# Genetic Technology and Agricultural Development

Genetic technologies provide necessary but not sufficient conditions for agricultural development.

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The recent introduction of genetic technology into several South Asian countries has spawned dramatic changes in their possibilities for increasing agricultural production. New fertilizer-responsive seeds, however, while necessary, have not constituted sufficient conditions for agricultural development.

Recent articles (*1*) have described the production potentials embodied in the improved varieties of wheat now widely used in Asia. This article describes the impact and limits of the green revolution triggered by the new genetic technology. While the primary focus of this article is on India, where the initial impact has been significant, the discussion also affords insights into problems of agricultural development in other South Asian countries.

The phenomenon currently called the green revolution is not unique to the 1960's. Insights gained from other countries that have experienced technological change in agriculture suggest caution in attributing increases in farm production in South Asia entirely to genetic technology. The improved genotypes currently spreading throughout that area are highly visible, while changes in the use of other farm inputs are not.

Japan, Taiwan, Korea, and Mexico passed through periods in which agricultural production shifted markedly upward in a few years (*2*). Rice yields per hectare in Japan increased rapidly between 1910 and 1920. In Japan, Taiwan, Korea, and Mexico, the periods of dramatic increases in yield were the result of an accumulation of agronomic research findings, extension efforts, and farm capital (*3*). With the exception of Japan, these countries imported much of the scientific knowledge upon which these increases in yield were based. Genetic technology, however, was not the single or even the most important factor in the agricultural growth of these countries.

In Mexico, for example, increases in the use of farm inputs accounted for over one-half of the annual rate of increase in agricultural output between 1940 and 1965 (*4*). The remainder was attributed to increases in production efficiency (output per unit of input, measured in value terms). Embodied in the latter, however, were improvements in farm management practices as well as unmeasurable qualitative changes in the inputs themselves.

## Dimensions of Technological Change

Agricultural production in India from 1948 to 1962 grew at a compound rate of 3.1 percent per year, just slightly higher than the annual population increment (*5*). Beginning in the 1967-68 crop year, the rate of growth in agricultural production appears to have shifted to a higher trend line (*6*). Food-grain production increased from 88 million metric tons in 1964–65, the year preceding the two severe droughts, to 95 million metric tons in 1967–68, and 100 million metric tons in 1969–70 (*7*). Even in 1968–69, despite severe shortages of rainfall in many parts of the country, production of food grains increased 1.5 million metric tons over that of the preceding year.

Underlying this apparent shift in trend is the rapid diffusion of semi-dwarf varieties of wheat imported from Mexico and high-yield varieties of rice from the International Rice Research Institute at Los Baños, Philippines. In the 5 years since 1965–66, the first year in which these seeds were available in India, 4.4 million hectares of semi-dwarf wheat have been planted, and 3.7 million hectares of high-yield rice have been planted (*7*).

## Wheat and Rice

To date, advances in genetic technologies have primarily affected the production of wheat. Wheat, however, is of secondary importance in most of South Asia; rice is the predominant cereal. Effects on the yield of rice, thus far, have been much less dramatic than on the yield of wheat.

In Punjab, the major wheat-producing state in India, the output of wheat since 1965–66 has more than doubled (*8*). A large portion of this increase is explained by a 76 percent increase in output per hectare.

Wheat is generally grown in the dry season, and in Punjab—a state that has experienced long-term agricultural growth—about 70 percent of the cropped land is irrigated. The availability of water in the dry season made semi-dwarf wheats readily applicable in this region.

As compared with a 62 percent increase in the production of wheat, the production of rice in India in 1969–70 was only 5.2 percent greater than in 1964–65 (*7*, *9*). While 27 percent of the area sown with wheat is now sown with semi-dwarf varieties, only 10 percent of the area sown with rice is in high-yield varieties (Fig. 1).

The relatively slower progress in the production of rice is related to many factors. Improved varieties of rice are more susceptible to disease. Further, they require stringent water management. Finally, many improved varieties are discounted heavily in the market because of the inferior quality of the grain (*10*).

