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# Rice Breeding and World Food Production

## Revised research practices and greater international cooperation will advance the green revolution.


Peter R. Jennings


In this article I discuss the relation of technology to the green revolution, the role of plant breeders in inducing change in stagnant agriculture, and the tools required by production scientists to increase yields of basic food crops in developing countries.

The words "green revolution" constitute an ill-chosen term applied by the world press to certain recent changes in the culture of wheat, rice, and, to a lesser extent, other cereals. This term has unjustified overtones of magic or miracles. But, in fact, it describes the modification and application of accumulated information developed over past decades in North America, Europe, and Japan to cereal production in the developing countries.

The green revolution is dependent largely on new varieties with higher yield potential. The new rice and wheat varieties resulted from two fundamental varietal changes: (i) a drastic shortening of straw to reduce lodging and to increase the ratio of grain to straw, and (ii) a marked increase in adaptability over latitude, elevation, and a range of other environmental factors.

It is clear that the new varieties must be tied to improved husbandry. Seed alone induces little change. A complex of seeding rates, water and weed control, adequate fertilizer levels and timing, and so forth was developed for the new varieties. The combination of new seed and improved cultural practices is necessary to achieve the potential for greatly increased farm yields.

This package of varieties and husbandry contains only the potential for change. The extension of this technology alone does not automatically stimulate production, especially in the impoverished agricultural sector represented by small, subsistence farmers. Thus, the final component essential for change is effective and sustained governmental commitment and incentives for bigger harvests. This includes attractive farm prices, credit, availability of inputs, transport, drying, and storage.

What has the green revolution accomplished? In the crop year 1972–73 there were an estimated 27 million hectares in the new small grain varieties of which rice accounted for about 15 million hectares. It is difficult to estimate the yield benefit of the new varieties because they are usually grown on the better land. Discounting this factor, it appears that the new varieties contribute an average of at least an


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additional 0.5 ton of grain per hectare.

The changes in Philippine rice production attributable to the new technology were calculated for the five crop years of 1967 to 1968 through 1971 to 1972. Rice production increased an average of 12.4 percent annually.

The release of three new varieties in Colombia since 1967 resulted in essentially 100 percent adoption of the new technology in the irrigated rice areas. The average yield of irrigated rice in 1966 was about 3 tons per hectare. Today it is approximately 5.4 tons per hectare.

Agricultural research pays handsomely in developing countries. In Colombia the value of the additional production associated with the new rice technology from 1967 to 1972 was about 100 million U.S. dollars. This more than paid for government investment in research, extension, and education for all crop and animal programs during the period. The Colombia program has had a significant influence elsewhere in Latin America, so that the total payoff is greater than the figure cited by a factor of 3 to 4. The value of the total additional rice output on a world basis since 1966 exceeds $2.5 billion.

These are some aspects of the positive side of the green revolution. In the face of these gains, world grain production fell 4 percent in 1972, a significant deviation from a 20-year trend of rising per capita food production in developing countries. This decline caused violent reactions in prices, transportation, and foreign exchange. The decline in production clearly is related to drought in the wheat areas of the U.S.S.R., China, and Australia, in the sorghum area of Africa, and in portions of the rice bowl of Southeast Asia. Contributing factors were unprecedented floods in central Luzon in the Philippines and massive grain shipments, particularly from India, to the war-devasted rice producer Bangladesh.

The world press increasingly has attacked the green revolution, saying that it is a hoax and that there has been no sustained advance in the technology of food production—rather, only a series of favorable weather years in the late 1960's. This is not true. The facts are that we have had increases in wheat yields in Mexico, India, and Pakistan, and elsewhere, and in rice productivity in selected areas of the Philippines, Indonesia, India, Pakistan, and Latin America. It is also clear that the new technology is unable to change weather cycles, particularly those resulting in excess or insufficient moisture.

Likewise, adverse criticism has been made about some technological aspects of the green revolution. It is alleged that the new varieties require heavy resource inputs of fertilizer, water, insecticides, and the like. They do require additional care and inputs to give maximum yield, but they differ from traditional varieties in that they respond to these improvements and are vastly more efficient in terms of grain per kilogram of nitrogen or per unit of water applied.

