

## The Green Revolution: An End of Century Perspective

R.E. Evenson  
Douglas Gollin\*

Modern plant breeding originated in the late 19<sup>th</sup> century, drawing on techniques of selection and crossing. The success of this technology encouraged the development, during the first decades of the 20<sup>th</sup> century, of crop improvement programs targeted to virtually all developed country agroecological zones. These programs generally succeeded in developing large numbers of improved varieties, using farmer-selected varieties (typically termed landraces) as their basic germplasm stocks. Many crop improvement programs in this era also made use of elite germplasm introduced from other regions. By mid-century, wide-crossing techniques enabled plant breeders to combine cultivated species with “wild” or uncultivated species in the same genus. Gene bank collections of landraces, mutants, and wild species were developed to support these breeding programs. In recent decades, genetic engineering techniques have been added to the toolkit of breeders seeking to develop improved crop varieties, but these techniques are of relatively recent origin.

During the same period, the challenges facing agricultural science expanded in scope. In particular, the second half of the 20<sup>th</sup> century brought an increased awareness of the problems of poor countries – including occasional food shortages and chronically low productivity in agriculture. As the developing world emerged from colonialism, and as improvements in transportation and communication changed perceptions of the

---

\* Robert Evenson is Professor of Economics, Yale University (Robert.Evenson@yale.edu). Douglas Gollin is Assistant Professor of Economics, Williams College (Douglas.Gollin@williams.edu). As indicated below, this paper summarizes major findings from a study conducted by researchers from a number of institutions and disciplines. The study was commissioned by the Standing Project on Impact Assessment of the Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR). We would particularly like to acknowledge the following individuals who are authors of component chapters of the study: F. Afonso de Almeida, A. Aw Hassan, M.C.S. Bantilan, Y.P. Bi, V. Cabanilla, E. Cabrera, S. Ceccarelli, T. Dalton, S. De Silva, U.K. Deb, A.F. Dias Avila, A.G.O. Dixon, H.J. Dubin, W. Erskine, P.C. Gaur, R. Gerpacio, E. Grande, S. Grando, R. G. Guei, P.W. Heisey, M. Hossain, R. Hu, J. Huang, N. Johnson, S. Jin, G.S. Khush, P. Kumar, M.A. Lantican, J.H. Li, V.M. Manyong, J.W. McKinsey Jr., A. McLaren, M. Mekuria, M. Morris, S.N. Nigam, D. Pachico, M. Rosegrant, S. Rozelle, A. Sarker, K. Shideed, R. Tutwiler, T. Walker, C.S. Wortmann. In addition, we acknowledge specific comments on a draft of this article from Dana Dalrymple, Don Duvick, Guido Gryseels, Guy Manners, and Michael

developing world, a consensus emerged that the international community could play a useful role in encouraging the application of modern plant breeding technologies to the problems of poor countries.

The development of modern crop varieties (MVs) for developing countries began in a concerted fashion in the late 1950s, using conventional plant breeding methods. The term “Green Revolution” entered the popular literature in the mid-1960s when modern or high-yielding varieties of rice and wheat were developed and released to farmers in Latin America and Asia. These MVs were rapidly adopted by farmers in environments that were regarded to be favorable to crop production; *i.e.*, environments in the tropical and sub-tropical regions with good irrigation systems or reliable rainfall. These MVs were associated with the first two of what are currently 16 international agricultural research centers (IARCs): the International Center for Wheat and Maize Improvement in Mexico (CIMMYT) and the International Rice Research Institute in the Philippines (IRRI).

Over the past 35 years, scholars have produced a large literature on the Green Revolution. This literature evaluates both the accomplishments and shortcomings of the Green Revolution. Although the literature includes a number of field studies of specific countries and crops, comprehensive data on MV production and adoption have not been available until the completion of a recent study conducted under the auspices of the Special Project on Impact Assessment (SPIA), under the auspices of the Technical Advisory Committee (TAC) of the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is the umbrella organization through which most donor support for international agricultural research is channeled.

The study assembled comprehensive data on varietal production, release, and adoption for eleven major food crops, by region and country, for the 1965-2000 period.<sup>1</sup> Taken together, these data allow a more comprehensive picture of the Green Revolution than previously available.

In this paper we summarize the data and offer some interpretations. Our chief objective is to provide a more comprehensive picture of the Green Revolution. Although it is not our intent directly to confront or challenge the older Green Revolution studies, we do note that the comprehensive picture that has emerged both reinforces and challenges some earlier perceptions of the Green Revolution. In particular, we find that:

1. Varietal improvement gains have been realized in all 11 crops studied. More than 8,000 modern varieties were produced in these crops between 1965 and 1998. More than 400 breeding programs in more than 100 countries, and more than 5,000 agricultural scientists, are currently engaged in crop improvement. These varieties are the product of literally hundreds of thousands of crosses made in developing countries, with subsequent selection and testing. The varieties also reflect an enormous scientific effort: To develop a typical modern variety requires approximately ten years of sustained work by scientists and experiment station staff.
2. The production of MVs in these crops has been overwhelmingly dominated by public-sector research programs based in developing countries. International centers have been extraordinarily successful in producing MVs, primarily by providing elite materials to national programs in poor countries.<sup>2</sup> Private firms have produced MVs only in hybrid maize, sorghum and millets; and these represent less than five percent of all MVs. Somewhat surprisingly, plant breeding programs in developed countries

---

<sup>1</sup> The crops are: rice, wheat, maize, sorghum, pearl millet, barley, beans, lentils, groundnuts, potatoes, and cassava.

<sup>2</sup> Most of the international centers chose consciously not to release varieties themselves from the 1970s onward, and instead elected to build collaborative relationships with national programs, through which the international centers would focus on

contributed less than one percent of the MVs released in developing countries – and virtually none after 1980.

3. International centers have supported NARS breeding programs by providing germplasm and other inputs. The data suggest that the work of international centers has encouraged additional investment by many national programs, rather than “crowding out” such investments.<sup>3</sup>
4. The production of MVs has differed by crop and by region for several reasons, including: the high degree of location-specificity of crop varieties; differences in production ecosystems; and differences in the initial adequacy of “germplasm stocks” on which breeding programs rely.
5. There are striking differences in MV adoption rates by crop and region, paralleling the differences in MV production. Breeding programs have worked to incorporate traits (chiefly host plant resistance to diseases and insect pests) that allowed for the diffusion of modern varieties into areas not suitable for the “first generation” varieties. This has led to a steady growth in the area planted to modern.
6. Despite the efforts of national and international breeding programs, the production and diffusion of modern varieties has remained uneven across crops and regions. Thus, farmers in Sub-Saharan Africa received few CGI gains until the 1990s, whereas Asian and Latin American farmers were realizing high rates of CGI gains in all periods.
7. While biotechnology methods will be important in the future, almost all the crop improvement relevant to developing countries over the past forty years has been based on conventional breeding, with some limited use of wide-crossing methods.

---

supplying breeding materials, promoting the exchange of germplasm, and training scientists.

<sup>3</sup> For some small countries, the international centers substituted for national investments; for large countries, they complemented one another.

