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Science **300**, 758 (2003);
DOI: 10.1126/science.1078710

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Assessing the Impact of the Green Revolution, 1960 to 2000

R. E. Evenson* and D. Gollin

We summarize the findings of a recently completed study of the productivity impacts of international crop genetic improvement research in developing countries. Over the period 1960 to 2000, international agricultural research centers, in collaboration with national research programs, contributed to the development of "modern varieties" for many crops. These varieties have contributed to large increases in crop production. Productivity gains, however, have been uneven across crops and regions. Consumers generally benefited from declines in food prices. Farmers benefited only where cost reductions exceeded price reductions.

The development of modern or high-yielding crop varieties (MVs) for developing countries began in a concerted fashion in the late 1950s. In the mid-1960s, scientists developed MVs of rice and wheat that were subsequently released to farmers in Latin America and Asia. The success of these MVs was characterized as a "Green Revolution." Early rice and wheat MVs were rapidly adopted in tropical and subtropical regions with good irrigation systems or reliable rainfall. These MVs were associated with the first two major 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). There are now 16 such centers that operate under the auspices of the Consultative Group for International Agricultural Research (CGIAR) (*1*). These centers currently support about 8500 scientists and scientific staff, and the annual budget of the CGIAR is currently around $340 million.

A recent study initiated by the Special Project on Impact Assessment (SPIA) of the CGIAR's Technical Advisory Committee (TAC) has compiled the most extensive data yet assembled on the breeding, release, and diffusion of MVs (*2*). The SPIA study allows for a detailed analysis of the impact of international research for 11 major food crops, by region and country, for the period 1960 to 2000 (*3*). Here we summarize and report the major findings of the SPIA study.

In focusing on the impact of international research, we do not in any sense disparage the work of national agricultural research systems (NARS), which played a crucial role in creating varieties suitable for farmers. Strong national programs have provided effective research in many developing countries, and some are leaders in the science and technique of plant breeding. The SPIA study specifically considers the interaction between IARC plant-breeding programs and NARS plant-breeding programs and finds that the two generally fill complementary roles (*4*).

Breeding of Modern Varieties

The early successes in breeding rice and wheat MVs reflected the advanced state of research on those crops in the late 1950s. Researchers at IRRI and CIMMYT had access to rich stocks of genetic resources and drew on extensive breeding experience in developed countries. For both crops, breeders incorporated dwarfing genes that allowed the development of shorter, stiff-strawed varieties. These varieties devoted much of their energy to producing grain and relatively little to producing straw or leaf material. They also responded better to fertilizer than traditional varieties. Farmers adopted the new semidwarf MVs rapidly in some areas—chiefly those with access to irrigation or reliable rainfall—and the new varieties yielded substantially more grain than previous varieties (*5*, *6*).

The early success of these MVs was widely referred to as the "Green Revolution," and popular accounts have tended to equate the Green Revolution with the initial wave of MV releases in the late 1960s and early 1970s. Our findings suggest, however, that this early episode of MV adoption was only the beginning of the Green Revolution. Over the following years, the Green Revolution achieved broader and deeper impacts, extending far beyond the original successes of rice and wheat in Latin America and Asia.

For many other crops, however, breeding work aimed at the developing world could not rely on prior work in developed countries. In cassava or tropical beans, for example, there was essentially no research or elite germplasm available in the 1960s (*7*, *8*). As a result, the development of MVs was slower for these crops. But over the following decades, international research led to the development of improved varieties in all 11 crops studied. By 2000, the SPIA study documents more than 8000 MVs released in the 11 crops studied (Fig. 1). These MVs were released by more than 400 public breeding programs and seed boards in over 100 countries (*9*). Contrary to some views of the Green Revolution, the rate of MV releases has actually increased since the 1960s. There are, however, a number of important disparities in the development of MVs, especially by agroecological zone (AEZ). For sorghum, millet, and barley—crops grown primarily under semiarid and dryland conditions—few MVs were bred until the 1980s. The same was true for the major pulses and for root crops—especially cassava. Regional disparities were also important. Even for maize and rice, few varieties were available until the 1980s for the Middle East–North Africa and for Sub-Saharan African countries (*10*, *11*).

