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THE IMPACT OF THE GREEN REVOLUTION AND PROSPECTS FOR THE FUTURE

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The Green Revolution (a term used for rapid increases in wheat and rice yields in developing countries brought about by improved varieties combined with the expanded use of fertilizers and other chemical inputs) has had a dramatic impact on incomes and food supplies in many developing countries. However, the impact goes far beyond these immediate and very important results. The Green Revolution has facilitated institutional and social changes in rural areas and provided opportunities for self-sustaining economic growth and reduced poverty.

The final outcome of technological change is influenced by the institutional and policy environments within which it is introduced. Where such environments have been favorable, the distribution of the benefits has been widespread, but where they have been unfavorable and appropriate changes have not been made, the potential benefits from the Green Revolution to promote

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economic growth, reduce poverty, and facilitate self-sustaining development have not been fully exploited. The importance of the interaction between the Green Revolution and the institutional and policy environments has been recognized in much of the debate about the impact of the Green Revolution. However, in spite of such recognition, a great deal of the literature has failed to distinguish between the impact of the two. This has often lead to the argument that the Green Revolution is to blame for undesirable developments occurring as a consequence of inappropriate institutions and policies. Technological change offers an opportunity for enlarging total agricultural production through more productive use of resources. Whether the opportunity is used and how the associated benefits are distributed among population groups are largely a question of institutions and public policy although, as further discussed below, the nature of the technology plays a role as well. This does not mean that technological change should await appropriate institutional change. The former may help bring about the latter and both should be pursued simultaneously.

This article explores these and related issues. As the Green Revolution has matured, more has been learned about its actual and potential impacts. Errors of judgment and incorrect predictions based on earlier studies are gradually being corrected. Initial studies focused on immediate effects and often erroneously made long-term predictions on the basis of data from the initial phases of the Green Revolution. More recent work has benefitted from data from a longer period, thus providing a better basis for predictions and policy recommendations. Longer-term implications such as the multiplier and environmental effects and future organization of the agricultural research that makes continued technological change possible are also receiving more attention than previously.

This article addresses some of the issues considered to be of great importance for continued success of the Green Revolution. The most recent data on its impact on food production are discussed first. Then follows a discussion of the impact on production fluctuations. Current evidence of the impact on poverty and nutrition is summarized in the third section. Recent research has shown that the multiplier or linkage effects of technological change may be very important for assuring a desirable path of self-sustaining growth. This issue is dealt with in the fourth section, followed by a discussion of the role of women in technological change, an important growth as well as equity issue which has received little attention until recently. Then follows a brief assessment of the actual and potential environmental effects. A number of other issues with important implications for the future contribution of technological change, such as future control over germ plasm, organization of and control over the international agricultural research institutes, the needs for institutional and policy changes in many developing countries, and the need for new technology to facilitate a solution to the acute food problem in Sub-Saharan Africa, are discussed in the last section.

IMPACT ON FOOD PRODUCTION

The impact of the Green Revolution on wheat and rice production is a function of the area sown to the new wheat and rice varieties, and the increase in yields per unit of land. Increasing yields have made rice and wheat more profitable for farmers than certain other crops. Thus, in addition to yield increases on traditional wheat and rice land, more land has been brought into cultivation of these two crops. The Green Revolution has also facilitated significant expansion of irrigation and multiple cropping in many countries, thereby adding to the total acreage of these crops. Shorter growing periods and reduced photoperiodicity are important properties of the new varieties which have enabled increased multiple cropping.

It is estimated that between one-third and one-half of the rice areas in the developing world is grown with high-yielding varieties. Table 1 shows estimates for 11 Asian countries, varying from 9% in Thailand to 78% in the Philippines.

In Latin America, about 2 million ha of rice is irrigated and another 1 million grown under favorable rainfall and soil conditions but without irrigation (1). According to estimates by Dr. Peter Jennings, head of CIAT's[1] rice program, high-yielding varieties are now grown on about 90% of these 3 million ha. Estimated yield increases due to these varieties are about 1 ton/ha in irrigated areas and 0.75 tons/ha on favored upland rice areas. Thus, total annual

[1] International Center for Tropical Agriculture, Colombia.

Table 1. Area Grown with Modern Rice Varieties in 11 Asian Countries

Country	Year	1000 ha	% of Rice Area
Bangladesh	1981	2,325	22
India	1980	18,495	47
Nepal	1981	326	26
Pakistan	1978	1,015	50
Sri Lanka	1980	612	71
Burma	1980	1.502	29
Indonesia	1980	5,416	60
Malaysia W	1977	316	44
Philippines	1980	2,710	78
Thailand	1979	800	9
South Korea	1981	321	26

Source: Ref. 2.

production increases in Latin America are around 2.5 million tons. Assuming a price of $200/ton of paddy rice, the value of the production increase for 1 year is $500 million. Although these estimates are rough and subject to considerable error, it is clear that the production impact is very large.

Such conclusion is supported with evidence from Asia. Herdt and Capule (2) estimate that modern rice varieties added 27 million tons to the production of rice in eight Asian countries (Burma, Bangladesh, China, India, Indonesia, Philippines, Sri Lanka, and Thailand) which produced 85% of Asia's rice in 1980. Another 29 million tons was added by fertilizers, and irrigation contributed 34 million tons. It should be noted that since modern varieties generally have a higher response to fertilizers and possibly other inputs, a clear distinction among the contribution of each factor is difficult.