## **Production of modern varieties**

Fifty years ago, as interest arose in crop varietal improvement for the developing world, two crops offered particular promise: rice and wheat. For these crops – unlike many others – scientists had access both to rich stocks of genetic resources and to extensive breeding experience. In the case of wheat, a breeding program sponsored by the Rockefeller Foundation, located in Mexico and led by Norman Borlaug, had been established in 1943. This program eventually evolved into the CIMMYT wheat program. The Rockefeller program drew on experience with temperate zone spring wheats and winter wheats and also had access to substantial collections of landraces and advanced breeding lines that had been acquired before 1940. This program received a major gain in 1953 when semi-dwarf germplasm was introduced into breeding lines.

For rice, many years of breeding experience, particularly in Japan, had improved *japonica* types in the first half of the 20<sup>th</sup> century, although *indica* rices remained relatively unimproved. The “ponlai” rice varieties developed in Taiwan in the 1930s combined some of the features of both *japonica* and *indica* types. In the 1950s, the Food and Agriculture Organization of the United Nations (FAO) supported a program of *japonica-indica* crossing. This program set the stage for the subsequent work of IRRI.

Given this background, it was not surprising that successes came fairly rapidly in both wheat and rice. In both crops, high-yielding varieties suited to developing countries were developed by the mid 1960s. For both crops, the new varieties were based on a new “plant type” with semi-dwarf characteristics. Farmers adopted the new varieties rapidly in some areas – chiefly those with access to irrigation. Yields for the new varieties were substantially higher than yields for the varieties that they replaced.

For many other crops, however, breeding work aimed at the developing world had far less of a platform on which to build. In cassava, for example, there was essentially no research or elite germplasm available in the 1960s. For most of these crops, international research achieved success later and less dramatically. Yet even in

the 1960s and 1970s there were substantial achievements in these crops. Breeding efforts in both international and national institutions resulted in the production of large numbers of modern varieties.

Figure 1 shows annual releases of “modern” varieties for 11 food crops. Across all crops, regions, and time periods, the data suggest a substantial amount of breeding success, measured in terms of varieties released by national research programs.<sup>4</sup> There are, however, a number of important disparities in the production of modern varieties. For sorghum, millet, and barley – crops grown primarily under semi-arid and dryland conditions – there was relatively little improved germplasm available until the 1980s. The same was true for the major pulses and for root crops – especially cassava. The production of MVs in these crops has lagged production in other crops. This effect has been particularly pronounced for the Middle East/North Africa and for Sub-Saharan African countries.

Figure 1 shows that varietal production for all crops doubled from the 1960s to the late 1970s, then doubled again by the 1990s. Varietal production rates for wheat and rice have been roughly stable for the past 15 years but have been rising for all other crops.

### **Adoption of modern varieties**

As noted above, varietal releases are not necessarily a good measure of the success of research. A better measure is the use of these varieties by farmers. All of the modern varieties produced by national and international research institutions went through exhaustive field tests before release, and eventually all were made available to farmers. When a farmer chooses to adopt a new variety in place of an older variety, it reflects the farmer’s judgment that the new variety offers some net benefit or advantage. Some of the varieties in the data were widely adopted; but many did not generate much interest from farmers and consequently have been little used.

---

<sup>4</sup> This is admittedly a weak measure, since varieties could be released without being adopted by farmers, but in practice such

Figure 2 depicts adoption rates by region and decade. The figure shows that, for most crops, in most regions, modern variety adoption follows modern variety production. There are, however, important differences across crops and regions in the date of first adoption and in the subsequent rates of increase in adoption. Particularly striking are the data on modern variety adoption from Sub-Saharan Africa. Although significant numbers of modern varieties were produced in this region in the 1960s and 1970s, there was little adoption by farmers, except for wheat. Why was Sub-Saharan Africa different? The data suggest that in the 1960s and 1970s, national and international programs sought to “short-cut” the varietal improvement process in Sub-Saharan Africa by introducing improved varieties from Asia and Latin America, rather than engaging in the time-consuming work of identifying locally adapted germplasm and using it as the basis for breeding new varieties. This pattern remained until the 1980s, when more suitable varieties finally became available – based on research targeted specifically on Africa.

Location-specific breeding thus has been crucial for the adoption of modern varieties across regions and countries. For most of the research institutions involved in crop genetic improvement, the research strategy was first to develop a productive “plant type” (for example, a high-yielding semi-dwarf) to serve as a platform for local adaptation, and then to breed in subsequent generations for location-relevant qualitative traits – such as host plant resistance to diseases, pests, and abiotic stresses. This second-stage research was extremely important for adoption. For India, the SPIA-TAC report suggests that the first generation of improved rice varieties (the basic semidwarf plant type) would have been planted on only 35 percent or so of rice irrigated/rainfed area. The subsequent generations of trait incorporation increased adoption to more than 80 percent, with large ensuing benefits for both producers and consumers.

---

“phantom releases” appear to be rare and do not occur in any systematic way.

## **Direct and indirect contributions of international research**

For most of the modern varieties in the study, complete or near-complete genealogies could be constructed, back to landrace ancestors or other original progenitors. Study participants analyzed these genealogies to look for two types of international contributions to varietal improvement. Direct contributions were defined as varieties developed in international institutions and then released by national programs without further crossing. Indirect contributions were defined to include varieties that were crossed in national institutions but where parents or other ancestors originated in international research programs. Several striking results emerge from this analysis.

### *1. Exceptional Direct and Indirect Contributions by IARC programs.*

More than 35 percent of MVs released and adopted were based on crosses made in IARCs. Fifteen percent of NARS-crossed MVs had an IARC-crossed parent, and an additional seven percent had another IARC crossed ancestor.

### *2. Relatively Low Rates of International Flows for NARS-crossed MVs.*

For rice, where such data were available, only 6 percent of MVs originated when one national program released a variety that was crossed by a NARS in another developing country. By contrast, most IARC-crossed MVs were released in at least one country other than the IARC's host country.

### *3. Negligible Developed Country Contributions to the Green Revolution.*

Fewer than 1 percent of MVs included in their genealogies any crosses made in modern research programs in developed countries.

### *4. High Direct Contributions to Adopted Varieties*

The contributions of international centers were not limited to “phantom releases” of varieties never actually used by farmers. For almost all crops, regions, and periods, we find that on average, a typical



IARC- related variety accounted for more cultivated area than an average variety with no IARC ancestry. This suggests that varieties with direct and indirect IARC contributions have had disproportionate impacts on production.

In focusing on the impact of international research, we hasten to note that we do not in any sense disparage the work of national programs, which played the crucial role in creating varieties suitable for farmers. Strong national programs made an enormous difference in China and India, as well as many smaller countries. Increasingly over time, some national programs have also been leaders in the science and technique of plant breeding.

Nonetheless, the impact of international research is striking. To put the data in perspective, note that international centers account for only small fractions of the scientists working in crop improvement programs in developing countries – roughly 3 percent of the developing world’s maize researchers, and no more than 15 percent of the rice scientists in South and Southeast Asia, excluding China. The fractions of expenditures on crop improvement in developing countries are somewhat higher, since IARCs have higher expenditures per researcher.

### **Productivity growth impacts of crop breeding**

The impact of agricultural research on production can be measured in terms of productivity gains. The study included estimates for each crop of the productivity advantages of converting crop acreage from traditional varieties to modern varieties. In some cases, estimates of productivity advantages of converting from early generation MVs to later generation MVs were also reported. The project also included three country

studies for India, China and Brazil. All approaches to measuring productivity gains reported similar estimates of impact.