Adoption of Modern Varieties

When a farmer chooses to adopt a new variety to replace an older variety, it reflects the farmer's judgment that the new variety offers some net benefit or advantage. For most crops, in most regions, MV adoption occurred soon after MVs were released (Fig. 2). There are, however, important differences across crops and regions in the date at which significant adoption of MVs first occurred and in the subsequent growth rates of MV adoption. For example, although large numbers of MVs were released in Sub-Saharan Africa in the 1960s and 1970s, there was little MV adoption by farmers, except for wheat. The data suggest that in the 1960s and 1970s, national and international programs may have sought to "short-cut" the varietal improvement process in Sub-Saharan Africa by introducing unsuitable 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 to African conditions (*10*, *11*).

More generally, diffusion patterns reflect the importance of location-specific breeding. For

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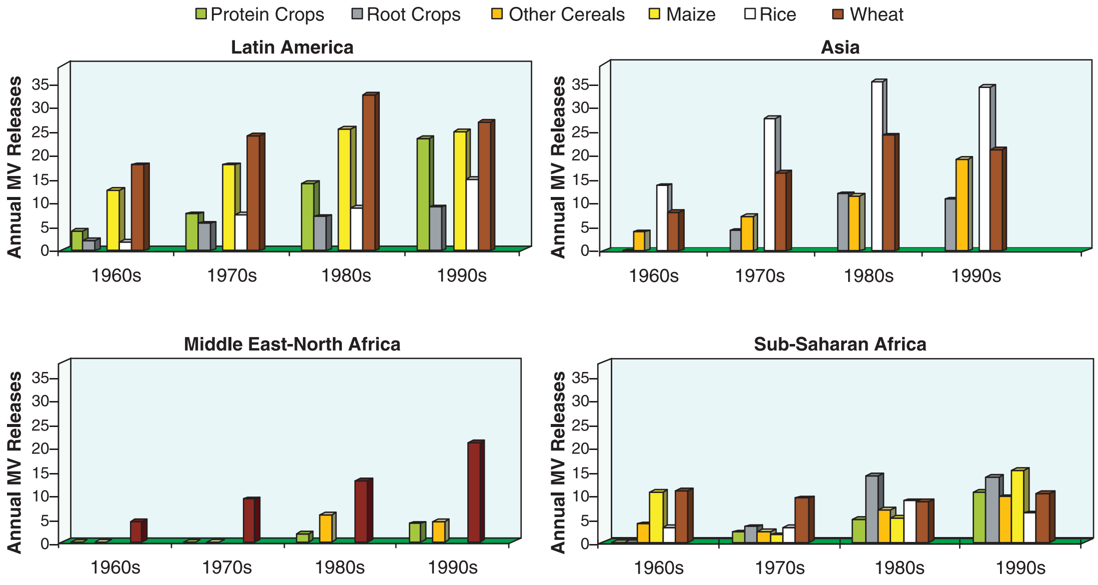

Fig. 1. Modern variety production by decade and region.

most crops, researchers sought first to develop a productive "plant type" (for example, a high-yielding semidwarf) for each major AEZ to serve as a platform for local adaptation, and then subsequently bred for location-relevant traits—such as resistance to diseases, pests, and abiotic stresses. This second-stage research proved extremely important. For India, the SPIA study suggests that the first generation of improved rice varieties (the basic semidwarf plant type) would have been planted on only ~35% of irrigated and rainfed rice land. The subsequent generations of MVs increased adoption to more than 80%, with large benefits ensuing for both producers and consumers (*12*).

Direct and Indirect Contributions of IARC Programs

For most of the MVs in the study, complete or near-complete genealogies could be constructed. The SPIA study 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 NARS programs but that had parents or ancestors bred in IARCs.

The evidence on contributions points to several striking results:

1) Large IARC contributions. More than 35% 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 7% had another IARC-crossed ancestor (*13*). Varieties with IARC ancestry were also more widely planted than other varieties.