Earlier estimates of the production impact of modern rice varieties were considerably below those reported above. The impact was estimated to be about 10 million tons in the Far East and less than one-half of a million tons in Latin America for the year 1976/1977 (3). While differences in estimation procedures explain some of the variation between the two sets of estimates, rapid increases in adoption since 1976/1977 account for a large part, particularly in Latin America. Rapid increases in rice production due to modern varieties and associated inputs were not limited to the late sixties and early seventies but are still going on. In fact, except for Colombia, the bulk of the increase in Latin America has occurred since the mid-seventies.

The wheat areas grown with modern varieties are of magnitudes similar to those for rice. It was estimated that about 30 million ha were grown with these varieties during 1976/1977 (3) and about 35 million today (5). However, since much more land is used for rice than for wheat in developing countries, modern varieties occupy a larger percentage of the wheat area. James (5) estimates that the contribution of the new varieties to increased wheat production in developing countries was 7 million tons in 1982/1983 worth $1200 million. Earlier estimates for 1976/1977 were 19.9–26.7 million tons (6) and around 21 million tons worth $2500 million (3). The large difference among the estimates is due primarily to the different assumptions about average yield increases which are not known with a high degree of precision. However, irrespective of whether the actual increase is closer to the lower or the higher estimates, it is still extremely impressive.

While the term *Green Revolution* was originally used for wheat and rice, high-yielding varieties have been developed for a number of other food crops important to the developing countries. These include sorghum, maize, cassava, and beans. The area grown with improved maize varieties and hybrids derived from CIMMYT[2] germ plasm in developing countries runs into millions of hectares (5). Massive efforts to develop high-yielding technologies for many other food crops grown under developing country conditions are of a more

[2] International Center for Maize and Wheat, Mexico.

recent date, and attempts to estimate the global production impact would be premature. However, evidence for some crops in a few countries, e.g., beans and cassava in Cuba and beans in various Central American countries, shows considerable promise. Similarly, results from farm trials of improved varieties and cultural practices for various food crops show a great potential for yield increases.

IMPACT ON PRODUCTION FLUCTUATIONS

As shown above, the Green Revolution has enabled many developing countries to achieve impressive rates of growth in national foodgrain production since the mid-1960s. At the same time though, the variability of national foodgrain production around the trend has also increased. India, for example, increased its average cereal production by 47% between the periods 1952/1953–1964/1965 and 1967/1968–1977/1978. At the same time the coefficient of variation around trend of total cereal production increased from 4.7% in the first period to 5.9% in the second period (7).

Despite this increased variability, countries like India are still much better off, even in drought years, in ensuring national food consumption because of the increased food output these technologies have permitted. But increased production variability can, in the absence of stabilization policies, lead to more volatile prices, creating problems for farmers and poor consumers alike. The degree of price instability induced can be quite large in countries where a high proportion of total production is consumed on the farm. This is because year-to-year fluctuations in production are then transmitted to relatively thin markets. In India, only one-third of foodgrain production is actually marketed, and farm price variability has more than doubled since the mid-1960s for wheat and rice.

Mahra (8) argues that much of this increased instability is due to the widespread adoption of improved seed/fertilizer-intensive technologies since the mid-1960s. Similar arguments are made by Barker et al. (9). The yields of crops grown with the new technologies may be more sensitive to weather and disease. Perhaps more importantly, because they require modern inputs, such as fertilizer, their yields may also be sensitive to year-to-year variations in input use arising from frequent price changes, or from supply restrictions.

Mehra's work for India (8) supports the view that the new technologies have contributed to increased yield variability at the farm level, particularly in semi-arid regions with limited irrigation. Consequently, current efforts to breed for more stable yields are directly beneficial to farmers.

However, even if the new technologies have increased yield risks at the farm level, this need not imply that they are an important source of increased instability in national cereal production. Other factors affecting aggregate supply include changes in interyear variability in crop areas sown, changes in yield correlations between farms and crops, production expansion into riskier areas, and increases in average yields and average areas sown.

Hazell (7,10) used statistical identities to provide an exact decomposition of the components of change in the variance of total cereal production between pre- and post-Green Revolution periods in India. He found that increased yield variances within crops and states directly accounted for less than 10% of the increase in the variance of India's total cereal production. More important were increased covariances between crop yields, and particularly between the yields of the same crop grown in different states. A part of these increased yield covariances is attributable to more variable yields, but part is also due to increased yield correlations between states. In the pre-Green Revolution period, there were stronger offsetting patterns of variation of yields between states. Today, yields have a stronger tendency to move up and down together over large parts of India.

This pattern is even more pronounced for maize in the United States (7); interstate yield correlations increased sharply between the periods 1950-1966 and 1967-1980. In fact these increased yield correlations account for about half of the increase in the variability of total cereal production in the United States between these two periods.

Why have the yields of the more important cereals become more highly correlated between states in India and the United States? Since the phenomena in the United States is specific to maize, this suggests a crop-specific cause. A possible explanation lies in the common genetic base of most of the hybrid maize varieties grown.

Hargrove et al. (11) report how in the spring of 1970, a mutant form of *Helminthosporium maydis* (southern corn leaf blight) struck in Florida, and spread rapidly northwards throughout the cornbelt with devastating effects on yields. This susceptability to *H. maydis* was limited to hybrids carrying cytoplasm associated with male sterility—a feature of considerable value to plant breeders. Unfortunately, almost every maize farmer in the United States was growing such varieties in 1970. The total crop loss was limited to about 15% because of unfavorable weather conditions for *H. maydis*. Although an extreme example, this episode illustrates how maize yields could have become increasingly correlated over time between states as varieties become more genotypically similar with a common susceptability to the same kinds of pest, disease, and weather conditions.[3] The risk associated with this loss in genetic variation has been recognized by plant breeders, and recent years have seen significant attempts to reverse the problem.

