia and elsewhere. For the past two years, I have asked these students toward the end of the course what level of inputs they would apply (fertilizer, insecticides, and herbicides) and what yield they would anticipate if they themselves were to farm a hectare of land in Laguna. Their answers suggest, in general, that these students are concerned with maximizing yields and not profits. In fact, their return above costs for fertilizer and chemicals is about the same as the average of the Laguna farmers whom we have been surveying. But their input cost is four to five times higher than that of the farmers. The widest divergence between student recommendation and farmer practice occurs in the area of insecticide use.

Part of the reason for this divergence undoubtedly lies in the fact that the students are constantly exposed to the practices on the IRRI farm. Furthermore, because of the much higher insect population on the IRRI farm as compared with the farmers' fields, the yield increases that result from spraying are substantially greater than in farmers' fields. At some periods of the year failure to apply insecticides at the IRRI farm will result in a complete crop failure.

Because of our concern with the non-representative nature of the experiment station findings, we began experimenting with different levels of insecticide and fertilizer on a farmer's field in Laguna province about 10 kilometers from IRRI. Over the six crop seasons that we experimented in this location (from 1968 to 1970), the level of insect infestation was relatively low, as it appears to have been on most Laguna farms in the same period. The yield benefits from using insecticides on variety IR20 were not significant, but they were significant for IR8. Table 1 shows an example of our results. We were able to increase the yield of IR8 by more than a ton through the use of insecticides on well fertilized plots. But the benefits from applying insecticides were slight when low rates of fertilizer were used. If a farmer has only P100 (about US$15) to spend on chemicals (about the average from our Laguna surveys), how should he allocate it between fertilizer and insecticide? The answer in this case is clear. Both the level of profitability and the assurance of a return favor the purchase of fertilizer when credit is limited.

The results presented here, however, are for only one location and for a very short time period. They suggest that with present levels of credit availability, Laguna farmers are behaving in a rational economic manner even though their average level of insecticide application is from US$1 to US$2 per hectare as compared with US$10 to US$20 for fertilizer. The answer could be very different in other regions or periods that have higher levels of insect infestation. In fact, with the outbreak of tungro virus during the current wet season in many parts of the Philippines, including Laguna province, the payoff for the use of insecticides properly applied would be very high in many locations. One objective of workers

TABLE 1.—RETURNS ABOVE COSTS FOR CASH INPUTS ON INSECTICIDES AND FERTILIZER FOR IR8, CALAUAN, LAGUNA, 1970 WET SEASON

Number of insecticide applications	Grain yield (*metric tons per hectare*)	Cash cost[a] (*pesos per hectare*)	Net return[b] (*pesos per hectare*)
		FERTILIZER: NONE	
0	3.3	0	1,188
1	3.3	50	1,138
2	3.4	100	1,124
3	3.6	150	1,146
4	3.9	200	1,204
		FERTILIZER: 30 KG. N PER HECTARE	
0	4.0	40	1,400
1	4.1	90	1,386
2	4.2	140	1,372
3	4.4	190	1,394
4	4.8	240	1,488
		FERTILIZER: 60 KG. N PER HECTARE	
0	4.5	80	1,540
1	4.5	130	1,490
2	4.7	180	1,512
3	5.0	230	1,570
4	5.4	280	1,664
		FERTILIZER: 90 KG. N PER HECTARE	
0	4.5	120	1,500
1	4.7	170	1,522
2	4.9	220	1,544
3	5.2	270	1,602
4	5.7	320	1,732
		FERTILIZER: 120 KG. N PER HECTARE	
0	4.3	160	1,388
1	4.5	210	1,410
2	4.8	260	1,468
3	5.1	310	1,526
4	5.6	360	1,656

[a] Insecticide cost at P50 per hectare for each application (labor and P25 per kg. of active ingredient), and fertilizer cost at P1.33 per kg. N, for urea in 50-kg. bags.
[b] At P16 per cavan of IR8 or P0.36 per kg., rough rice.

in pest control should be to improve methods of predicting when and where damage is likely to occur. Advanced countries such as Japan and the United States have developed elaborate systems designed to alert farmers of the impending attack. Far simpler systems could perhaps be developed in most Asian countries to enable us to determine both the location and the time of year in which the payoff for insecticide use is likely to be greatest.

Weed Control

Hand, mechanical, and chemical methods of weed control can be easily substituted for each other. These methods are widely used singly or in combination throughout Asia. Our surveys in Laguna, for example, show that among this progressive group of Philippine farmers, the majority use all three methods. Farmers spend about US$1 to US$2 per hectare for herbicides, the most common of which is 2,4-D sprayed about three weeks after transplanting. In 1965 most of the herbicides being tested at IRRI cost US$15 or more per hectare for complete control. More recently IRRI researchers found that excellent control of weeds including grasses can be achieved by the application of 2,4-D, four days after transplanting (which is before the weeds emerge). The cost of the granular form commonly used at the Institute is US$7 per hectare. The cost can be cut to less than half this figure by using the liquid form.