It is claimed that the high yielding varieties are generally more susceptible than traditional ones to diseases and pests. This is not true. Traditional varieties grown at wide spacing and minimal fertility levels escape epidemics; but when they are closely spaced, heavily fertilized, and supplied adequate moisture they are recognized to be susceptible. The danger, rather, has been the rapid replacement of thousands of old varieties by a few new ones. This uniformity of germ plasm over vast areas is an invitation to sudden epidemics, but we are moving away from this danger with the release by national programs of many new high yielding varieties. International cooperation on the development of resistance, stimulated by the successes of the green revolution, has never been greater than at present, and, in general, progress toward healthier crops is satisfactory.

It is said that some of the new varieties have inferior eating or milling quality. This was true with the rice variety IR8 in Colombia. Initially only the farmers wanted IR8 because of its prodigious yields. The millers, grain merchants, and some researchers, accustomed to thinking only of fine grain for the affluent sector, were opposed. Fortunately, the government was encouraged to place a moderate price support on IR8 to stimulate production. This pleased the farmers because the heavy harvests offset the somewhat lower farm price. The government bought inexpensive rice and retailed it at popular prices to poor urban consumers who liked the price and accepted the quality. Demand, production, and consumption increased until new high yielding varieties with improved quality were released to replace IR8. It is relatively easy to breed for eating and milling quality so that the newest wheat and rice varieties are virtually identical in grain characters to the traditional varieties.

Social scientists also frequently criticize secondary problems related to the green revolution. They argue that research resulting in recent production increases has had undesirable social effects. Among others they cite labor displacement, inequitable income distribution, and the favoring of large farmers. Such criticism is probably justified, and to avoid these social problems it is essential that agricultural economists develop better guidelines to help the production scientists establish research strategies to reduce the adverse consequences of increased production. Until these strategies are formulated we have no choice but to pursue the simplistic goal of increased food production. To do otherwise is to risk the disaster of world famine.

## Role of Plant Breeders in Developing Agriculture

What is the role of plant breeders in moving stagnant agriculture? How do we avoid unwanted consequences of having discoveries adopted by only a sector of the farmers? To what extent are we concerned with intermediate level technology for farmers unable or unwilling to follow all recommendations for optimum yields?

The wheat and rice production packages are clearly environment-specific even though the area of impact may be broad. They originally were directed toward the areas of favored soil, water, and climate as the fastest way to increase food production rapidly. This was a logical, initial decision to stimulate public acceptance of technology and a favorable political climate for continuing research. The limited adoption of the new wheats in the septoria, the stripe rust, and other areas of Latin America and the Middle East or of the new rice technology in areas of pronounced water deficit or excess situations demands a modification of technology to overcome distinct but definable factors now limiting production in many areas.

In terms of fertilizer response the new widely adapted grain varieties are superior in production at both intermediate and optimum fertility levels. Farmers can choose their own levels. Breeders need greater recognition of the importance of conducting station, regional, and demonstration-yield trials at intermediate and high fertilizer levels to ensure release of new varieties for a range of natural soil fertility and the ability of farmers to purchase fertilizer.

Varieties more widely adapted to other production limiting factors are needed. It is essential that breeders expose their materials to severe selection pressures. Too often we control insects, diseases, and water stresses simply to dress up our plots. This, of course, reduces our ability to recognize the most tolerant segregates. We need to bring together greater tolerance to a wider range of diseases, pests, cold, heat, moisture supply, and soil problems. This involves extensive international testing and selection through the international research centers that offer invaluable linkages to separate national programs.

We production scientists must ask ourselves why the new rice technology produces only about 0.5 ton per hectare more than the traditional varieties on farmers' fields in Asia. We know that the same comparison made on Asian experiment stations or on farms in Latin America gives a yield benefit of two or more tons. Our single factor experiments show, for example, that the new varieties yield at least as well as the traditional varieties at minimal levels of fertilizer and yield a great deal more at higher levels. These experiment station results cause invalid generalizations regarding the comparative worth of the new and traditional varieties under all environments. We are confused by the limited adoption of the new technology and the modest increases in yield in certain stress areas. The extreme consequence of this seeming paradox is to conclude that the extension agents are not conveying the message to the farmers.

This problem is directly related to the multiple stresses of water, weeds, and pests characteristic of large production areas—but relatively absent on experiment stations. When the stresses are numerous and severe our new varieties seldom show a marked yield advantage and often are inferior. In Asia about 60 percent of the rice land is rainfed and depends upon rainfall for irrigation water. This huge rainfed area simply lacks adequate technology. The 20 percent of Asia's rice that has good water control has benefited handsomely from the new technology.