Another possibility is the role of increased price variability. Farm gate maize prices were relatively stable around trend in the United States over the period 1950-1972; the standard deviation was $0.20 per bushel. However, after 1972,

[3] Chang (12) has reported similar problems with rice in Asia.

their variability increased considerably; the standard deviation around trend went up to $0.33 per bushel. Since price variations affect all U.S. farmers, any adjustments they make to input usage in response to price movements could lead to more highly correlated yields across states.

In India, interstate yield correlations have increased for all cereals except sorghum and minor millets. Possibly the narrower range of genotypes for rice and wheat resulting from widespread adoption of high-yielding varieties has contributed to these increased correlations. However, other causes may be important.

Kothare (13) provides evidence that rainfall was more erratic in many parts of India during the more recent period of analysis. The use of fertilizers and irrigation on cereal crops has also increased at a time when the supplies of these inputs have become more erratic. For example, an increase in electric irrigation pumps since the mid-1960s has coincided with increased irregularities in electricity supplies. Since power outages affect large areas of India simultaneously, they are likely to have a simultaneous and negating effect on crop yields in many states.

As in the United States, cereal yields in India are also responsive to price signals, and increasingly so since the widespread adoption of input-intensive technologies. The standard deviation of detrended harvest prices for rice in West Bengal (the most important rice-growing state) increased from Rs. 14.9 per quintal in 1952/1953–1964/1965, to Rs. 40.3 per quintal in 1967/1968–1977/1978. Likewise, the standard deviation of the detrended harvest price for wheat in Uttar Pradesh (the most important wheat-growing state) increased from Rs. 8.2 per quintal in 1955/1956–1964/1965, to Rs. 19.8 per quintal in 1967/1968–1977/1978 (7).

Other important sources of the increased variability in India's total cereal production were increases in the cropped area, in the year-to-year variability of the areas sown to individual crops, and in more positive correlations between areas sown and yields. These sources of increased production variability reflect the importance of increases in the gross cropped area (from 89.7 million to 101.0 million ha between 1952/1953–1964/1965 and 1967/1968–1977/1978) as well as increases in mean yields in enlarging total cereal production in India. In contrast, nearly all of the 2.7% per year growth in U.S. cereal production since 1950 can be attributed to increased yields.

Given the potential link between the new technologies and increased instability, should greater priority be given to reducing instability in agricultural research?

In developing countries continued growth in foodgrain production is of paramount importance, and any trade-off between breeding for growth and breeding for stability may prove costly. But a strengthening of ongoing efforts to develop genetic resistence or tolerance to pests may meet growth as well as stability goals. Also, there are often other important sources of increased variability in production that would not be affected by changing research priorities. These may be amenable to, or even the consequence of, government policy. For example, policies to provide more stable farm prices and electricity supplies could help stabilize cereal production in India.

Appropriate policy intervention can also alleviate some of the problems posed by increased instability. Storage schemes and international trade can stabilize food supplies for consumers, and credit and insurance schemes and futures markets can help farmers to cope with yield risks. Government could also give greater priority to increasing production in the more stable areas, and in areas where production is not strongly correlated with other regions.

DIRECT IMPACT ON POVERTY AND NUTRITION

A number of early studies on the impact of the Green Revolution concluded that the rural poor did not receive their fair share of the generated benefits. It was argued that mostly large farmers adopted the new yield-increasing technology, leaving small farmers unaffected or actually worse off because the Green Revolution resulted in (a) downward pressures on the prices of the commodities they produced, (b) upward pressures on the prices of the inputs they purchased, (c) efforts by large farmers to either increase rents to tenants or force the tenants off the land, and (d) attempts by large farmers to increase land holdings by purchasing smaller farms, thus forcing small farmers into landlessness. Furthermore, it was argued that the Green Revolution resulted in reduced rural employment. The net result, as argued by some, was a rapid increase in the inequality of income and asset distribution and a worsening of rural poverty in areas affected by the Green Revolution (14–18).

While the general validity of these conclusions has always been questioned, recent studies have produced a sizable body of evidence which proves beyond a reasonable doubt that they are wrong. Recent evidence clearly shows that, although exceptions exist, as a general rule the Green Revolution has resulted in a very significant improvement in the material well-being of the poor.

Where did the early studies go wrong? Primarily on four accounts. First, the studies failed to distinguish between early and subsequent adoption of new technology. Thus, studies undertaken soon after the release of the first high-yielding rice and wheat varieties found that only large farmers adopted these varieties together with complementary inputs such as fertilizers. While it was true that early adopters were primarily large farmers, the studies failed to recognize that small farmers would follow quickly once the uncertainty was reduced by observing success under farm conditions.

Second, the benefits to the poor as consumers of rice and wheat through lower prices were largely overlooked. Third, little or no attention was given to the multiplier effects of the Green Revolution and the resulting impact on incomes of rural poor. Fourth, the impact of the Green Revolution was frequently confused with the impact of institutional arrangements, agricultural policies, and labor-saving mechanization. Such confusion lead to incorrect identification of the causes of rural poverty and thus incorrect recommendations for action to reduce such poverty.

This section provides a brief summary of current evidence of the direct impact of the Green Revolution on the poor and how institutional and policy changes may alter this impact.[4] The indirect impact is dealt with in the next section.

Five factors are of great importance in determining the distribution of economic gains from technological change in agriculture. These are (a) the nature of the technology, (b) the structure of the agricultural sector and particularly the land tenure system, (c) the structure of the markets for inputs (fertilizers, labor, etc.) and credit, (d) the market for agricultural products, and (e) agricultural policy. The impact of each of these factors is analyzed elsewhere (3) and will only be summarized here together with evidence from more recent studies.