Some of the problems associated with high-yield rice can be illustrated by considering its acceptance in the northern part of West Pakistan (Table 1). In terms of agroclimatic conditions, this area contains some of the best rice-producing land in Asia. Because high-yield rice has been widely accepted in this area, one-fifth of the total rice area in West Pakistan in 1968–69 was planted with high-yield varieties.

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Table 1. The total area planted with rice, with new varieties of rice, and with new varieties of rice as a percent of the total area planted with rice, in selected South Asian countries, 1968–69 (*10*).

| Country | Rice: Total (1000 hectares) | Rice: New varieties (1000 hectares) | Rice: New varieties (% of total) |
|---|---|---|---|
| Ceylon | 663 | 7 | 1.0 |
| India | 36,966 | 2,631 | 7.1 |
| Indonesia | 8,478 | 168 | 1.9 |
| West Pakistan | 1,514 | 308 | 20.3 |
| Philippines | 3,199 | 1,059 | 33.1 |
| Others* | 18,022 | 490 | 2.7 |
| Total | 68,842 | 4,663 | 6.7 |

* Burma, Laos, Malaysia, Nepal, East Pakistan, and Republic of Vietnam.

The area contains fertile soils. Underground water for irrigation is in abundant supply (*10*). Even during the monsoon season—the season in which most rice is produced—the climate has a relatively low humidity. This combination of factors affords a particularly favorable environment for growing rice.

High humidity, which affords good conditions for the growth of insects and disease, prevails during the rainy season in most other rice-producing areas of Asia. Conversely, lower humidity is less conducive to these hazards. Also, since too much water is as deleterious to yields as is too little, water management is quite important. With irrigation by tube wells, West Pakistani farmers can exercise precise water management. Hence, a significant quantity of rice is produced, much of it from the new seeds and the farming practices that must accompany them.

In India, rice is grown during the monsoon season, when the humidity is high. It is grown primarily on rainfed or canal-irrigated land. Farms are frequently fragmented into plots of one-half acre or less. Given this degree of farm fragmentation, water management is difficult on canal-irrigated land and is virtually impossible on rainfed land. Consequently, the new varieties of rice have been less readily accepted in India than in West Pakistan.

## Further Expansion of Genetic Technologies

The impact of genetic innovations on agricultural and economic development depends upon the rate and the degree of their adoption. Both of these factors are tremendously important in a decentralized agriculture, where there are innumerable decision-makers.

The American experience with hybrid corn offers an interesting parallel to the adoption of genetic technology in South Asia today. "Hybrid corn was an innovation which was more profitable in the 'good' areas than in the 'poor' areas" (*11*). Hybrid corn was not only introduced into good areas earlier, but the rate and degree of adoption were greater in the good areas than in the poor areas. For example, hybrid corn was introduced in Iowa in 1936, and was sown on 90 percent of the Iowa corn land within 5 years. A variety suited to Alabama, however, was not available until 1948, and by 1959 it had not yet been planted on 90 percent of the corn land.

Those areas of India in which the necessary conditions were present have responded most readily to infusions of genetic technology. The importance of irrigation has been described already. Only 20 percent of the cropped area in India is irrigated, and this is not evenly distributed throughout the country. High-yield wheat and rice are grown almost exclusively on irrigated land. Consequently, a distinct regional bias can be observed, in which some regions are experiencing rapid development and others are experiencing very little. Further, the easiest gains have been made during the first 5 years of the green revolution. Additional gains are to be achieved, but they are likely to be less dramatic and more difficult to obtain.

In areas where high-yield varieties are now widely used, there are still farmers who have yet to adopt them. In addition, further gains are possible on farms that are already using high-yield varieties. These later gains will result from more sophisticated farm management practices, including more efficient allocation of fertilizer and pesticides.

In areas where high-yield varieties have yet to make a substantial impact, more genetic research is required to develop varieties suited to local conditions. Relatively little change has been made in coarse grains (maize, millet, and sorghum) produced on rainfed land. These crops, grown on 38 percent of the land in food grains, account for only 25 percent of India's production of food grains. Only 6.5 percent of the land sown with coarse grains is sown with high-yield varieties (*7*). The basic problem is to develop varieties that respond to fertilizer under conditions of water scarcity. Due to the difficulty of solving this problem, yield differentials between new varieties and existing ones are not likely to be as dramatic in nonirrigated, rainfed farming areas as in those where water management is possible.