The solution for marginal areas is not to settle for the traditional varieties but to adapt, modify, and extend the new technology to produce varieties for each stress or combination of stresses. Thus, breeding methodology must be altered to reflect these stresses in our plots at experiment stations. For example, when rains are late farmers delay transplanting seedlings past the optimum date by as much as 3 or 4 weeks. This alone greatly reduces yield in the new varieties. Yet, breeders continue to transplant their materials at the ideal time for optimum yield. It might be more useful to vary the age of transplanted seedlings from one generation to the next. Similarly, it does not seem reasonable invariably to apply optimum levels of 80 to 120 kilograms of nitrogen per hectare to segregating populations when rainfed farming is so risky that nitrogen cannot be applied in heavy dosages in commercial fields. Water control in breeding plots should be relaxed to more accurately represent rainfed farm conditions. These and other research practices hold the key to the development of technology for areas as yet unfamiliar with the green revolution. The point is that production scientists must identify yield limiting factors on farms before they can attack them on experiment stations. Some breeders are changing their methodology to develop modified technology for marginal rice producers in rainfed, upland, deepwater, and problem soil areas. More work of this sort is needed.

There appears to be an insufficiently appreciated biological principle related to the improvement of crops within their centers of origin. The following correlative statements seem to characterize all major food and industrial crops: (i) Yields are lowest within the centers of crop origin. (ii) Yield limiting factors are most numerous and complex in the centers of crop origin. (iii) Resistance to change in production methods is greatest in the centers of crop origin. (iv) The impact of any given amount of technology is least within the centers of crop origin.

There are several biological explanations for these observations including greater insect and disease pressures within centers of origin. Another possibility of overriding significance is that crop varieties developed through natural selection in their centers of origin are vegetatively large and vigorous and have great intra- and interspecific competitive ability. Improvements in yielding ability inevitably result in reduced competitive ability. Thus, man must artificially control in improved varieties those restraints to crop yield which were partially curbed by the natural defense mechanisms of unimproved, competitive land varieties.

One conclusion from the foregoing observations is that crops within their centers of origin are most difficult to improve, and that a complex technological package is essential for progress. The export of a portion of that package, however, may increase yields greatly in areas outside the centers of origin. Conversely, it often is apparently futile to import specific technology from outside to within centers of crop origin.

I believe that plant breeders working in disciplinary isolation within centers of origin face insurmountable barriers to success. The only valid criterion for judging plant breeding work is its effect on national or regional food production. Food production is the objective, not varieties, or pest control, or cultural practices. This simple criterion demands the creation of multidisciplinary breeding teams composed of crop physiologists, agronomists, entomologists, pathologists, economists, breeders, and others. Pooled contributions from team members overcome problems that would hinder breeders working alone. Organizations responsible for two or more commodities should organize research by crops rather than by discipline. The point is that a rice breeder has more in common with a rice entomologist, pathologist, or agronomist than with a breeder of any other crop.

A critical charge of the plant breeding team is the definition of objectives and priorities. Breeders occasionally fail to identify the production limiting factors from among the plethora of secondary problems that often are more interesting academically. Contrast the situation for rice and corn in the tropics. The administration of the International Rice Research Institute (IRRI) from the beginning demanded varieties of greater yielding potential. Elegant work by institute crop physiologists indicated in detail on paper an ideal plant type and pinpointed the vegetative characters of traditional varieties requiring drastic modification. In retrospect, it was a relatively simple task for the breeders to follow this blueprint and produce a series of productive dwarfs beginning with IR8. The institute would have failed if it had concentrated initially on the genetics, disease resistance, quality, or cultural practices of existing varieties.

In contrast, I rarely have seen a highly productive corn crop in its ancestral home in the American tropics. The problem appears to be that the plants are too tall, giving an uneconomic grain-to-stalk ratio and lodging before harvest. The insistence on the development of genetically uniform and narrowly adapted hybrids for hundreds of thousands of small farms is a departure from common sense. The genetic uniformity results in massive insect and disease problems while the sowing of double cross hybrids demands the replenishment of seed of each crop. Corn yields in the tropics are not moving forward. In Colombia a recent crash program to develop and extend the same old maize with greatly improved nutritional value based on the *opaque-2* gene failed, as could have been predicted. More realistically, the first aim should be to produce short, efficient, widely adapted, open-pollinated varieties and later to improve their quality.