The poor may be affected by the Green Revolution through changes in their assets, incomes, and/or the prices they pay for food. The impact on a particular household is influenced by the extent to which it depends on rice or wheat for its income and the importance of these commodities in the household budget. The impact will differ among poor producers, landless labor, and poor consumers. Recent evidence of the impact on each of these three groups is briefly discussed below.

Impact on Poor Producers

High-yielding wheat and rice varieties have been adopted widely by producers irrespective of farm size and tenurial status (2,3,19–22). Earlier conclusions that the Green Revolution was predominately a large farmer phenomenon were clearly incorrect. In many, if not most, regions suited for the high-yielding varieties, low-income farmers have adopted at least to the same extent as larger farmers, and the most recent studies suggest that net gains per unit of land tend to be larger on smaller farms (see above references). However, many regions are not suited for high-yielding rice and wheat varieties. Thus, the Green Revolution has contributed to a considerable change in regional income distribution in some countries, as illustrated in India. The Green Revolution has benefitted producers who control optimal production environments or who have access to such environments, irrespective of farm size. In some countries, not least in Latin America, optimal production environments are frequently

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[4] See Ref. 3 for a more detailed synthesis of available evidence up to 1982.

controlled by the larger and better-off farmers. In many other areas, including those where good soil has been distributed through land reforms, they are often controlled by low-income farmers.

The most important lesson from these findings is that the physical production environment, e.g., soil quality, access to irrigation water, etc., is much more important in determining adoption patterns than farm size. Therefore, as long as new technology is suited only or mainly for optimal production environments farmers without access to such environments, irrespective of farm size, will not benefit. While a great deal of research is now under way to increase the productivity of less-favored areas, available technology is still limited.

The impact of technological change on poor farmers depends very much on institutions and policies. Although small farmers in many developing countries generally utilize available land more efficiently than those with larger farms, policymakers often see large farms as more desirable. Therefore, attempts by early adopters of the Green Revolution technology to enlarge their farms by land purchase or termination of rental arrangements were supported by public policy. Such policies were fueled by the belief during early phases of the Green Revolution that smaller farmers would not adopt the new technology. Based on hindsight it is obvious that what was needed during those initial phases were policy measures and institutional changes aimed at reducing the time lag between the adoption of the new technology on large and small farms such as the removal of input market constraints for small farmers.

Up until a few years ago, there were indications that a combination of early adoption generation of large economic gains among large farmers, and policies adverse to small farmers led to increasing land concentration and increasing numbers of landless farm workers during the initial phases of the Green Revolution. However solid empirical evidence that this is a widespread phenomenon does not exist. While changes in land tenure have occurred, the role of the Green Revolution is not clear. Demographic pressures, regional migration, and other factors may have been important.

Impact on Landless Labor

The Green Revolution is based on a combination of varieties with high yield potential, fertilizers, irrigation, and in some cases chemical pesticides and mechanization.[5] One result of this combined package has been higher labor

[5] Although the complete set of inputs is discussed here, it should be pointed out that the high yield potential of modern varieties did not depend on the adoption of all inputs, e.g., mechanization. Furthermore, as discussed below, the impact of high-yielding varieties should be viewed separately from the impact of other inputs such as chemical pest control and mechanization. Many past studies have failed to do so and much confusion exists regarding the impact of each of the components. For example, while the yield of modern varieties generally does not increase with increasing farm size, economic benefits from

productivity and increased labor demand. In areas with high unemployment and a highly elastic labor supply, this has resulted in a considerable expansion in employment. In regions with little unemployment and an inelastic labor supply, whether existing prior to the introduction of, or brought about by, the technology, considerable wage increases have occurred. However, in-migration of labor from other regions and availability of labor-saving mechanical technology has limited such wage increases.

In many regions where technological change has made a significant impact on production, real wages have increased little if at all in spite of increased labor demand. The primary reason is that these same regions have experienced high rates of population growth, and the growth in labor demand may merely have kept pace with the growth in the labor force. The important question is how the landless would have fared in the absence of the technological change. Clearly they would have been worse off.

Mechanical technology has not always reduced employment. Much of the investment in irrigation equipment and in some cases investments in machines for land preparation and harvesting has resulted in larger production increases partly due to a shorter cropping season and due to expansion from single to double cropping. Shorter season varieties have also contributed to this. The result has been increased employment. However, there are many cases where mechanization has been introduced for the explicit purpose of reducing labor demands while the output effects have been minimal. For example, Binswanger (23) concluded that existing studies of the effects of tractors in South Asia failed to provide evidence that they substantially contributed to increases in cropping intensity, yields, and timeliness while they did substitute for labor. Investment in labor-saving technology has frequently been a reaction to labor shortages at the local level and difficulties in labor management. Increasing labor mobility, whether within or among countries, would make such investments less attractive while increasing employment.

Impact on Poor Consumers

Empirical evidence of consumer gains from technological change in developing country agriculture is plentiful (24–29). The consumer gains come about because food prices are lower than they would have been in the absence of the production increases induced by technological change. Import substitution, exports, and domestic price policies can dampen the price reduction. In fact, price and foreign trade policies have been used extensively to strike a desired

certain types of mechanization may. Furthermore, benefits from modern varieties may be achieved irrespective of whether mechanization takes place. Yet, the negative impact of mechanization on labor demand is often credited to modern varieties.

balance between the harmful effects of price falls on farmers and future food production and the beneficial effects on consumers. Since the Green Revolution generates an economic surplus by more efficient utilization of resources and reduced unit costs, consumer gains need not imply producer losses. Both may gain.