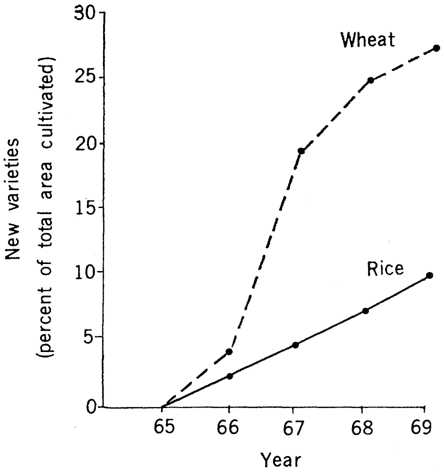


Fig. 1. An area in India sown with improved genetic varieties of wheat and rice as a percent of the total area sown with each crop, 1965–66 to 1969–70 (*7, 9*).

Further genotypic improvements are likely, and research on new varieties is being conducted on a large scale. The Indian Agricultural Research Institute, for example, recently announced the release of a new, triple-dwarf wheat capable of yielding 5 to 8 tons per hectare as compared to 4 to 6 tons for earlier varieties. Another potential opportunity for significant gains from genetic technology may be in soybeans, a crop not widely produced in India. A growing industrial demand for soybean oil, however, has stimulated research on the agronomic and economic conditions necessary to make soybean production economically feasible.

## Prospects for Agricultural Development

One phenomenon that occurs coincidentally with the modernization of traditional agriculture is a change in consumption of farm inputs, particularly purchased inputs. Fertilizer consumption in India has increased threefold since 1964–65; the number of tractors and pumpsets has doubled during the same period. Data in Table 2 illustrate differences in the use of inputs between farms that produce high-yield varieties and those that do not. These data also caution against overemphasizing the effect that genetic technology has on output. Much of the increase in output must be attributed to the increased use of purchased inputs, especially fertilizer. Increased applications of purchased inputs are usually profitable when applied to improved, as compared with traditional, varieties.

Nevertheless, the seed technologies and associated inputs have substantially affected output. They have permitted governments to shift some of their attention from expanding the output of food per se to other pressing issues related to social and economic development. Among these issues, problems related to the generating of employment and the distribution of income have been and continue to be of prime importance. Some analysts have identified these social and economic issues as second-generation problems resulting from the diffusion of modern farming practices (*12, 13*). Many of these problems, however, are not new, but have been amplified by the spread of genetic technologies. Nevertheless, relatively little could be done about these issues until some progress on the underlying problem of food production was visible.

## Employment

Given current and projected birthrates and rural-urban migration patterns, a relative (but not absolute) decline in the rural population of India can be expected over the next two decades. By 1985, the rural population in India is expected to be 477 million, an increase of 155 million since 1962 (*14*). Historically, absolute declines in rural populations have occurred only after a country has reached a high level of industrial development (*15*). Brown puts the matter simply: "The food population problem of the sixties is becoming the employment population problem of the seventies" (*16*).

The data in Table 2 clearly indicate a marked increase in expenditures per hectare for labor on farms that grow high-yield varieties, as compared with those farms that do not. With increased applications of fertilizer and water, better field preparations, greater crop volumes to harvest, and so on, more labor is required (*18*). Further, employment opportunities are expanded because the possibilities of double-cropping have been made more feasible by the new genotypes, which have a shorter growing period than traditional

Table 2. Cash input: cost of high-yield varieties as opposed to local varieties of rice and wheat, for 1967–68 (*17*).

| Crop | Input (rupees per hectare) | | | | | |
|---|---|---|---|---|---|---|
| | Seeds | Fertilizer | Labor | Irrigation | Other | Total |
| | | | *Wheat* | | | |
| High-yield | 69.9 | 232.8 | 191.5 | 58.6 | 52.6 | 605.4 |
| Local | 4.7 | 22.0 | 41.0 | 12.4 | 4.9 | 85.0 |
| | | | *Rice* | | | |
| High-yield | 30.1 | 332.8 | 367.4 | 27.7 | 40.5 | 798.4 |
| Local | 8.2 | 104.3 | 190.5 | 13.8 | 16.8 | 333.6 |

varieties do. Total expenditures on labor for rice are twice those for wheat. Further, rice, whether a new genotype or a local variety, is a much more labor-intensive crop than wheat.