This reduction in cost suggests that adequate weed control through chemical methods is likely to become a reality for a substantial number of Asian farmers. Many economists view this with considerable concern because of its potential impact on employment. But it is obvious as one travels through Asia that even with existing levels of labor availability large portions of the rice growing area are not being adequately weeded. Thus, the introduction of an inexpensive herbicide is likely to raise the productivity of existing labor in many areas. The potential productivity gains are even more pronounced in some of the rainfed and upland areas where weeds are a more serious problem. Low cost herbicides such as Saturn (a Japanese product) are being tested specifically for these areas.

Mechanization and Employment

Although the advantage of timely operations may have increased the marginal productivity of mechanization in some areas, I agree with Johnston that the seed-fertilizer technology and mechanization are separable (*16*). For example, our experiments show that for equal horsepower inputs there is no significant difference in yield between land prepared by water buffalo or by tractor. Although IRRI doesn't claim to operate its experimental farm economically, we do like high yields, and many visitors are surprised to find that the bulk of the experimental plots at the Institute are still plowed and harrowed by water buffalo. In contrast with many upland crops such as wheat in India or sugarcane in the Philippines, mechanization does not yet appear to offer substantial economies of scale in tropical rice production. There is no question, however, that the introduction of the high-yielding varieties has given a boost to mechanization in many areas (Chart 1). As yet, this does not seem to have created a problem of unemployment, although we have argued elsewhere that the imbalance between wage rates, interest rates, and over-valued currencies which exist in many countries does pose a threat to employment in the rice producing sector (7).

Other Factors

We have not discussed all factors that could influence yield. The question might be asked as to whether or not the high-yielding varieties *require* a higher standard of cultural practices such as better seedbed preparation or more precise planting. Judging from the large difference in the yields at zero fertilizer levels on experiment station plots as compared with farmers' fields, many of these improved management practices apparently lead to higher yields for both high-yielding and local varieties. We have no evidence, however, that there is a strong positive interaction between these practices and fertilizer response per se.

NEW DIRECTIONS FOR RESEARCH

The first of the high-yielding IRRI rice varieties—IR8—was released in 1966. Although some observers disagree, IR8 seems to have established at least a temporary yield plateau. The four subsequent varieties that have been named by IRRI to date have been bred principally for better grain quality and disease and insect resistance, and none of them is reported to have a higher yield potential than IR8.

Observations of the initial acceptance and performance of the high-yielding varieties led to four conclusions. First, in terms of milling and eating quality these varieties were considered to be inferior in many domestic Asian markets and in the international export market. Second, in many parts of Asia these varieties performed poorly because of their susceptibility to local insects and diseases. Third, the varieties were rapidly accepted in many of the well irrigated areas, but have made little headway in the poorly irrigated, rainfed, and upland areas that make up the bulk of tropical Asia's riceland. Fourth, output per unit area has increased rapidly in some regions, and alternatives to rice production should be considered. These problems, which have been widely discussed by my colleagues in the social sciences, have had a marked effect on the direction of research in rice technology both at IRRI and in many of the rice research centers throughout Asia.

Improving Quality

As the technological base in agriculture grows, there is a tendency for the new varieties to become increasingly location specific (*10*). Varieties must be developed that are suited to local tastes and local environmental conditions. Consumer preference for rice in Asia varies widely with the appearance, taste, cohesiveness, texture, and aroma of rice. For most consumers, IR8 and IR5 rank low in both appearance and eating quality. Poor appearance is due to the chalkiness or "white belly" found in a portion of the kernel. This chalkiness also increases the percentage of broken grains in milling. A major influence on eating quality is the *amylose* content of the rice which influences the degree of stickiness. IR8 and IR5 are high in amylose and as a result the cooked rice is dry and flaky, but tends to become hard when allowed to cool.

Because of appearance or eating quality, IR8 and IR5 sell from 10 to 20 per cent below the better varieties and grades of rice throughout most of Asia. For example, in India they are classed as coarse rices, and in the Philippines they normally receive Class II milling (i.e., they are undermilled in comparison with the best quality rices). The appearance and the percentage of broken grains are the major factors determining price in the export market. Hence, in Thailand, where rice is a major export, it was decided not to grow these varieties.

The experience of Thailand offers one of the best examples of the adaptation of the new rice technology to local conditions. In 1970, the Rice Department released three new varieties, RD1, RD2, and RD3 (*14*). RD1 and RD3 are the selections of a cross between the local Thai variety Leuang Tawng and IR8. RD2 is a glutinous rice suited to the local needs of northeast Thailand. It is one of the lines bred at IRRI, a cross between the Thai variety Gan Phai 15/2 and Taichung (Native) 1.