2) Low international flows of NARS-crossed MVs. For rice, where such data were available, only 6% 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 several countries.

3) Negligible developed country contributions. Fewer than 1% of MVs included in their genealogies any crosses made in public or private sector plant-breeding programs in developed countries.

4) Small private sector contributions. Private sector contributions were limited to "hybrid" varieties of maize, sorghum, and millet. Private sector breeding programs for these crops were developed only after "platform" varieties were developed in IARC and NARS programs. It should be noted that genetically engineered MVs appeared only after 1996 and have been planted in only three or four developing countries.

5) IARC research complemented NARS breeding. By providing improved germplasm for NARS breeding programs, international breeding efforts increased the productivity of national programs. Because of this IARC-NARS complementarity, the existence of the international centers actually stimulated national investment in NARS research.

Production, Area, and Yield Growth: MV Contributions

Ultimately, the release of new MVs is not a measure of research success. Farmers must first adopt MVs. This will lead to increased production and yield (*14*). Table 1 provides data on the production impacts of MVs over the past 40 years. Not all of the production growth from 1961 to 2000 was due to MVs; this table shows how production growth can be disaggregated into area growth and yield growth. Yield growth in turn can be decomposed into the contributions

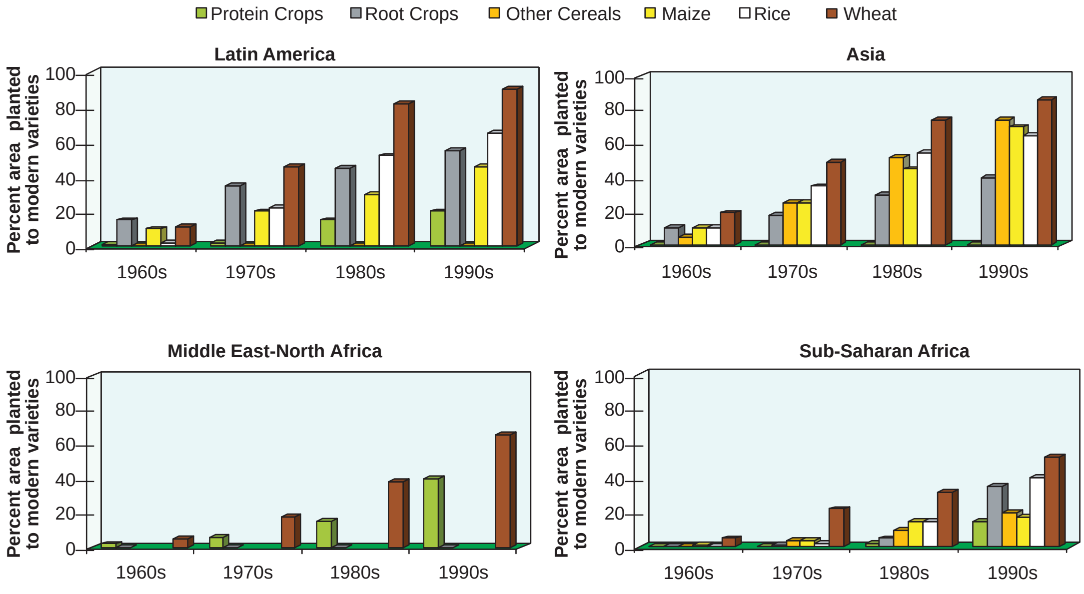

Fig. 2. Modern variety diffusion by decade and region.

of MVs and the contributions of all other inputs (e.g., fertilizer, irrigation, mechanization, and labor) (*4*).

One striking feature of the data in Table 1 is that the gains from MVs were larger in the 1980s and 1990s than in the preceding two decades—despite popular perceptions that the Green Revolution was effectively over by this time. Overall, the productivity data suggest that the Green Revolution is best understood not as a one-time jump in production, occurring in the late 1960s, but rather as a long-term increase in the trend growth rate of productivity. This was because successive generations of MVs were developed, each contributing gains over previous generations.