Figure 3 depicts average annual crop breeding contributions to productivity growth by crop, by decade, and by region. These contributions were obtained by multiplying MV adoption rates by the productivity advantages and converting these to ten-year growth rates. These calculations were then compared to actual aggregate yield growth over the periods. The calculated growth rates were highly correlated with actual yield changes by crop and region. The study concluded on the basis of this analysis that more than half of the real productivity growth in developing country agriculture can be attributed to crop breeding.

We note from Figure 3 that growth from varietal improvement has been realized in all crops, but at very different rates by region. Regional differences in the effectiveness of varietal improvement reflect differences in crop mix and in rates of adoption. Figure 3 thus goes a long way toward explaining one of the puzzles of the agricultural development literature. Observers have noted that Sub-Saharan Africa and the Middle East-North Africa regions have had relatively high “investment intensities” in agricultural research and extension. Yet the productivity performance of these two regions has not matched Asia’s record. Figure 3 indicates that in the 1960s Asian agriculture was already realizing significant growth from varietal improvement, while Sub-Saharan Africa was realizing none. In the 1970s and 1980s Asian agriculture was realizing roughly one percent per year from crop breeding alone, while Sub-Saharan Africa was realizing only one quarter as much. Even in the 1990s, Sub-Saharan Africa was realizing only about half the growth of other regions.

For all crops in all regions, the gains from breeding were highest in the 1980s and 1990s. Popular perceptions suggest that the Green Revolution was effectively over by this time; but in fact, as Figure 3 shows, plant breeding contributions were highest for the 1980s – even for rice and wheat. This was particularly

important because in most developing countries, the 1980s and 1990s saw the largest increments ever recorded in human populations.

In spite of the population explosion, however, crop breeding helped to keep food production per capita rising. As a result, the real price of food declined over the 1980s and 1990s, for the world as a whole and for most developing countries.

Why did Sub-Saharan Africa get so little growth from varietal improvement? Were institutions and policies simply inadequate? Are accidents of geography a fundamental barrier? Are there institutional and political failures? Or is this outcome linked to historically determined cropping patterns and the inherited colonial background? We have argued throughout this paper that the cropping mix and inherited state of knowledge (and of germplasm) are the dominant factors in differential regional performance. Clearly there are institutional and political failures in all regions, and we do not intend to downplay these issues. But Figure 3 and the underlying data point to differential research investments and research time lags as primary reasons for differential performance by region. The implications for Sub-Saharan Africa are actually promising: recent varietal improvement efforts appear to be working, and the technological “pipeline” for the region finally contains the materials needed to deliver future growth.

### **Welfare effects and counterfactual scenarios**

As noted earlier, the Green Revolution has been the subject of many studies, both critical and laudatory. Most of these studies have compared the Green Revolution experience against some normative “standard,” explicit or implicit. A frequent (implicit) comparison is to ask how the Green Revolution contributed to meeting human nutritional needs or requirements. Another common implicit comparison is with some set of desirable social and environmental outcomes.

The SPIA-TAC study did not attempt a comparison against standards of this kind. Instead, it chose to perform “counterfactual” comparisons. That is, the counterfactual studies attempted to compare actual Green Revolution outcomes (prices, production, trade, and welfare) against outcomes that would likely have obtained in the absence of the Green Revolution. This is in essence a positive analysis, rather than a normative one. Needless to say, there are difficulties in carrying out such counterfactual analyses, but we believe they offer a more appropriate point of reference than the normative standards described above.

The SPIA-TAC analysis compared the actual experience of developing countries with two “counterfactual scenarios” reflecting different levels of agricultural research activity. The analysis was conducted using an international multi-market model developed by the International Food Policy Research Institute (the IFPRI-IMPACT model) and used for a number of widely cited projections of agricultural production and trade. The IFPRI/IMPACT model contains 18 agricultural commodities and 37 countries or country groups. The model solves for an economic equilibrium that allows researchers to see how crop yields, crop area, crop production, crop trade and international prices would change under different scenarios. This model also calculates two welfare indexes associated with this equilibrium: the percent of children (0-6) malnourished, and average food caloric consumption.

The two counterfactual scenarios considered in our research were the following:

1. How would the food and agricultural situation in 2000 have differed if poor countries had failed to achieve any of the actual productivity gains realized through breeding from 1965 to 2000, assuming that rich countries achieved the same productivity gains that they actually realized? This is termed the No Green Revolution (NGR) case.
2. How would the food and agricultural situation in 1999 have differed had international research not been carried out? This is termed the No IARC Research (NIARC) case. It differs from the first

counterfactual in that it assumes that national programs would have invested in research on their own, with varying rates of success across crops and regions.

Both cases are compared to a base case, which incorporates productivity growth components for crops and countries based on actual experience. These are quite high for developed countries because, over the period analyzed, the agricultural sectors in many rich countries – including the U.S. – had higher rates of productivity growth than other sectors of the economy. For developing countries, productivity rates in the base case were also quite high – even without international contributions, NARS research would have increased productivity substantially.

For each counterfactual, “high” and “low” scenarios are reported. The “low” scenario for the NGR counterfactual simply subtracts the modern variety contributions to productivity growth (shown in Figure 3) from base case productivity gains. This essentially corresponds to a world with no productivity growth from plant breeding in developing countries. The “high” scenario assumes that impacts would have been higher because some other productivity gains would have been lost along with the gains from agricultural research. In particular, it was assumed that one-fourth of the non-breeding gains would have been lost as well.

The NIARC simulation was constructed by subtracting all the benefits associated with international research. The “low-impact” and “high-impact” scenarios were based on different assumptions about the response of national programs to the loss of IARC research. The “low” scenario presumed that NARS programs would have compensated for the loss of international research by producing 50 percent more MVs than they actually did. The “high” scenario presumed that they would have produced only 25 percent more MVs than they actually did. This simulation also assumed that productivity in developed country agriculture

would have fallen by an amount consistent with estimates of the impacts of the IARCs on agricultural productivity in those regions (from Pardey *et al.*).

Figures 4, 5, and 6 show how food prices and other welfare measures in developing countries would have responded to the two counterfactuals (four scenarios). Consider first the NGR (No Green Revolution) case. This comparison suggests that in the absence of any crop genetic improvement in developing countries, prices of food crops would have been 35 to 66 percent higher in 2000 than they actually were. Many observers are surprised that these price effects are not larger. The main reason is that for a number of crops – including wheat and maize – the ensuing production declines in developing countries would have been offset by increased production from developed countries, which would have responded to higher prices by expanding production (and exporting food to the developing world). Moreover, in some crops – such as other grains, potatoes and root crops – the price increases that would have occurred are modest because there were relatively low gains in productivity from genetic improvement. For these crops, the absence of research would have made little difference on prices.

The effects of the NGR counterfactual are further illustrated in Figure 6, which shows that developed country yields, areas, and production would all have risen if developing countries had failed to generate the productivity gains of the Green Revolution. In the developing countries, the slower productivity growth would have implied reduced yields and production (relative to what actually happened). The area under cultivation would have expanded, however, due to price effects. Because food prices would have been higher, more area would have been devoted to food production in both rich and poor regions. This in turn would have had substantial implications for the environment. Cropland increases must come at the expense of other land uses. This has implications for soil and water erosion and biodiversity. The Green Revolution, interpreted in this light, spared land for nature, and the quantity spared is significant.