The distribution of consumer [illegible] between the poor and the rest depends primarily on the amount spent [illegible] group on the commodities in question, e.g., rice and wheat. The larger the amount, the greater would be the gain. In most cases the poor spend less than the better-off population on wheat and rice; thus larger absolute gains are obtained by the latter. However, in many countries, the share of total incomes spent on wheat and rice is larger for the poor than the better-off. Thus, real income gains relative to current incomes are larger for the poor.

A study of the population of Cali, Colombia (30) illustrates these conclusions. In this study it was found that low-income consumers obtained larger absolute gains than did higher-income consumers from output-expanding technology for basic staples (cassava, maize, and plantain). For all other foods including rice and wheat, the absolute gain obtained by low-income consumers was smaller than that obtained by those with higher incomes. However, the distribution of benefits from output-expanding technology was less skewed than existing income distribution for all foods. This means that in the absence of government intervention and with no changes in imports or exports, new technology would provide larger relative benefits to the poor and improve the existing income distribution among consumers.

Impact on Nutritional Status

Technological change in agriculture influences human nutrition through its impact on:

1. Incomes acquired by households at risk of having malnourished or undernourished members
2. The prices they have to pay for food commodities
3. The nature of the production systems among semisubsistence farmers
4. Risk and fluctuations in food production, storage, prices, and incomes
5. The nutrient composition of the foods available to malnourished households
6. Household income composition, intrahousehold income and budget control, and women's time allocation
7. Labor demand and energy expenditures
8. Infectious diseases

Although the reasons for existing calorie-protein deficiencies differ among countries and population groups, low household incomes, insufficient food availability, and high food prices are likely to be the primary ones. Changes in either of these three factors are likely to influence food consumption. Changes in food supplies affect the nutritional status only to the extent that the food consumption of malnourished or at-risk individuals is affected. The degree to which expanded food production is translated into expanded food consumption by the malnourished varies greatly depending on the crop or livestock species for which production is expanded, the nature of the technology which brought about the expansion, and who produces the increase. Thus, using total production expansion as a proxy for nutritional impact is likely to be misleading. What is important from a nutritional point of view is not how much more is produced but how food consumption by the malnourished is affected.

Although studies of the nutritional impact of the Green Revolution are very scarce, it is well known that the poor spend a large share of additional incomes on food. Furthermore, since wheat and rice are preferred staples among the poor in most developing countries, the poor tend to make relatively large adjustments in wheat and rice consumption in response to price changes. Thus, increased incomes and reduced wheat and rice prices are likely to cause significant increases in their food consumption. The extent to which these increases are reflected in nutritional status depends on intrahousehold food distribution, health, and related factors which in turn may be influenced by technological change through changes in the intrahousehold income control, demand for women's time, use of child labor, etc.[6]

Since nutritional problems are found among urban as well as rural poor, the most desirable technology from a nutritional point of view is that developed for food commodities primarily produced by poor farmers or, if produced by better-off farmers, causes a large increase in labor demand, and which occupy a large share of the budget of poor consumers. In many developing countries, particularly in Asia, wheat and/or rice are such commodities. In other countries, millet, sorghum, maize, cassava, or beans would better meet these criteria.

Because of the higher productivity of rice and wheat relative to other crops for which no Green Revolution has yet occurred, many farmers have substituted wheat or rice for other crops on their land. Some concern has been expressed that such substitution may have resulted in negative nutrition effects. Substitution of wheat for pulses in India is a case in point. However, the net impact of this substitution has been an increase in the production of calories,

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[6] These relationships are further discussed in Ref. 31.

protein, and essential amino acids per unit of land (32). The impact on the poor and malnourished is not known.

Shifts from multiple to monocropping present a risk of negative nutrition effects among semisubsistence farmers. Empirical evidence on this topic is very limited and more research is needed to assess the nutrition effects of such shifts and how negative effects may be avoided and positive ones enhanced.[7] In particular, it would be useful to further study these and other on-farm linkages between agricultural production activities and the nutritional status of the semisubsistence farm family as part of ongoing and planned farming systems research.

THE INDIRECT INCOME AND EMPLOYMENT EFFECTS OF THE GREEN REVOLUTION

The indirect effects arising from technological change and agricultural growth can be substantial. Mellor and Lele (33,34) have argued the importance of increased food production in relaxing the wage goods' constraint on economic growth. In an empirical study of agricultural and industrial performance in India, Rangarajan (35) found that a 1% addition to the agricultural growth rate stimulated a 0.5% addition to the growth rate of industrial output, and a 0.7% addition to the growth rate of national income. At a regional level, Gibb (36) found that each 1% increase in agricultural income in the Nueva Ecija Province of Central Luzon in the Philippines generated a 1–2% increase in employment in most sectors of the local nonfarm economy. Similarly, in a study of technological change in rice in the Muda region of Malaysia, Bell et al. (37) found that for each dollar of income created directly in agriculture by the project, an additional 80 cents of value added was created indirectly in the local nonfarm economy.

An important aspect of growth linkages to the nonfarm economy is that they are predominantly due to increases in household consumption expenditure. Bell et al. report that about two-thirds of the 80 cent income multiplier in Muda was due to increased rural household demands for consumer goods and services; only one-third was due to agriculture's increased demands for inputs and processing, transport, and marketing services. Gibb also found strong employment links to the nonfood consumer-oriented sectors in his study of Nueva Ecija. These findings strongly support Mellor's contention (38) that because much of the accepted wisdom on development strategy ignores these consumption linkages, it has tended to seriously underestimate the potential

[7] These relationships are further discussed in Ref. 4.

importance of agriculture. Hirschman, for example, in his influential study of the importance of linkages in promoting development (39), focused only on production linkages, and he found these to be weak for agriculture compared to most other sectors of the economy. On this basis, he recommended the greatest priority be given to public investment in nonagriculture.