We find it useful to distinguish between an "early Green Revolution" period (1961 to 1980) and a "late Green Revolution" period from 1981 to 2000. Table 1 shows that in the early Green Revolution, MVs contributed substantially to growth in Asia and Latin America, but relatively little in other areas. For all developing countries, MVs accounted for 21% of the growth in yields and about 17% of production growth in the early Green Revolution period. Area expansion accounted for about 20% of the increases in production; the rest came from intensification of input use.

The late Green Revolution period (1981 to 2000) differed from the early period in several important respects. In part because prices to farmers were declining, production growth was lower in all regions except Sub-Saharan Africa. The area under food crop cultivation remained flat overall, with declines in Latin America offsetting the continued expansion of agricultural lands in Sub-Saharan Africa and the Middle East–North Africa region. Yield growth accounted for almost all of the increases in food production in developing countries (86%). Furthermore, the MV contribution to yield growth was higher in the late Green Revolution period than in early Green Revolution period, accounting for almost 50% of yield growth and 40% of production growth for all developing countries. This indicates that in the late Green Revolution period, production gains were more dependent on MVs than in the early period, and that MV contributions were greater in the late period.

Table 1. Growth rates of food production, area, yield, and yield components, by region and period. Data on food crop production and area harvested are taken from FAOSTAT data, revised 2003 (http://apps.fao.org/page/collections?subset=agriculture), on total cereals, total roots and tubers, and total pulses. Asia consists of "Developing Asia" excluding the countries of the "Near East in Asia." Africa consists of "Developing Africa" excluding the countries of the "Near East in Africa" and the countries of "North-West Africa." The Middle East–North Africa consists of "Near East in Africa," "Near East in Asia," and "North-West Africa." Latin America includes Latin America and the Caribbean. Crop production is aggregated for each region using area weights from 1981. Estimates of production increases due to MVs are from (*4*). Growth rates of other inputs are taken as a residual. Growth rates are compound and are computed by regressing log time series data on a constant and log trend variable. The totals for "All Developing Countries" are derived by weighting the regional figures by 1981 area shares.

	Early Green Revolution	**Late Green Revolution**
	1961 to 1980	**1981 to 2000**
	Latin America	
Production	3.083	1.631
Area	1.473	-0.512
Yield	1.587	2.154
MV contributions to yield	0.463	0.772
Other input per hectare	1.124	1.382
	Asia	
Production	3.649	2.107
Area	0.513	0.020
Yield	3.120	2.087
MV contributions to yield	0.682	0.968
Other input per hectare	2.439	1.119
	Middle East–North Africa	
Production	2.529	2.121
Area	0.953	0.607
Yield	1.561	1.505
MV contributions to yield	0.173	0.783
Other input per hectare	1.389	0.722
	Sub-Saharan Africa	
Production	1.697	3.189
Area	0.524	2.818
Yield	1.166	0.361
MV contributions to yield	0.097	0.471
Other input per hectare	1.069	−0.110
	All developing countries	
Production	3.200	2.192
Area	0.683	0.386
Yield	2.502	1.805
MV contributions to yield	0.523	0.857
Other input per hectare	1.979	0.948

Although input use intensified in the late Green Revolution period, productivity gains from MVs allowed food production to increase dramatically with only modest increases in area planted to food crops—and with relatively slow growth in the use of inputs such as fertilizer and irrigation.

The Sub-Saharan African region is unusual in both periods. Yield growth made only minor contributions to production growth in both periods, and the MV contributions to yield growth were also low—although considerably higher in the more recent period. Production growth was based almost entirely on extending the area under cultivation. In short, this region achieved a very partial and incomplete Green Revolution, with a number of countries realizing virtually no MV contributions to food production growth.

The limited scope of the Green Revolution in Sub-Saharan Africa was in part due to the mix of crops grown in the region (where root crops and tropical maize are dominant food crops) and in part due to the agroecological complexities of the region and associated difficulties in producing suitable MVs. The table shows that such yield growth as was realized in Sub-Saharan Africa was almost entirely contributed by MVs, with little contribution from fertilizers and other inputs.