Yield losses in developing countries – and the implied production losses – would not have been translated directly into consumption losses. In the absence of the Green Revolution, developed countries would have exported more to developing countries, making up for some of the production shortfalls. The extent of this trade would have been limited, however, by the capacity of importers to pay for food imports.

The NIARC counterfactual generally runs parallel to the NGR counterfactual described above. Under this scenario, continued research by national programs in developing countries would have led to a Green Revolution, but of reduced magnitude. As a rough generalization, this “lite” Green Revolution would have been about 60 percent of the magnitude of the one actually achieved.

Figure 6 shows welfare consequences of the counterfactuals and scenarios. Had the Green Revolution not occurred, the percent of children (0-6) in developing countries deemed to be malnourished (based on weight and height) would have been six to eight percentage points higher than it was. For South Asia, it would have been 12 to 15 percentage points higher. Put in perspective, this suggests that the Green Revolution succeeded in raising the health status of 32 to 42 million pre-school children. The effects on calorie availability are also large and these also have very important implications for welfare.

### **A retrospective interpretation**

Critics of the Green Revolution have argued that the Green Revolution was delivered in a very uneven fashion to farmers in different countries. Some have claimed adoption biases favoring commercial farmers over subsistence farmers and large farms over small farms. Our more comprehensive data certainly do not call into dispute the unevenness of delivery of MVs to farmers. Figure 3 shows major differences in MV delivery by crop and region. More detailed country data show unevenness within countries as well. Even for crops where MV adoption rates are high, we do not find complete adoption by all farmers.

However, our reading of the MV production and diffusion evidence leads us to the conclusion that much, perhaps most, of the unevenness in modern variety diffusion rates is associated with location specificity and diversity of production environments (or agroecologies). Successful breeding typically builds on “germplasm platforms” appropriate to particular production environments. In some cases, these platforms must be built from scratch; sometimes, the incorporation of qualitative traits (e.g., disease resistance) enables a platform suited to one region to be moved to another. There are some differences in adoption rates of MVs due to local institutions and to different levels of farmer knowledge. But these do not appear to be the major source of differences across regions. Instead, the major story appears to be the availability of suitable platforms for different crops, regions, and agroecologies.

Critics of the Green Revolution have noted that MVs often lead to increased use of fertilizer and other chemical inputs than was the case for the traditional varieties that they replaced. As a consequence, most MVs pose a larger threat to the environment through ground water contamination and related issues. This is hardly surprising; the modern varieties produced for farmers in developed countries had the same characteristics. Even with extensive adoption, however, no developing countries yet approach the levels of use of fertilizers and other chemicals (herbicides, insecticides) currently common in developed countries.

On the positive side of the Green Revolution, our more comprehensive perspective and the counterfactual studies confirm that the Green Revolution had major welfare impacts on millions of poor people. Had the Green Revolution (or the international research component of it) not been realized, child mortality rates would have been higher, child morbidity and malnutrition rates would have been higher, and calorie consumption would have been lower. There is little doubt that the research units bringing MVs to developing countries had a major impact on consumers. Standard consumption economics suggests that this impact would have been



highest for those consumers most affected by food prices, who are in general the poorest consumers (some of whom are also producers).

Our counterfactual calculations also challenge the popular view that the world would have experienced a “food crisis” had the Green Revolution not taken place. Food prices would have been higher, but not by huge proportions. This is because developed country agricultural productivity growth has been high. In fact, the agricultural sector outperformed the rest of the economy in terms of productivity growth in every developed country over at least the past fifty years.

But the economic studies also show significant effects on producers in both developed and developing countries. In rich countries, the combination of rapid productivity gains, new technological developments, and price inelastic demand for farm commodities has produced major and costly adjustments. The number of farms has declined as farm size has grown, and much of agricultural production is now industrialized. (This would have occurred even if the Green Revolution in developing countries had not occurred).

In poorer countries, the dislocations from productivity growth have so far been smaller. The serious problem for developing country producers has been the combination of uneven delivery of MV technology and the even delivery of falling world prices to producers. For many of the world’s poorest farmers, development programs have delivered lower prices but have not delivered lower costs. This combination has been deadly for countries in mass poverty. This, of course, represents a major criticism of the Green Revolution, but it does not imply that the world would have been better off without the Green Revolution. It implies that a Green Revolution where MV delivery reached more farmers would have been preferred.

But there is another issue here, and that is the question of alternatives to the Green Revolution for countries in mass poverty. The failure of the Green Revolution to reach these countries is clearly serious for farmers. But those countries are primarily agricultural, with 70 percent or more of their labor force earning their

living in agriculture. Development assistance for infrastructure and to support industrialization has also failed these mass poverty countries. In such circumstances, future green revolutions may be the only plausible option for escape from mass poverty.

## References

- Dalrymple, D. (1986a), *Development and Spread of High Yielding Rice Varieties in Developing Countries*. Washington, DC: Bureau for Science and Technology, Agency for International Development.
- Dalrymple, D. (1986b), *Development and Spread of High Yielding Wheat Varieties in Developing Countries*. Washington, DC: Bureau for Science and Technology, Agency for International Development.
- Evenson, R.E. (2001), "IARC 'Germplasm' Effects on NARS Breeding Programs," Chapter 21 in *Crop variety improvement and its effect on productivity: The impact of international agricultural research*, eds. R. Evenson and D. Gollin. Wallingford, UK: CAB International.
- Evenson, R.E. and D. Gollin, eds. (2001), *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*. Wallingford, UK: CAB International, 2001.
- Griliches, Z. (1957), "Hybrid corn: An exploration in the economics of technical change," in *Econometrica* 25: 501-22.
- Heisey, P.W., M.A. Lantican, and H.J. Dubin (2001), "Wheat," Chapter 4 in *Crop variety improvement and its effect on productivity: The impact of international agricultural research*, eds. R. Evenson and D. Gollin. Wallingford, UK: CAB International.
- Hayami, Y. and V.W. Ruttan (1985), *Agricultural development: An international perspective*. Baltimore: Johns Hopkins Press.
- Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan (1996), *Hidden Harvest: U.S. Benefits from International Research Aid*. Washington, DC: International Food Policy Research Institute.
- Stakman, E.C., R. Bradfield, and P.C. Mangelsdorf (1967), *Campaigns against hunger*. Cambridge, MA: Belknap Press.
- Timothy, D.H., P.H. Harvey and C.R. Doswell (1988), *The Development and Spread of Improved Maize Varieties and Hybrids in Developing Countries*. Washington, DC: Bureau for Science and Technology, Agency for International Development.