The increased demand for farm labor (particularly harvest labor) caused by changes in wheat technology is illustrated by an increase in the cost of farm labor in Punjab, the state in which high-yield wheat varieties have been most widely adopted [from 3.5 rupees, or approximately $0.47, per day in 1964–65, to almost 7 rupees per day in 1968–69 (*19*)]. This increase in farm wages also reflects a scarcity of farm labor in Punjab, relative to other areas in India. In Punjab, one of the most industrialized states in India, only 12 percent of the people engaged in agriculture are hired laborers, compared to 24 percent for the rest of India (*9*).

The increase in the cost of farm labor complicates the employment problem. Increasing labor-wage rates also imply that laborsaving implements are likely to become more competitive with labor. Many wheat farmers, responding to shortages of, and high wages for, harvest labor, are beginning to use small-scale, laborsaving implements. Reapers and threshers, unlike tractors, are relatively inexpensive and can be produced locally. Harvesting and stacking a hectare of wheat by hand, for example, requires 13 man-days of labor, while a bullock-drawn reaper accomplishes the same job with the reaper, 3-man-days, and 1 day of bullock labor (*20*).

Should these trends continue, the long-term effects on farm employment in rapid growth areas like Punjab may differ markedly from those observable in the short run (Table 2). The relatively high cost of farm labor in Punjab, however, is partially determined by the demand for labor by nonagricultural firms. Consequently, the long-term substitution of machinery for labor in Punjab agriculture will be partially the result of an active market for nonfarm labor.

Farm employment conditions elsewhere in India are quite different. Wages are lower, and a higher proportion of people involved in agriculture are hired laborers. Assuming no change in population trends, the prospects for improving rural employment opportunities depend largely upon the degree of progress that occurs in the farm sector. For example, of Maharashtra, a state with very limited irrigation, one economist has concluded, "With limited scope for irrigation and multiple cropping on one hand and rapid growth of population on the other, the man-land ratio is fast increasing and the average working time of a farm worker is declining. An overall 3.8 percent increase [estimated increase in demand for farm labor by 1983–84] is too small to have any marked effect on the employment of the rapidly growing labor force and the conversion of disguised into open unemployment among farmers . . . and agricultural laborers" (*21*).

Where new varieties of rice are adopted on a widespread basis, a marked increase in the demand for farm labor can be expected. Farms in major rice-producing areas tend to be small and are generally quite fragmented. Consequently, labor-saving implements are not as well suited to rice production and are not as apt to offset the effects on employment that are associated with increases in the demand for farm labor.

Agricultural development also stimulates the growth of agribusiness firms. Therefore, where genetic technologies are adopted, opportunities for rural, nonfarm employment may occur, thus affording additional employment for the rural labor force. Previous studies suggest that the employment linkages between farm and nonfarm sectors, in the context of a developing agriculture, are weak (*22*). In areas like Punjab, however, where long-term agricultural and nonagricultural growth have occurred, the employment characteristics suggest that possibilities for increasing nonfarm employment among the rural population should not be ignored. Some 77 percent of the population of Punjab is classified as rural, yet only 56 percent of those employed in the state are engaged in farm production (*8*). Hence, a significant portion of the rural population is engaged in nonfarm employment.

India has yet to experience the massive infusions of rural immigrants into urban areas that many other developing countries have (*23*). Rapid rates of increase in the urban population are usually accompanied by large increases in the demand for public services. Given other demands on public revenues, these are services that developing countries can ill afford. The need for such expenditures will be minimized to the extent that intersectoral migrations are. The degree to which intersectoral migrations are minimized depends, in turn, upon the extent to which employment opportunities are open to the rural population. Consequently, possibilities for expanding rural, nonfarm employment should be studied seriously, if the benefits of the technological change catalyzed by the new genotypes are to be realized.