Why did Sub-Saharan Africa get so little growth from varietal improvement until the 1990s? The inherited state of knowledge and the preexisting stocks of improved germplasm were important factors in differential regional performance. Clearly, institutional and political failures also mattered. But Fig. 1 and the underlying data suggest that some of Sub-Saharan Africa's low growth reflected the lack of usable MV technology until the 1980s and 1990s. Recent evidence is more promising, however. Varietal improvement appears finally to be making an impact in Sub-Saharan Africa in rice, maize, cassava, and other crops (*7*, *10*, *11*).

More generally, the differences in productivity impacts across regions reflect dramatic underlying disparities in the availability and impact of suitable MVs across different agroecological zones. The largest initial impacts (in wheat and rice) were in irrigated areas and in rainfed lowlands with good water control. But outside of these environments, varietal improvement was slower and more limited. This was not for lack of effort: IRRI and CIMMYT, along with many national programs, sought to adapt rice, wheat, and maize MVs to "marginal" environments. And newer IARCs—such as the International Center for Agriculture in the Dry Areas (ICARDA), the International Center for Research in the Semi-Arid Tropics (ICRISAT), the International Institute for Tropical Agriculture (IITA), and others—were specifically directed to marginal environments. But this research took time to yield dividends, and the diffusion of MVs into less favorable agroecologies was slow. Ultimately, however, the effort to broaden the Green Revolution has been successful, as shown in Fig. 2 and Table 1.

Welfare Effects and Counterfactual Scenarios

The SPIA study attempted to consider what would have happened had international research not taken place between 1960 and 2000. The analysis was conducted with an international multimarket model developed by the International Food Policy Research Institute (the IFPRI/IMPACT model) (*15*, *16*).

The counterfactual scenarios considered were the following:

1) "No Green Revolution" (NGR): How would the food and agricultural situation in 2000 have differed if poor countries had failed to achieve any productivity gains from crop breeding over the period 1965 to 2000? In this scenario, it was assumed that rich countries would have continued to achieve productivity gains, but the developing world would have been constrained to use the same technologies available in 1965.

2) "No IARC" (NIARC): How would the food and agricultural situation in 1999 have differed in the absence of internationally funded research, assuming that national programs would have responded by increasing their efforts to some degree? The NIARC scenario is intermediate between the NGR case and the actual experience.

Both cases feature "high" and "low" scenarios. They are compared to a base case, which incorporates productivity growth components for crops and countries on the basis of actual experience (Table 2) (*16*). The simulations indicate that without international research in developing countries, crop yields (for all study crops) would have been higher in developed countries by 2.4 to 4.8%—primarily because lower production in the developing world would have driven up prices and given farmers in rich countries an incentive to intensify production. Crop yields in developing countries would have been 19.5 to 23.5% lower—with price effects again playing a mitigating role. The model indicates that equilibrium prices for all crops combined would have been from 35 to 66% higher in 2000 than they actually were. Because real grain prices actually fell by 40% from 1965 to 2000, this means that prices would have remained constant or risen modestly in the absence of international research (*16*).

Table 2. Counterfactual simulations.

	Comparisons to base case (percent changes)	
	With no MVs in developing countries (NGR)	With no IARC programs (NIARC)
Crop yields		
Developed countries	2.4 to 4.8	1.4 to 2.5
Developing countries	−19.5 to –23.5	−8.1 to –8.9
Cropped area		
Developed countries	2.8 to 4.9	1.6 to 1.9
Developing countries	2.8 to 4.9	1.6 to 1.9
Crop production		
Developed countries	4.4 to 6.9	1.0 to 1.7
Developing countries	−15.9 to −18.6	−6.5 to −7.3
Crop prices, all countries	35 to 66	18 to 21
Increase in imports by developing countries	27 to 30	6 to 9
Percent of children malnourished, developing countries	6.1 to 7.9	2.0 to 2.2
Calorie consumption per capita, developing countries	−13.3 to −14.4	−4.5 to −5.0

Higher world prices would have contributed to an expansion of area planted to crops in all countries, with attendant environmental consequences. Taking area and yield effects together, crop production would have been from 4.4 to 6.9% higher in developed countries and 13.9 to 18.6% lower in developing countries. The world would not necessarily have experienced a catastrophic "food crisis"—as reflected in world prices—in the absence of international research; developing countries would have increased their food imports by 27 to 30%, partly offsetting their production decreases.