In addition to enhancing agriculture's contribution to national economic growth, the existence of strong consumer expenditure linkages between agricultural households and the nonfarm economy is important for two other reasons.

First, the income and employment generated by these linkages is predominately concentrated in rural areas. Rurally focused growth is desirable in many countries where rural areas have been severely disadvantaged in the past through urban-biased policies (40). Such policies have encouraged excessive migration from rural to urban areas and have exacerbated problems of rural underemployment.

Second, the kinds of goods and services demanded are typically produced by small labor-intensive enterprises. They are focused on such sectors as transportation, hotels and restaurants, entertainment, personal services, health, distributive trades, and housing and residential construction. Increased household demands for specialty agricultural products, particularly fresh fruits and vegetables, and fish and livestock products, can also provide important increases in rural employment.

Strong household links to the rural nonfarm economy not only help alleviate problems of rural underemployment, but, because the major beneficiaries of the increased employment earnings are typically the poor, they also contribute to the reduction of rural poverty and malnutrition. Survey evidence from many countries confirms that the small farmers and landless workers obtain substantial shares of their total income from nonagricultural sources. Consequently, the beneficiaries of the indirect employment gains generated by agricultural growth need not be limited to poor, nonagricultural households residing in towns. Rather, they have the potential to touch a wide range of occupation groups within the poorer segments of society.

The indirect benefits from agricultural growth are not restricted to the poor. They can increase the earnings of skilled workers as well as providing lucrative returns to capital and to managerial skills. In the Muda study, for example, Bell et al. found that the indirect benefits of the project were skewed in favor of the nonfarm households in the region, many of whom were relatively well off. They also found that even among agricultural households, the landed households fared better than the landless. The point to be made is that although the indirect effects of agricultural growth do not necessarily improve the relative distribution of income within rural areas, they can still have wide-reaching effects in alleviating absolute poverty.

Determinants of the Size of the Indirect Benefits in Rural Regions

Given the importance of household consumption expenditures in generating income and employment multipliers, three key considerations stand out as determinants of the size of the indirect benefits that can be induced by technological change and agricultural growth within rural areas.

The first consideration is the amount of extra income generated among farmers as a result of increased agricultural output. Obviously, the greater the increase in farm incomes, the greater the incremental expenditure by farm households on consumer goods and services. Agricultural growth is not always accompanied by increases in farm incomes, particularly when the growth is rapid and the national demand for the output is price inelastic. Some governments also hold farm prices artificially low in an attempt to reduce the price of food for urban consumers.

Technological change of the Green Revolution type usually reduces the cost of producing a unit of agricultural output. Consequently, some reduction in prices can still be consistent with increases in farm incomes. More generally, though, price reductions act to transfer income from rural to urban areas, and they reduce the amount of indirect growth generated within rural regions.

A second consideration is the structure of rural household expenditure patterns (33). To a regional economy, local household expenditures on imported goods (from outside the region) represent a direct leakage which reduces the size of the local income and employment multipliers. But as Siamwalla has argued (41), if incremental income is spent on locally produced goods that could be exported from the region at a constant price, that expenditure represents a loss in export proceeds and is as much a leakage as if the money were expended upon imported goods. Thus the stimulative effect of increased household expenditure on the local economy depends crucially on the expenditure share allocated to locally produced goods and services that are not usually exported from or imported into the region (nontradables).

For most rural regions in developing countries, the major output is food or cash crops, the greater part of which is exported out of the region at given prices. In return, these areas import from outside the region manufactured goods for investment, production, and household consumption. Nonfood goods and services are also produced in the towns and larger villages which cater almost exclusively to local demand. Local nontradable goods may also include some specialty agricultural commodities such as fresh fruits, vegetables, and livestock products.

Hazell and Röell analyzed household expenditure data from Malaysia and Nigeria and found that the share of incremental income allocated to rural nontradables increases with household income and farm size (42). This suggests that within a region agricultural growth will have a greater stimulative impact on the local economy if the growth is concentrated on the larger farms. It should be stressed though that their data did not include any really large farmers or any really rich households. It is quite possible that the marginal budget share for local nontradables reaches a peak for some intermediate farm size, and that really large farmers have less desirable expenditure patterns for regional economic growth. Larger farmers may also generate other leakages from the local economy. For example, they may allocate larger shares of their income to savings which are not invested locally in goods with a high content of local nontradables. They may also use farm technologies that require larger shares of regional imports than the technologies used by smaller farmers.

While household expenditures on local nontradables are an important determinant of the size of the regional income and employment multipliers, it is also crucial that the supplies of these goods be elastic. This leads to the third key consideration of our argument—the supply structure of rural regions.

If the supply structure of nontradables is inelastic, then increased household demands for these goods and services will simply increase prices rather than real incomes and employment. As it happens, most nontradables are services (transportation, hotels and restaurants, entertainment, personal services, health, education, housing, and distributive trades, etc.). These activities tend to be labor intensive, so we should expect their supply to be more responsive to demand in labor surplus regions. This is more likely to be the case in South Asia than in Africa. Other factors that may be important are the status of the local infrastructure (roads, electricity, market centers, banking, etc.) and government policy towards small businesses. Again these factors tend to be more favorable in Asia than in Africa. Since the Green Revolution has tended to be focused in labor surplus areas, and particularly in Asia, it probably has generated substantial rounds of indirect benefits within these areas.

THE ROLE OF WOMEN IN TECHNOLOGICAL CHANGE

Although earlier work on the Green Revolution paid little attention to the role of women in technological change and implications of their role for technology adoption and utilization and distribution of benefits, a number of studies have now been completed on the subject (43–47).