Figure 1. Modern Variety Production by Decade and Region

(Annual MV Releases)

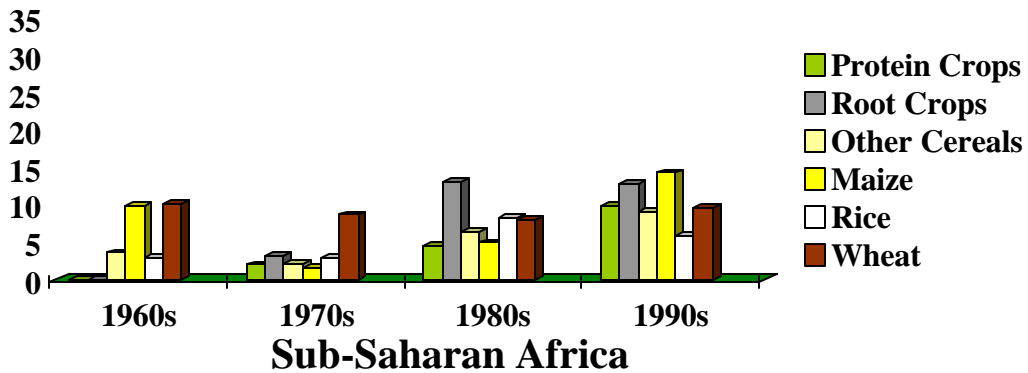
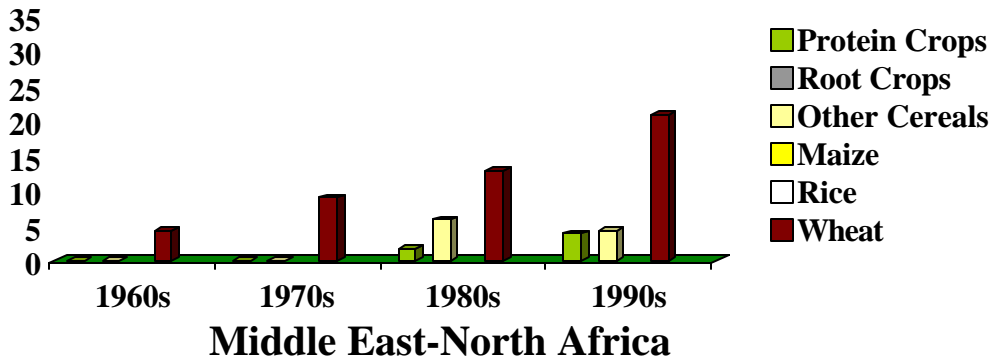
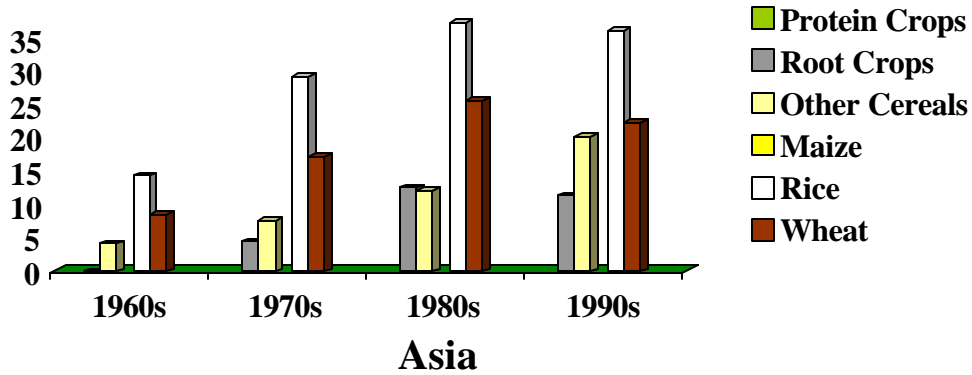
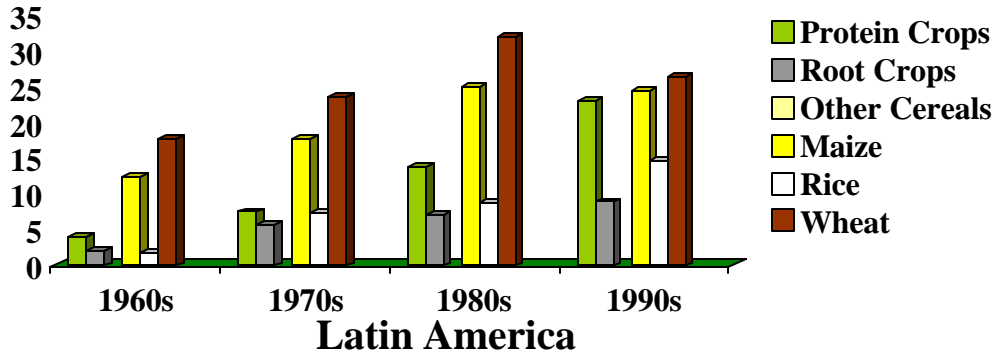
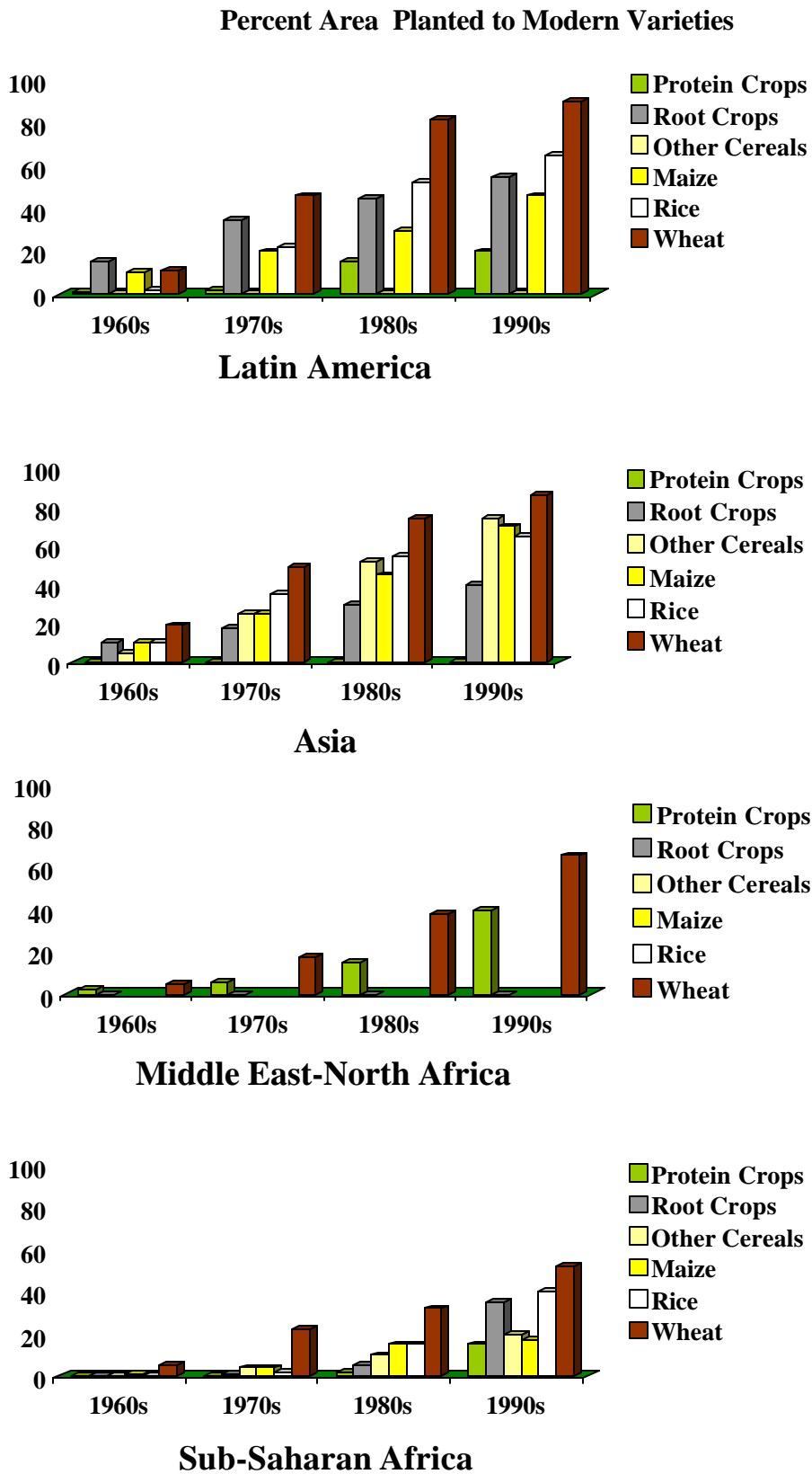
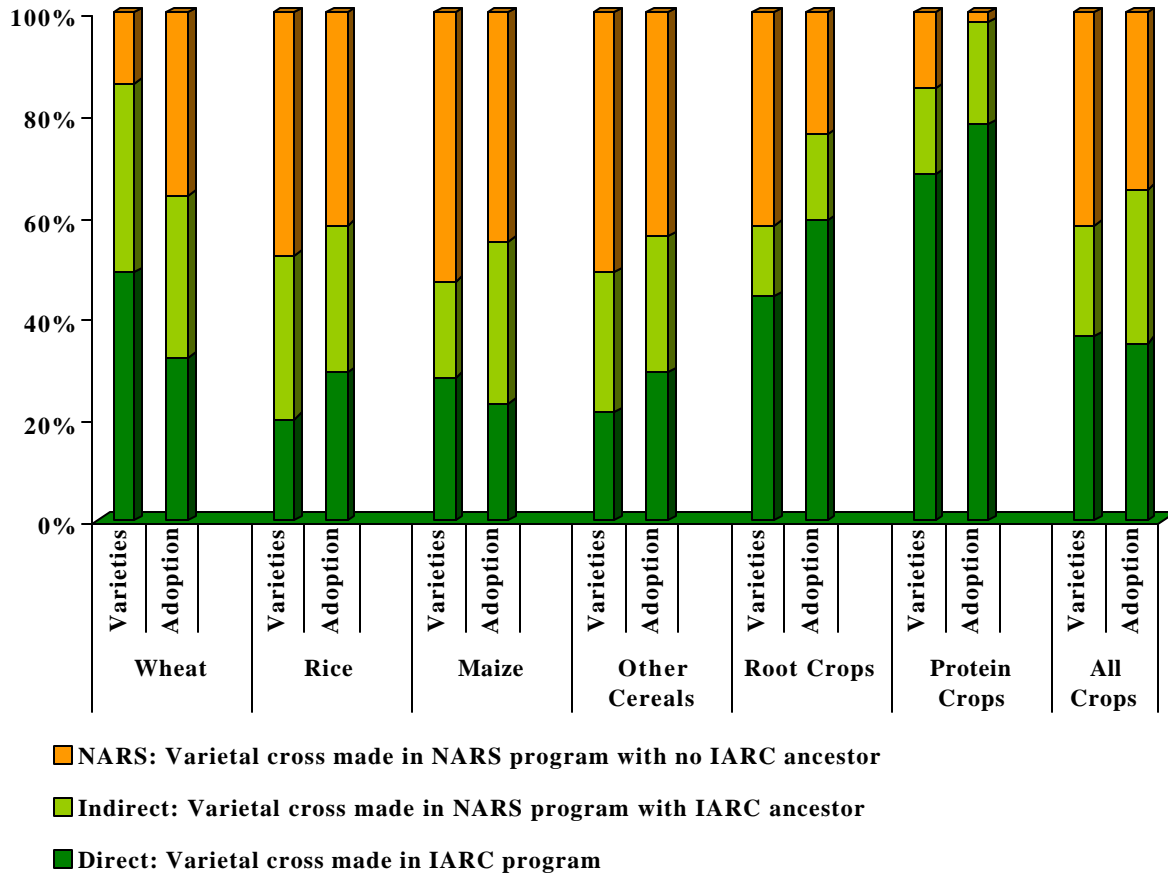