The model does indicate, however, that in the absence of international research, the world would have experienced a "human welfare" crisis. Caloric intake per capita in the developing world would have been 13.3 to 14.4% lower, and the proportion of children malnourished would have been from 6.1 to 7.9% higher. Put in perspective, this suggests that the Green Revolution succeeded in raising the health status of 32 to 42 million preschool children. Infant and child mortality would have been considerably higher in developing countries as well (*16*).

The simulations for the "No IARC" scenarios show that aggressive NARS research programs would have succeeded in producing a "muted" Green Revolution. As a rough generalization, this "lite" Green Revolution would have been about 60% of the magnitude of the one actually achieved.

The SPIA study included benefit-cost calculations for IARC and NARS programs. These calculations showed very high benefit-cost ratios for IARC programs and for most NARS programs (*4*, *17*).

Summary: Evaluating International Research

The comprehensive picture that emerges from the SPIA study supports a nuanced view of internationally funded agricultural research. On the positive side, it is clear that productivity growth associated with MVs had important consequences. Increased food production has contributed to lower food prices globally. Average caloric intake has risen as a result of lower food prices—with corresponding gains in health and life expectancy.

Critics of further investment in research have noted that grain prices are at or near historic lows, and they question the need for further improvements in technology. They have also raised concerns about the sustainability of intensive cultivation—e.g., the environmental consequences of soil degradation, chemical pollution, aquifer depletion, and soil salinity—and about differential socioeconomic impacts of new technologies (*18*–*21*). These are valid criticisms. But it is unclear what alternative scenario would have allowed developing countries to meet, with lower environmental impact, the human needs posed by the massive population expansion of the 20th century. Nor is it true that chemical-intensive technologies were thrust upon the farmers of the developing world. Both IARC and NARS breeding programs attempted to develop MVs that were less dependent on purchased inputs, and considerable effort has been devoted to research on farming systems, agronomic practices, integrated pest management, and other "environment-friendly" technologies. But ultimately it is farmers who choose which technologies to adopt, and many farmers in developing countries—like those in developed countries—have found it profitable to use MVs with high responsiveness to chemical fertilizers.

The end result, as shown in Table 2, is that virtually all consumers in the world have benefited from lower food prices. Many farm families also benefited from research-driven productivity gains—most clearly those whose productivity rose more than prices fell, but also those who produce much of their own food. But some farmers and farm workers experienced real losses from the Green Revolution. Those who did not receive the productivity gains of the Green Revolution (largely because they were located in less favorable agroecological zones), but who nonetheless experienced price declines, have suffered actual losses of income. The challenge for the coming decades is to find ways to reach these farmers with improved technologies; for many, future green revolutions hold out the best, and perhaps the only, hope for an escape from poverty.

Yet the prospects for continued green revolutions are mixed. On the one hand, the research pipeline for the plant sciences is full. Basic science has generated enormous advances in our understanding of plant growth and morphology, stress tolerance, pathogen resistance, and many other fields of science. This understanding should lead in due course to improvements in agricultural technologies. But on the other hand, IARCs and NARS are faced with numerous challenges to their survival. The budgets of many IARCs, not to mention many of their national program counterparts, have declined sharply in real terms over the past decade. The funding crunch reflects a number of factors. Development agencies, faced with public suspicions of new agricultural technologies, and perhaps eager to find shortcuts to development, have tended to shift funding away from agricultural research and toward other priorities. Moreover, life science biotechnology firms have been eager to claim that private sector research will take over the functions formerly occupied by public sector agricultural research.