New varieties with good grain quality and high-yield potential have been developed under several national breeding programs: C4-63 in the Philippines; Pelita 1 and 2 in Indonesia; Jaya, Padma, Pankaj, Jagannath, Krishna, Ratna, Vijaya, and others in India (*24*; *25*). In spite of this progress, in many parts of Asia farmers are still looking for a high-yielding variety well suited to local conditions. In some countries where these varieties have already been developed, inadequate methods of seed multiplication and distribution appear to be a bottleneck.

While the latest varieties (IR20, IR22, and IR24) have a considerably better grain quality than IR8 and IR5, the work of improving grain quality should continue to be an important part of the various country research programs. Meanwhile, research workers at IRRI have begun to examine another dimension of the quality problem—protein content.

The protein content of rice is generally low, perhaps 6 to 8 per cent (measured in terms of brown rice) and highly variable according to environment, variety, level of inputs, and other factors. Nevertheless, in Asian diets cereal grain provides as much as 60 per cent of the total protein intake (*28*). Thus, raising the protein content by even as little as 2 percentage points (providing that the quality of the protein is maintained) could mean a substantial improvement in the diets of many Asians.

In 1967 IRRI scientists screened 7,419 entries (3,431 in the wet season and 3,988 in the dry season) to identify varieties with high protein content (*4*; *12*). Six high protein varieties were found, all but one of them, *japonica*, temperate-type rices. The six were crossed with *indica* (tropical) varieties that have good plant type. The attempt to transfer high protein from temperate zone varieties to the high-yielding *indica* varieties has not been successful. Breeding for high protein is difficult because so many environmental factors affect the protein content of rice in addition to genetic potential. It also appears that some mechanisms exist which prohibit the achievement of high protein content and high yield in the same plant.

On the basis of current knowledge, it might be possible to increase the protein content of rice 20 to 25 per cent. But, it may be several years before a rice variety that has genetically high protein content is released for adoption by Asian farmers.

Improving Resistance to Disease and Insects

Athwal noted recently that (*3*, p. 26):

> The increased productivity per unit area has also begun to create problems for plant breeders. The modern production practices used for the new strains provide environments which not only are good for plant growth but also provide ideal conditions for the development of diseases and harmful insects. The shift in varieties and plant environment is, no doubt, favoring the appearance of pests which were previously unknown or unimportant. To exploit fully the potential offered by the semi-dwarf plant type, a high degree of resistance to different plant parasites must be incorporated in the new varieties. Any complacency or inadequate investment in research could keep the new productive potential unrealized and precipitate renewed food crises.

Blast (a fungus disease) and bacterial leaf blight are widespread and destructive diseases in rice. Plant pathologists are working with rice breeders at IRRI and elsewhere to develop varieties with stable genetic resistance that is not specific to a particular race of blast (*20*).

The most widespread and destructive pest of rice is the stem borer. The principal method of control has been through the application of insecticides. Selecting and breeding for insect resistance had been tried in other crops, but was not tried in rice until 1962. From 1962 to 1965, IRRI entomologists screened thousands of varieties for resistance to stem borer. Twenty varieties were identified as highly resistant (*21*; *22*). In 1965 several resistant varieties were crossed to combine resistance to stem borer with improved plant type and other desirable characteristics. In 1969, one of these selections was named IR20 by IRRI.

Research also has been undertaken to identify varieties resistant to the green leafhopper which transmits tungro virus and the brown planthopper which transmits grassy stunt virus (*26*). Viruses have been a particular problem in some areas of Asia. One objective is to develop a variety that has both resistance to the virus and resistance to the insect transmitting the virus. It has also been discovered through genetic studies that in some varieties the gene for resistance to a species of insect is distinctly different from the gene for resistance in other varieties. Thus, it might be possible to combine the two sources of resistance to an insect in a single variety.

Breeding for resistance to insects is a major objective of the rice breeding program at IRRI. Varietal resistance would be the best long-run solution to many of the insect and disease problems. Depending upon the particular disease encountered in a given location, resistant selections could be made available where needed.

Unfortunately, however, insect and disease problems are not likely to be eliminated in the near future. The current outbreak of tungro virus in the Philippines illustrates the problems rice scientists face. On two previous occasions this virus caused serious damage to the rice crop in parts of the Philippines, once in 1941, and again in 1957. Providing adequate control measures will require a better understanding of the biological interactions between the host (rice plant) and the pest (green leafhopper) (*19*). Problems of pest management require a thorough knowledge of the insect ecology, and in 1970 IRRI added a second entomologist to the senior staff to give particular attention to these problems (*9*). There will be a continuing need to explore economical ways of controlling pests through traditional methods such as the use of insecticides, or through less conventional methods such as biological control.