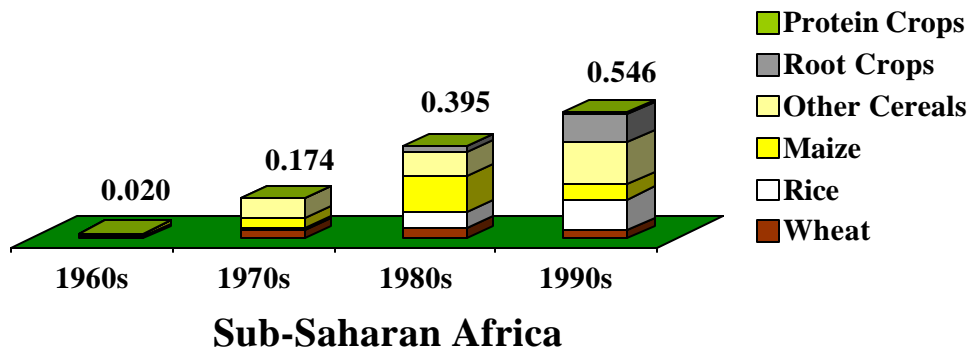
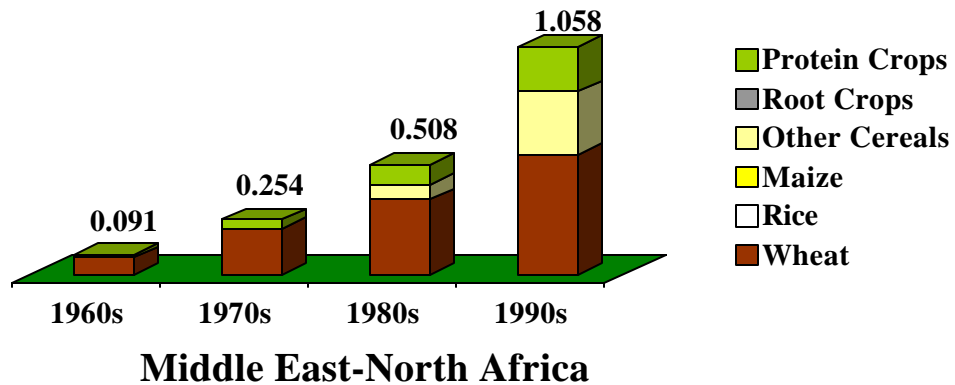
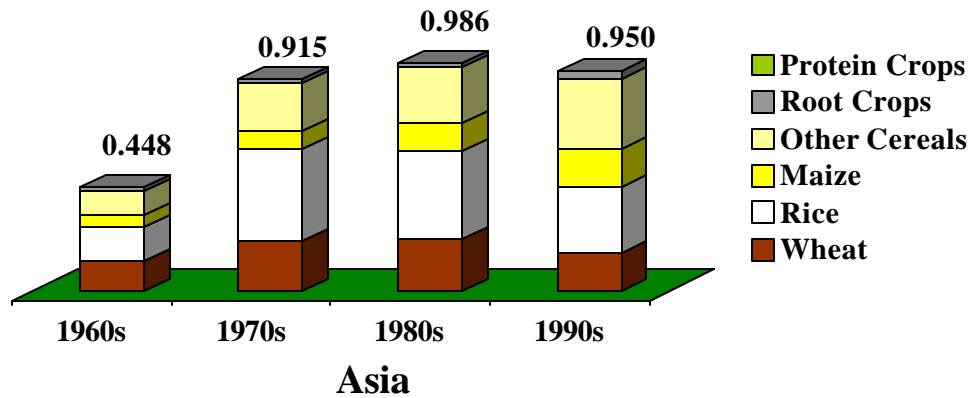
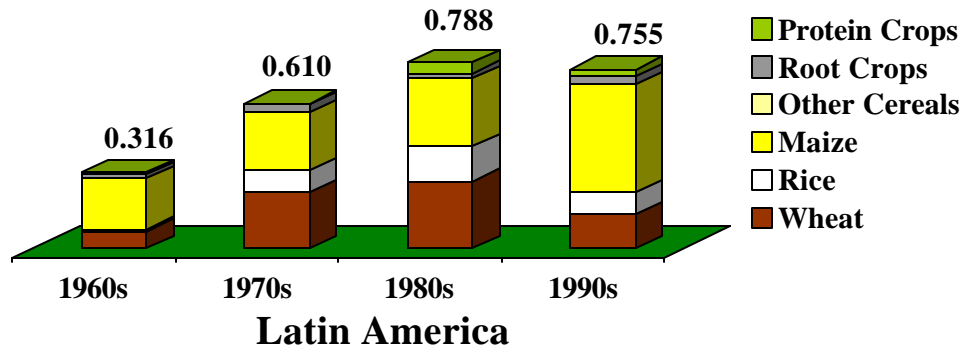
Figure 2. Modern Variety Diffusion by Decade and Region.