But if the past offers guidance for the future, a strong public sector role will continue to be needed. In most crops and most regions of the developing world, private sector agricultural research is not likely to generate large impacts on production or social welfare. Continued green revolutions will depend on strong programs of national and international public sector research. The welfare of farmers and farm workers not reached by the Green Revolution ultimately depends on extending the Green Revolution beyond present boundaries. The IARCs will have an important role to play in generating and sustaining future advances in agricultural technology for the developing world.

References and Notes

1. The CGIAR is the organization through which most donor support for international agricultural research is channeled. In addition to IRRI and CIMMYT, the other centers include CIAT (International Center for Tropical Agriculture), CIFOR (Center for International Forestry Research), CIP (International Potato Center), ICARDA (International Center for Agricultural Research in the Dry Areas), ICLARM (International Center for Living Aquatic Resources Management), ICRAF (International Center for Research in Agroforestry), ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), IFPRI (International Food Policy Research Institute), IITA (International Institute of Tropical Agriculture), ILRI (International Livestock Research Institute), IPGRI (International Plant Genetic Resources Institute), ISNAR (International Service for National Agricultural Research), IWMI (International Water Management Institute), and WARDA (West African Rice Development Association). Some unaffiliated centers (e.g., the International Centre of Insect Physiology and Ecology; International Fertilizer Development Center) have also engaged in related research.
2. R. E. Evenson, D. Gollin, Eds., *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research* (CAB International, Wallingford, UK, 2003).
3. The crops are rice, wheat, maize, sorghum, pearl millet, barley, beans, lentils, groundnuts, potatoes, and cassava. The study did not address the impact of research done by CGIAR centers on livestock, fisheries, or forestry, nor on broad-based management, policy, or resource issues.
4. R. E. Evenson, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 21.
5. D. Dalrymple, *Development and Spread of High Yielding Wheat Varieties in Developing Countries* (Bureau for Science and Technology, Agency for International Development, Washington, DC, 1986).
6. D. Dalrymple, *Development and Spread of High Yielding Rice Varieties in Developing Countries* (Bureau for Science and Technology, Agency for International Development, Washington, DC, 1986).
7. N. L. Johnson, V. M. Manyong, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 16.
8. N. L. Johnson, D. Pachico, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 12.
9. Our measure is of varieties released through a formal process. This is admittedly a weak measure, because varieties could be released without being adopted by farmers, but in practice such "phantom releases" appear to be rare and do not occur in any systematic way.
10. V. M. Manyong *et al.*, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 8.
11. T. J. Dalton, R.G. Guei, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 6.
12. J. W. McKinsey, R. E. Evenson, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 19.
13. By comparison, IARC programs represented fewer than 3% of the agricultural scientists and less than 5% of agricultural research expenditure in developing countries.
14. The study included estimates for each crop of the productivity advantages of converting crop acreage from traditional varieties to MVs. 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.
15. The IFPRI/IMPACT model includes 18 agricultural commodities and covers 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 proportion of children (0 to 6%) malnourished, and average food caloric consumption. It is described more fully at www.ifpri.org/themes/impact.
16. R. E. Evenson, M. Rosegrant, in *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, R. E. Evenson, D. Gollin, Eds. (CAB International, Wallingford, UK, 2003), chap. 23.
17. The lowest benefit-cost ratios were realized in Sub-Saharan Africa.
18. K. B. Griffin, *Political Economy of Agrarian Change: An Essay on the Green Revolution* (Harvard Univ. Press, Cambridge, MA, 1974).
19. V. Shiva, *Monocultures of the Mind: Perspectives on Biodiversity and Biotechnology* (Zed, Atlantic Highlands, NJ, 1993).
20. C. Hewett de Alcántara, *Modernizing Mexican Agriculture: Socioeconomic Implications of Technological Change, 1940–1970* (United Nations Research Institute for Social Development, Geneva, 1976).
21. See also the Web sites of activist groups such as Food First (www.foodfirst.org) and the Turning Point Project (www.turnpoint.org).
22. 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 particularly 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, and C. S. Wortmann. In addition, we acknowledge specific comments on a draft of this article from D. Dalrymple, C. Doss, D. Duvick, G. Gryseels, G. Manners, and M. Morris.