Similar examples of competent research on nonlimiting production problems of basic food crops in the tropics could be mentioned. I cannot think of a food crop associated with static agriculture in which the primary breeding objective should not be the doubling of yielding ability.

Once a breeding team has accepted increased yield potential as the prime objective it is imperative that it set high goals. Gains in productivity of 100 percent are reasonable for all food crops in the tropics. We must seek quantum jumps in productivity and not be content with a cumulative series of minor improvements. It has been argued that the peasant farmers cannot handle abrupt changes in varietal types and their husbandry related to greatly increased yielding ability. The fact is that peasant farmers have adopted and benefited from radically new wheat and rice technology. Furthermore, the rate of adoption is proportional to the magnitude of improvement offered by the new technology. This does not conflict with the recognized need for intermediate levels of technology for farmers in stress areas who cannot use all of the available technology. There is no more prospect of moving agriculture in marginal areas with 10 percent gains in productivity than there is for favored areas.

Breeders who seek massive jumps in productivity can ignore all of the tedious detail and routine of demonstrating that modest differences are statistically valid. How much more simple and efficient it is to eliminate ruthlessly all but the obviously elite material, freeing precious time to handle vast volumes of crosses and segregates.

Even rice and wheat, recently doubled in yield potential to levels of 6 to 9 tons per hectare on better farms in developing countries, cannot be considered to have reached yield ceilings. Complex theoretical calculations for rice in the existing tropical environment, based on known variability within the species in photosynthetic efficiency and in storage capacity within the grain, indicate a yield potential of 14 or more tons per hectare. These traits are difficult to handle with existing breeding methodology but the point is that there is scope for another doubling of yield potential. We must encourage radical thought and research for increased food production. Such a seemingly farfetched scheme as the fusion or hybridization of rice or wheat with corn or sugar cane, to transfer to small grains the more efficient photosynthetic pathway of these donor species, may one day be considered routine practice.

## Research Tools Required for Developing Agriculture

I should like to refer briefly to the research tools required by plant breeders and other production oriented scientists involved in overcoming stalled agriculture. In contrast to today's fever for ever more complex and recondite equipment in much of science, the requirements for a sustained assault on unsatisfactory food production are disarmingly simple. These include a team of scientists dedicated to a common goal, a comprehensive collection of germ plasm, abundant labor, land, and power to till it, assured water supply, a sprinkling of simple seed rooms and greenhouses, and money for massive practical training of young researchers in materials and methods. These basic inputs, coupled with enlightened administration coordinating applied research on limiting problems, the means to test experiment station results directly on farms in diverse areas, and a mechanism for functional linkages to national research programs are essential for success.

This characterizes the situation at IRRI from its beginning in 1962 to the release of IR8 four years later. One fears, however, that many who seek to analyze the brilliance of IRRI have missed the basic point. The trend at the new research centers for the tropics appears to reflect the conclusion that luxurious facilities are indispensable for progress. The point is that bricks and mortar bear scant relation to progress in the tropical environment. Dedicated people, simple facilities, and hard work on limiting problems are the key. The brilliant wheat program in Mexico is a classic example of clarity of purpose. It made extraordinary contributions before there were any government stations in existence.

There are inevitable consequences of failure to provide essential research needs. Obviously, money spent on esthetically attractive but unnecessary building is unavailable for labor, tractors, pickups, wells, and other critical needs. Massive physical plants eventually limit flexibility and the ability to shift people and resources to meet constant changes in research priorities and problems as they occur in different areas. A program that does not attack a new or old problem away from its headquarter facilities is a program in trouble. Finally, it is futile to attempt to attract peasant farmers, the ones we are criticized for ignoring, to opulent research centers. They will only return to their villages more convinced of the inapplicability of the rich scientists' hocus-pocus to change their situation.

I conclude by reiterating my belief that the green revolution is alive and well and that greater advances will be forthcoming. Technological shortcomings and socioeconomic problems will continue, and we will not lack for those to point them out. Yet, this is a time for optimism and confidence in ourselves, in our work, and in the farmers we serve. Pessimism and defeatism have no role in the struggle to increase food production in the developing nations.