## Distribution of Benefits

Some analysts (*13*, *24*) have suggested that the distribution of benefits from the new technologies parallels existing resource endowments. That the rate of agricultural development varies among regions, depending upon the indigenous crops and water resources, is not questioned. Regional differences in the rate of adoption of modern farm technologies implies that all regions do not benefit equally from the introduction of these practices. This is, in itself, an important problem. However, the distribution issue addressed by these analysts is intraregional in nature and focuses on whether the new technologies are being adopted by a relatively small number of operators of large farms to the exclusion of the more numerous, less prosperous farmers. If the benefits of the new technologies accrue primarily to relatively few farmers, the subsequent economic problems and political consequences will not be small.

While definitive answers are not available to support or refute these contentions, some insights are available. Noteworthy is the fact that the practices associated with the new genotypes can be adopted regardless of the size of a given farm, everything else being equal (*25*). Data were collected from a cross section of farmers in three areas of India. In all three areas (one wheat- and two rice-producing), the use of high-yield varieties is widespread. The data indicate that the adoption of modern technologies is not especially determined by farm size. In 1967–68, three-fourths of the farmers in the wheat-producing region, as well as 82 and 90 percent of the farmers in the two rice-growing areas, had begun using the high-yield variety suited to their immediate locale (*26*). Farmers in the wheat-producing region were stratified, by size of farm, into five groups. Within each stratum, the proportion of farmers using high-yield wheat was (in ascending order of farm size) 70, 87, 60, 80, and 77 percent, respectively. This rate of adoption has occurred since 1965–66. As expected, the operators of the smallest farms were the last to adopt. Also, relatively few farmers had completely discontinued the production of traditional varieties. Nevertheless, the fact that, in 3 years, these proportions of the farmers in each region had begun using the high-yield varieties is phenomenal.

Irrigation facilities and farm implements represent large investments for low-income farmers. Irrigation, in particular, is a key prerequisite for determining the applicability of high-yield varieties on a given farm. Many farms are too small or fragmented to invest in tube wells and irrigation equipment. In some areas, however, small farms can purchase water from neighboring farms at rates slightly higher than the marginal cost of pumping (*27*). Moreover, smaller farms tend to have a higher proportion of irrigated land than do larger farms (*28*). Also, in some areas of North India farmers are beginning to share wheat threshers. Thus, even though many farmers cannot afford to buy many of the implements associated with producing high-yield varieties, a fractionization of "lumpy inputs" (inputs that are not easily divided) is possible by means of custom operations.

Operators of both small and large farms, therefore, appear to be adopting inputs and practices associated with the green revolution. Operators of large farms, however, tend to control resources and volume of production to a degree far exceeding their proportion of the population. For this reason, they may be obtaining a proportionately greater share of the benefits of green revolution practices than are operators of small farms.

## Summary


The genetic technologies being adopted in South Asia are significant factors in the agricultural development of the area. But, labeling them "miracle seeds," solely responsible for recent agricultural growth, is misleading. Certainly the introduction of new genetic technology has catalyzed South Asian agriculture and has instilled a new dynamism essential to economic development. Somewhat similar phenomena have, however, been observed in other parts of the world in other periods of history.

The nature of these genetic technologies, how they are being applied, and their limits and potential have been explored above. Also, the effects of these varieties on the generation of employment, and the distribution of benefits accruing from them have been examined in preliminary fashion.

Stemming from the preceding discussion, two areas of priority appear obvious. First, the close association of genetic technologies with irrigation suggests that irrigation should receive more attention than it has in the past. Large-scale public irrigation schemes are expensive and have tended to yield low rates of return. However, there appears to be room for marginal increases in, or improvements of, existing irrigation facilities.

Second, even with a rapid spread of the practices associated with high-yield varieties, it may be too much to expect the farm sector to absorb the expected increases in the rural labor force. The generation of employment is a major problem in India as well as in most other developing countries. Hence, possibilities for expanding rural, nonfarm employment and controlling population growth should be sought vigorously.