**Figure 3. IARC Content in MVs**



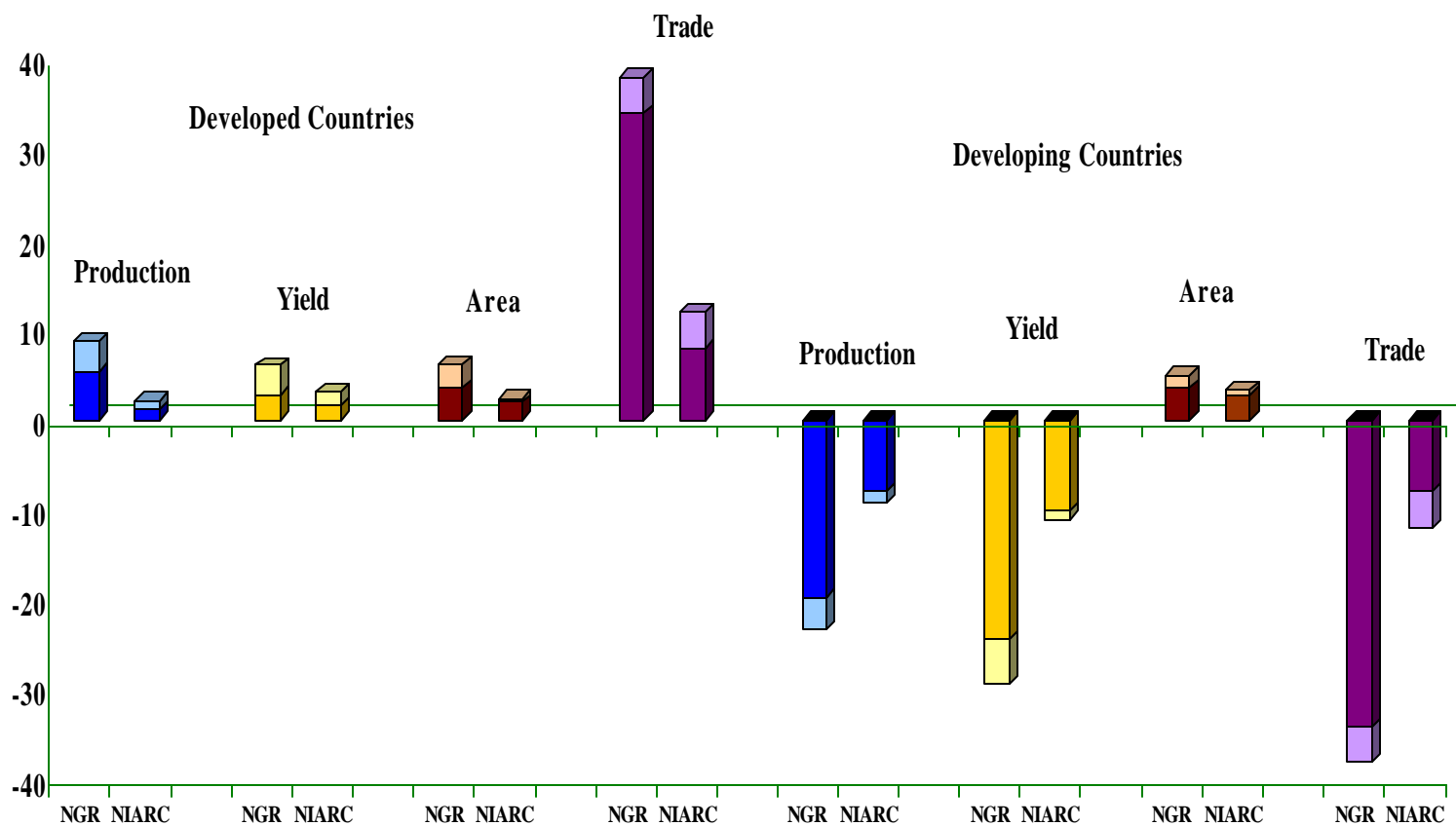
**Figure 4. Annual Growth Contributions of Modern Varieties**