Improving Yields in Unfavorable Rice Growing Environments

In both Japan and Taiwan, population pressure and topography dictated the rapid expansion of irrigation facilities even before the introduction of the high-yielding rice varieties. Thus, historically there has been little need in these countries for much research on problems associated with growing rice under poorly irrigated, rainfed, and upland conditions.

The situation facing South and Southeast Asia today is far different. Improved irrigation and water control offer one way of increasing rice production in Asia. But regardless of how rapidly irrigation and drainage development proceeds, much of the rice in Asia will continue to be grown under rainfed, upland, and deep water conditions for the foreseeable future. Thus, a broad program of research on the problems of water management is needed. Attention must be given to the problems associated with the development and expansion of irrigation, whether by pumps or through gravity systems and, at the same time, the potential for improving production on the nonirrigated areas must be examined far more carefully than it has.

In 1969, a conference was held at IRRI to discuss the direction of rice research in the 1970s (*13*). Much of the discussion related to rainfed and upland rice. In 1970, the Institute added a soil physicist to the staff to devote special attention to the problems of plant-water relations and water management. Several departments have undertaken research to find out what happens to the rice plant grown with less than adequate water supply. A number of papers presented at a symposium on rice breeding at IRRI in 1971 dealt with this subject (*1*; *6*; *8*; *17*; *18*). I have also mentioned previously that research was undertaken in Thailand to examine the other end of the spectrum—deep water rices (*14*; *15*).

In addition to areas where poor water control is a critical problem, there are thousands of hectares of soil in tropical Asia where rice yields are low due to adverse soil conditions that cannot be economically corrected by soil management. Recent research by plant physiologists has helped to identify many of these conditions which lead to nutritional disorders in the rice plant (*27*). Often in the past these nutritional deficiencies had been incorrectly identified as diseases. Research in soil chemistry suggests that it may be possible in the future to breed varieties adapted to these adverse soil conditions that cannot be corrected economically (*23*).

In summary, the objective of much of the current research is to develop a set of inputs tailored specifically to unfavorable environmental conditions. An important element of this input package would be a fertilizer-responsive variety that can tolerate soil nutrient deficiencies, drought, or deep water levels or other unfavorable climatic conditions (e.g., low or high temperature). In addition, by the use of resistant varieties and low cost herbicides, we should be able to reduce the cost of the input package substantially. Low cost herbicides are important because in many rainfed areas farmers who use fertilizer cannot contend with the weed problem: the periodic lack of water cover stimulates weed growth. Naturally, the level of fertilizer input and yield gain will be below what can be achieved in the well irrigated areas. But I feel that there are potential benefits in this program through increased production and income on farms that have not yet been touched by the green revolution.

Multiple Cropping

Interest in the diversification of the agricultural sector and in multiple cropping (growing rice in combination with other crops) has come about largely as a result of the initial success encountered with the new varieties in some areas. A multiple cropping program was initiated at IRRI in the mid 1960s. Bradfield said that the time had come to give more attention to increasing production by increasing the number of crops grown on the land each year (*5*). It is also certain that his pioneering work in developing the technology for multiple cropping will be expanded in the future. Since multiple cropping puts a premium on timeliness in operations, the complementary research in mechanization and in breeding short-season varieties is extremely important.

The introduction of multiple cropping on Asian farms offers far more complications than have been encountered in the dissemination of the new rice technology. Even where market demand and production technology exist, it will be difficult to adjust the production and marketing systems to handle the new crops. There are rice farmers who are neither willing nor able to produce crops other than rice; there are irrigation systems with poor water control suited only for rice production (including the new 100,000-hectare Muda River system in Malaysia); there are government institutions and extension systems which have been focused for years on the task of achieving rice self-sufficiency; and there are market channels which must be improved or developed to handle these new products. Thus, in multiple cropping far more attention will have to be given to problems in extension and marketing if the technology developed at IRRI and elsewhere is to have a high payoff.

CONCLUSION

The recent technological change in rice production began with the release of fertilizer-responsive varieties designed to perform best where water control and supply are not limiting factors. As the varieties have spread to less favorable environments, the inputs used and the yield response have understandably been lower, and in many cases disappointingly low.

One of the most interesting phases of the current research in rice technology involves the attempt to develop input packages specifically suited to unfavorable environmental situations. There are two aspects to this research. First, varieties must be identified or developed that will perform well under the unfavorable environment. Second, efforts must be made to reduce the cost of the accompanying input package. Advances are being made at present in both directions. There is, thus, every reason to believe that the initial breakthrough in the release of the high-yielding rice varieties will lead to a steady evolution in rice technology and in yield gains on farmers' fields.

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