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18. Also noteworthy is the fact that the cost of labor, as a percent of total expenditures per acre, is lower on farms growing high-yield varieties than on farms producing local varieties (Table 2). Low farm wages, disguised unemployment, and underemployment in Indian agriculture have been explained as a consequence of overutilizing labor, relative to land. See, for example, G. Ranis and J. Fei [*Amer. Econ. Rev.* **51**, 533 (1961)]. The above explanation may be valid when only land and labor are considered as factors of production in developing agricultural economies. However, farmers adopting genetic technologies also use much larger quantities of other inputs—seed, fertilizer, and irrigation. The large absolute and relative increases in the use of these inputs permits large absolute increases in the use of farm labor, without increasing the amount of labor relative to the total package of farm inputs. This implies that the capacity of agriculture in general to absorb labor is enhanced by the adoption of new genetic technologies. Likewise, agriculture's capacity to absorb labor in regions where genetic technologies are applicable is apt to be much larger than in areas where genetic technologies are not applicable.
19. Unpublished data, Directorate of Economics and Statistics, Government of Punjab.
20. Many implements with laborsaving features are adopted to facilitate more intensive use of farm land. Consequently, in examining the effects on employment associated with a given implement, one must consider the change in the use of farm labor caused by more intensive land use, as well as differences in the technical substitution coefficient for a given operation. See I. Singh, R. H. Day, S. S. Johl, *Field Crop Technology in the Punjab, India* (Social Systems Research Institute, University of Wisconsin, Madison, 1968), p. 79.
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26. The wheat-producing region is Ferozepur District, Punjab; the first rice-producing region is Thanjavur District, Tamil Nadu. Data for these districts were drawn from the as yet unpublished 1967–68 report on the economics of farm management studies for these districts. The second rice-producing region is West Godavari District, Andhra Pradesh. Data on the rate at which new varieties were adopted in this district were obtained from a seminar by E. Rogers, USAID, Washington, D.C., September 1970, at which he presented the results of his as yet unpublished study of factors influencing the adoption of new farming practices in Brazil, India, and Nigeria.
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# Quantal Mechanism of Neural Transmitter Release

B. Katz

I have been asked on more than one occasion to explain the common denominator between the three of us who are sharing this year's award in physiology or medicine. I think the answer is quite simple: The work of all three has a single source, namely the "discoveries relating to chemical transmission of nerve impulses" for which Henry Dale and Otto Loewi received a previous award in 1936. Dale and his colleagues, W. Feldberg, Marthe Vogt, and G. L. Brown, had shown that, in spite of the rapid and unfailing nature of neuromuscular transmission, the motor nerve impulse is not simply passed on to the muscle fiber by a continuous process of electric excitation, but that there is intervention of a chemical mediator, involving the release from the nerve and the subsequent action on the muscle, of a specific transmitter substance, acetylcholine. This concept is summarized in the following scheme

$$\mathrm{N} \xrightarrow{\mathrm{I}} \mathrm{ACh} \xrightarrow{\mathrm{II}} \mathrm{M}$$

It was only to be expected that on closer examination this intermediate process would resolve itself into a sequence of reactions made up of a number of discrete steps, each of which calls for experimental study. What I should like to do in this lecture is to deal briefly with certain advances that have been made during the last 20 years in the investigation of the first stage of the transmission process, namely the mechanism by which arrival of an impulse enables the motor nerve ending to release the transmitter substance. I shall concentrate on studies made by a microelectrophysiological approach and shall refer in particular to the work carried out together with my colleagues Paul Fatt, José del Castillo, and Ricardo Miledi with all of whom I had the privilege to collaborate (*1*, *2*).


The author is professor of biophysics at University College, London. This article is the lecture he delivered in Stockholm, Sweden, on 12 December 1970 when he received the Nobel Prize in Physiology or Medicine, a prize he shared with Professor Ulf von Euler and Dr. Julius Axelrod. The article is published here with the permission of the Nobel Foundation and will also be included in the complete volume of *Les Prix Nobel en 1970* as well as in the series Nobel Lectures (in English) published by the Elsevier Publishing Company, Amsterdam and New York. The lectures of Professor von Euler and Dr. Axelrod will be published in subsequent issues.