There are many reasons why the role of women should be explicitly analyzed. First, women play a major role in providing the additional labor required to obtain the benefits from technological change. Failure to consider gender-related differences in labor availability and demand may result in low adoption rates and a lower yield impact than expected (48). In cases where additional labor is needed in activities traditionally done by women it is the female labor availability rather than total labor availability that is important.

A large number of studies of women's time allocation show that women in poor rural households are not generally underemployed. On the contrary, their working day is usually considerably longer than that of the men. However, much of their time is spent on low productivity but essential activities. Thus, introduction of new agricultural technologies which require additional female labor whether in production or processing should be associated with productivity-increasing technology in other activities traditionally done by women. Unfortunately, however, efforts to increase labor productivity in these activities are not widespread. Furthermore, attention should be paid to the impact of increasing demand for female labor on the production of subsistence commodities, child care, and other aspects of household welfare including, of course, the burden placed on the women themselves.

The Green Revolution has clearly increased employment of the landless poor, many of whom are women. However, labor-displacing technology has played a greater role than productivity-increasing technology in some activities characteristically done by women such as the substitution of chemical weed control for hand-weeding. Where traditional women's jobs have benefitted from productivity-increasing technology they are often taken over by men.

Second, a large proportion of small farms in developing countries are headed by women either all year or during periods when the men are away to work in other regions. Therefore, decisions determining the adoption and impact of technology are often made by women, a fact that should not be overlooked by agricultural extension and other efforts to spread new technology.

Third, there is increasing evidence that household-spending behavior and the resulting impact on welfare of individuals within the household, e.g. nutritional status of children, is influenced by the distribution of income control within the household. Thus, the impact of new technology may depend on how intrahousehold income control is affected. Technological change resulting in expanded production for sale at the expense of subsistence food production is a case in point. Although total household incomes may increase, household food consumption may fall if women are traditionally responsible for meeting food needs through own production while the cash from sales is controlled by the man and used for other things without sufficient increases in food purchases to offset the reduction in own production.

The principal message coming from recent studies of the role of women in technological change in agriculture is that gender specificity in labor activities, decision-making in production and consumption, and the general level of well-being among the rural poor is an important issue to be explicitly considered in technology design and diffusion as well as related policies and institutional changes. Ignoring these gender specificities may lead to inappropriate technologies and policies from the point of view of both growth and equity.

ENVIRONMENTAL EFFECTS OF THE GREEN REVOLUTION

While the contemporary distribution of benefits and costs among population groups is important, the effects on intergenerational distribution should not be overlooked. What has been the impact of the Green Revolution on the resource base needed by future generations to meet their food and other needs?

A continuation of current trends of agricultural expansion into marginal lands, rapid rates of deforestation, and overgrazing in dry areas are likely to have severe adverse environmental consequences. Land and water erosion and loss of organic matter lead to land degradation and desertification, which in turn will make it more difficult for future generations to fulfil their needs for food, fuel wood, and other agricultural and forestry products. Existing poverty and unsatisfied food needs, together with opportunities for quick political and economic gains without having to bear associated environmental costs, naturally lead to exploitation of the land base.

Such exploitation and the resulting degradation of the future land base may be avoided through a combination of technological change and public policy without serious adverse effects on short-run food supplies. New technology facilitates higher yields on existing agricultural lands. Thus, expanding the development and use of yield-increasing technology reduces the pressure on new lands to meet increasing demands for food and other agricultural products. There is little doubt that the development and use of high-yielding crop varieties, increased use of fertilizers, better production practices, and other yield-increasing factors have been of great importance in limiting land degradation in developing countries.

This very significant positive environmental effect of modern technology is frequently overlooked. To further restrain land degradation more—not less—yield-increasing technology must be developed and introduced. New technology may facilitate conservation of current agricultural land, and it may assist in avoiding adverse environmental effects of incorporating new land into production. But technological change may also promote further degradation of land and water resources, e.g., waterlogging and salinization of land and excessive usage of groundwater.

In addition to accelerating the development and use of modern technology, successful efforts to maintain or improve the productive capacity of the land base must include appropriate public policies and investment. In particular, policy measures are needed to ensure that long-term social costs are reflected in both public and private decision-making. Such policy measures are frequently absent in developing and developed countries.

Application of large quantities of pesticides may affect the ecological system adversely in a variety of ways. However, a continuation of current efforts to include genetic pest resistance in plants, together with greater emphasis on biological pest control and proper pesticide handling and application may greatly reduce the environmental risks associated with pest control.

As mentioned earlier, reduction of the genetic diversity in plants is another important environmental risk associated with technological change. As the diversity decreases on farms, effective steps must be taken to ensure that the genetic material is maintained elsewhere. A considerable amount of work—although probably not enough—is under way in this area (12).

Environmental risks associated with the use of chemical fertilizers appear to be rather insignificant, although excessive application rates and poor cultural practices may result in some eutrophication of streams and lakes. However, compared to the effects of urban and industrial sewage and wastes, fertilizer used in agriculture is a relatively insignificant pollutant.

LESSONS FOR THE FUTURE

What are some of the lessons learned from recent studies and observations of the Green Revolution? First, it has become abundantly clear that the technological barriers to expanded food production among small and large farmers in developing countries can be alleviated.

Another lesson learned from the Green Revolution is that, while technological change in agriculture provides a vehicle for development that reaches far beyond the more immediate goals of satisfying food and nutrition needs, its full potential for achieving growth as well as equity goals will be realized only if it is properly integrated into the overall development strategy and accompanied by appropriate public policy and institutional changes. The short-term impact on the poor is particularly sensitive to institutional arrangements and public policies. Where existing institutions favor very unequal asset and income distributions, technological change has tended to amplify the inequality. However, although the impact on the relative income distribution varies among regions, in most cases the Green Revolution has contributed to higher incomes of both poor and rich.