**Figure 5. Production, Area, Yield and Trade Effects: All Crops: Counterfactual Simulations.**



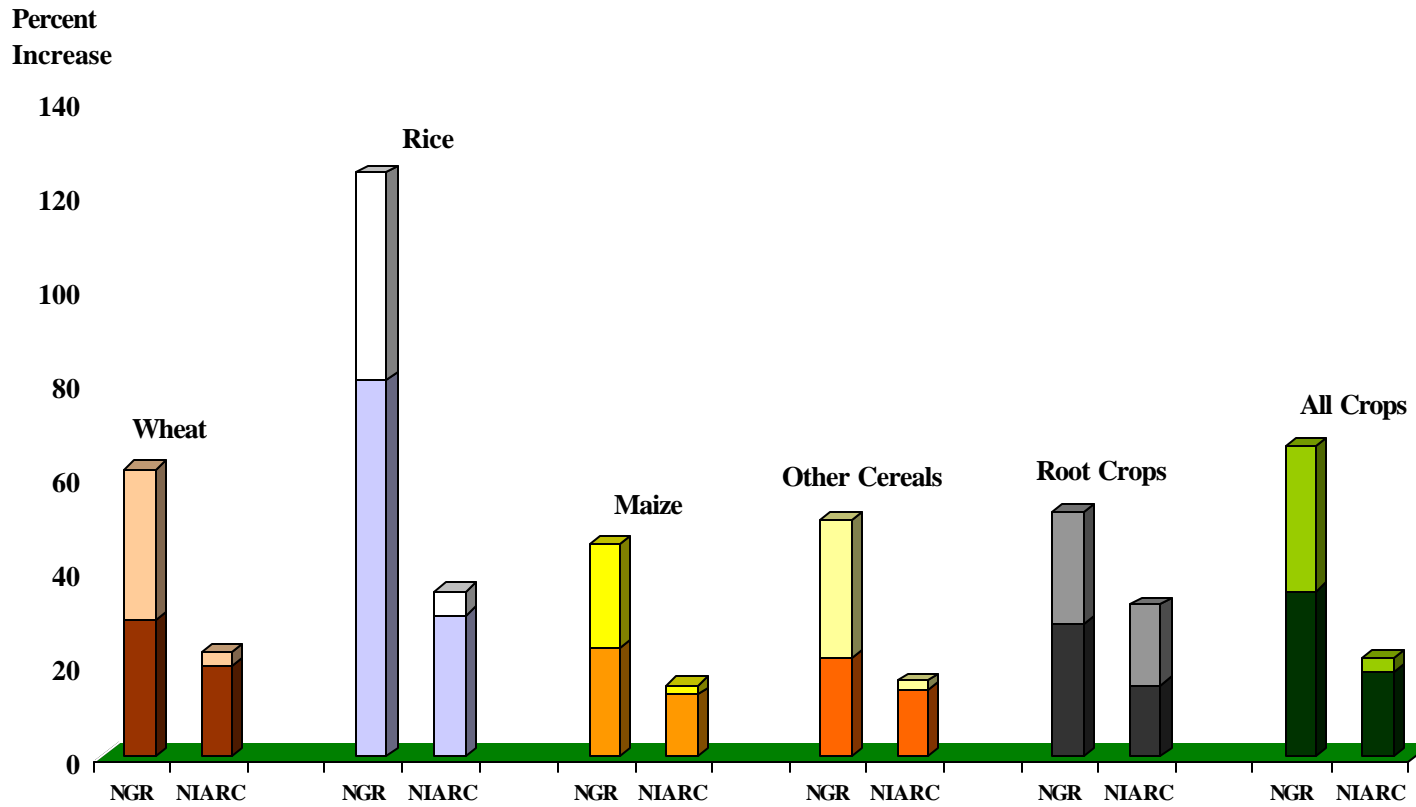
NGR: Simulations in percent differences if production in developing countries is constrained to use varieties available in 1965.

NIARC: Simulations in percent differences if IARC CGI programs had not been built.





**Figure 6. Global Price Effects: Counterfactual Simulations**

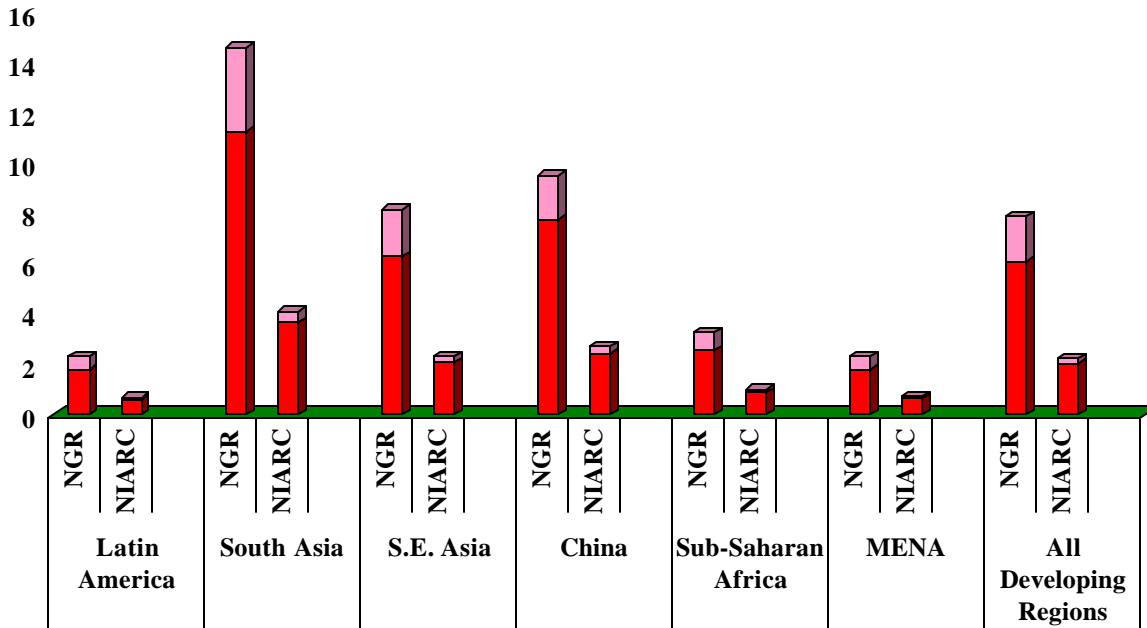


NGR: Simulations in percent differences if production in developing countries is constrained to use varieties available in 1965.

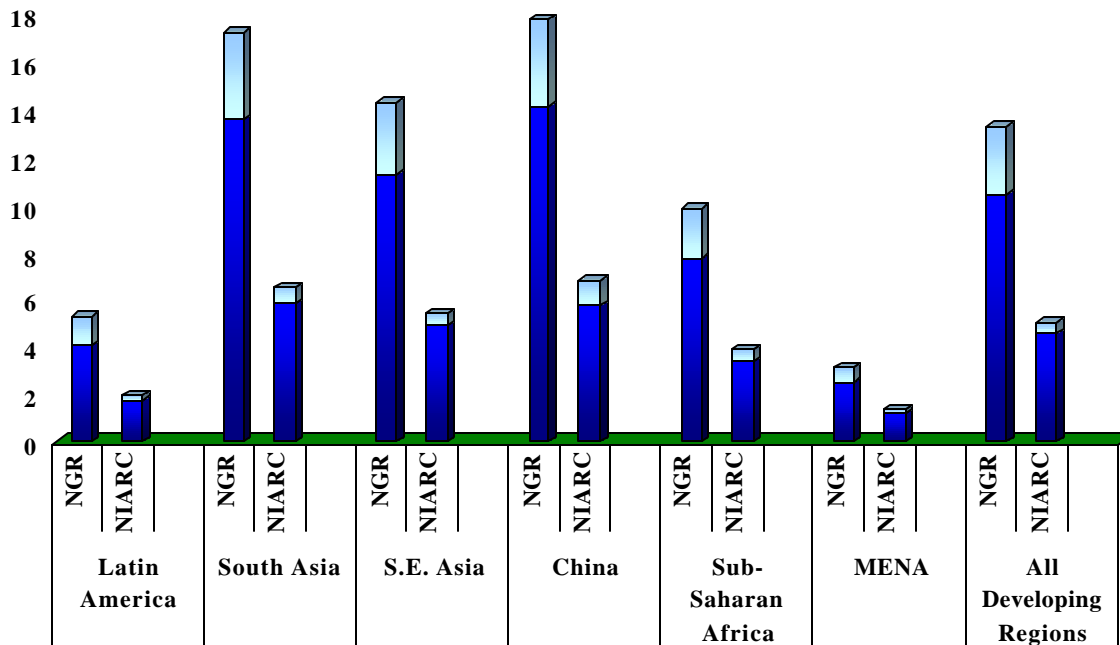
NIARC: Simulations in percent differences if IARC CGI programs had not been built.

Figure 7. Welfare Indexes: Counterfactual Scenarios

**Increase in Percent of Children (0-6) Malnourished**



**Percent Decrease in Calorie Availability**



NGR: Simulations in percent differences if production in developing countries is constrained to use varieties available in 1965.

NIARC: Simulations in percent differences if IARC CGI programs had not been built.