To further reduce rural poverty and inequalities, policy measures and institutional changes should focus on the root causes of the problem, i.e., uneven distribution of the ownership of productive resources, existing power structures, poor training and education, differential access to factor and product markets, and lack of access to health facilities. Such measures might include land reform, development of infrastructure and irrigation facilities, improved marketing facilities, access to credit for the poor, expansions of health facilities for the poor, and a series of other government intervention schemes aimed at changing the socioeconomic environment and strengthening the human resource. In addition to those interventions aimed at self-sustaining long-term reductions in rural poverty, income transfers to the poor such as food and credit subsidies are needed to alleviate poverty and malnutrition in the short run. This does not mean that technological change should await such policies and institutional changes. Technological change is needed to generate economic surplus which together with appropriate policies and institutional changes will facilitate growth and reduced poverty. However, technological change by itself should not be expected to remove serious inequities. The interaction between technological change and government policies is complex and additional research on this matter is urgently needed to facilitate effective policy design in pursuit of growth as well as equity goals.

Although the most obvious successes of recent technological change in agriculture refer to wheat and rice grown under relatively good physical environments, on-going agricultural research is likely to result in significant yield and production gains for other crops under less favorable production environments. However, if such gains are to materialize, investors in agricultural research must make a long-term commitment and should not expect quick results. Agricultural research must be viewed as an investment with a high but long-term payoff. Adverse effects of failure to invest in research today may be most severely felt 20 years into the future and beyond.

The initial successes in wheat and rice during the 1960s led to large expansions of the investment in agricultural research. In addition to the International Rice Research Institute (IRRI), CIMMYT, and CIAT which were key to the initial rice and wheat successes, a number of other international agricultural research institutes were created, international aid agencies made more funds available for agricultural research in developing countries, and many developing countries expanded their research activities. However,unless new highly visible successes outside rice and wheat come about within the not too distant future, there is a real danger that the incentive to continue to support agricultural research at current or increasing levels may begin to falter. In view of the critical role of technological change in economic development and the need for agricultural research to facilitate such technological change, including a great deal of research needed to maintain the impact of current technology, it would be very unfortunate and possibly disastrous for many countries if the current momentum in agricultural research for developing countries were lost.

An extremely difficult situation is already upon us with respect to food production in Sub-Saharan Africa. While the causes are complex, it may be hypothesized that this situation could have been avoided if massive investments in agricultural research, including manpower training for the food crops and production environments of Sub-Saharan Africa, had been made during the past 20–25 years. The lesson to be learned is not that hindsight is better than foresight but rather that such massive long-term investments in agricultural research are long overdue.

A continuation of current efforts to find "quick fixes" through price policies and increased dependence on export crop production as a *substitute* rather than a *complement* to long-term investments in research, training, and technological change will not lead to self-sustaining improvements in food production and human nutrition in Africa. Neither will it provide the vehicle for economic growth so badly needed in African agriculture. But technological change just might provide such a vehicle.

As mentioned above, IRRI, CIMMYT, and CIAT were instrumental in bringing about the Green Revolution. While many factors contributed to the success of these institutions, including prior research on rice and wheat, the abilities of the individual researchers, a very unbureaucratic research environment, and sufficient research support facilities undoubtedly were of great importance. As more international agricultural research institutes have been created and as each institute has become larger, it is important that the high level of research staff and the flexible and nonbureaucratic research environment so important to success be maintained within each institute.

Furthermore, as the system of international agricultural research institutes matures, it is very important that unnecessary and stifling bureaucratic structures not be permitted to enter the system. The individual institutes and the Consultative Group on International Agricultural Research (CGIAR) have suffered much less than most international institutions from the influence of and conflict among narrow political interests. It is of paramount importance that this situation be maintained in the future.

Closely related to this issue is the question of control over seed germ plasm. As mentioned earlier, widespread adoption of improved varieties has reduced the genetic diversity at the farm level. Thus, unless such diversity is maintained elsewhere, the genetic base for future production and research will be narrowed. In response to this concern the International Board for Plant Genetic Resources (IBPGR) was created in 1974 under the sponsorship of the CGIAR. In addition, most of the international agricultural research institutes collect and maintain large collections of germ plasm for the crops they work on. While guided by scientific considerations, these efforts have been relatively free of narrow political manipulations and conflicts and access to the germ plasm collections have been free to all countries. During the last few years, however, some developing countries have expressed serious concern about what they see as their lack of influence in germ plasm collection and maintenance. At the same time, private seed companies have pressed for a strengthening of patent rights on improved varieties and some developing countries argue that large multinational companies are extracting excessive profits from sales in developing countries of improved seed based on germ plasm contributed free of charge by these countries.

While it is clear that the development and multiplication of improved seed will not be undertaken by private companies unless they are able to recuperate costs and a reasonable profit, it is possible—although available evidence is scarce—that existing laws and insufficient competition enable individual companies to capture excessive profits at the expense of developing country farmers and consumers.

To avoid exploitation it is important that existing germ plasm is available to public and private institutions and companies in all countries and to promote competition among them. Effective competition among public and private enterprises in breeding, selection, and seed multiplication should reduce the opportunity for obtaining excessive profits. It is equally important that all countries permit collection of germ plasm for one or more common collection(s). If, as argued by some (49), the current system does not meet those two criteria, changes must be made. But it is important that such changes result in a system that permits efficient and timely collection and retrieval as well as conservation of germ plasm and not a strongly bureaucratic and politicized institution which, while capable of avoiding discrimination against any country, will be unable to provide efficient and timely support to agricultural research and technological change for developing countries.

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