In the absence of detailed information about the breeding history of maize MVs, it is not possible to formulate pedigree-based rules for assigning credit among different research organizations. Therefore, gross benefits are calculated using a range of plausible values for the parameter that denotes the contribution of CIMMYT materials (these values are shown at the top of Table 17, Columns 5 to 7). Under the most conservative value (25% of the germplasm effect attributable to CIMMYT), and depending on the average yield gain associated with MV adoption, CIMMYT's maize breeding program generates from US$ 167 million to US$ 501 million per year in gross benefits. Under the most generous assumptions (75% of the germplasm effect attributable to CIMMYT), and once again depending on the average yield gain associated with MV adoption, CIMMYT's maize breeding program generates from US$ 501 million to US$ 1.5 billion per year in gross benefits.

In a recent review of the literature on returns to agricultural R&D, Alston et al. (2000) point out that a common error made by research evaluators is mis-measurement of research costs and benefits. Here, every effort has been made to avoid inflating the benefits attributed to CIMMYT's maize breeding efforts by failing to account for other sources of maize productivity gains, including breeding research done by NARSs and private companies, as well as changes in farmers' management practices.

The gross benefits reported in Table 17 are somewhat speculative, but they point toward an important conclusion: Even under conservative assumptions, the CIMMYT maize breeding program pays for itself many times over. One factor contributing to this result is simply the global importance of maize. Considering the extensive area that is planted to maize, CIMMYT-derived varieties do not have to achieve complete dominance in order to generate attractive returns to the CIMMYT breeding effort; current adoption rates already translate into enormous benefits.

Summary and Conclusions

Past Impacts of International Maize Breeding Research

The first global impacts study for maize carried out by CIMMYT nearly 10 years ago concluded that international maize breeding research has been extremely successful. The information presented in this report confirms the central finding of the earlier study and shows that international maize breeding efforts continue to have enormous impacts. Maize MVs currently are grown on 58.8 million ha in developing countries, representing about 62.4% of the area planted to maize in these countries. The widespread diffusion of maize MVs is particularly impressive given the distinctive characteristics of maize compared to other leading cereals. Because maize is an open-pollinated crop, farm-saved seed quickly loses its genetic purity, so farmers who wish to grow maize MVs must replace their seed regularly. For this reason, maize MVs can disseminate only with the help of an effective national seed industry—something that is still lacking in many developing countries.

International maize breeding research has brought increased incomes to millions of maize-producing households that have adopted MVs. In developing countries, the additional grain production resulting from the use of maize MVs is worth from US$ 3.7 to US$ 11.1 billion per year (germplasm effect plus crop management effect). Production increases resulting from the use of maize MVs have also benefited consumers, food and feed processors, agricultural laborers, and many other groups via price- and income-transmitted multiplier effects, although these benefits are difficult to quantify and value.

Against a backdrop of declining public support for agricultural research, CIMMYT continues to play a vital facilitating role in support of international maize breeding efforts. As the hub of a global network dedicated to maize germplasm improvement and exchange, CIMMYT has been active in producing improved materials and promoting their dissemination. The effectiveness of CIMMYT's maize breeding program is evident from the extensive use of CIMMYT source materials by public and private breeding programs. Currently, CIMMYT-derived MVs are grown on at least 21.2 million ha in developing countries, including 18.2 million ha located in non-temperate regions. This represents nearly one-half (36.1%) of the area planted to maize MVs in the developing world and over one-half (58.7%) of the area planted to maize MVs in non-temperate regions of the developing world.

CIMMYT's maize breeding program, although modest in size by international standards, has achieved enormous payoffs. The value of additional grain production attributable to CIMMYT's maize breeding activities is estimated to range between US$ 167 million and US$ 1.5 billion per year, not including non-yield benefits associated with adoption of CIMMYT-derived MVs (for example, improved grain and fodder quality, shorter growth cycles).

Impressive though they may be, the economic benefits attributable to CIMMYT-derived MVs show only part of the CIMMYT impacts story. In addition to developing large amounts of improved germplasm, CIMMYT's maize breeding program generates benefits in other ways that are very difficult to quantify and value. What is the value of the international germplasm exchange network managed by CIMMYT, which serves as a major source of information and breeding materials for hundreds of public and private breeding programs? And what is the value of the training services that CIMMYT has provided to thousands of crop improvement researchers throughout the developing world?

The success of the CIMMYT maize breeding program is particularly impressive considering the intensely competitive nature of the global maize seed industry. Unlike most other food crops grown in developing countries, maize attracts a lot of interest from commercial breeding programs in industrialized countries. Because the global market for hybrid maize seed is so large, private firms invest more resources in maize breeding—by far—than they invest in breeding for any other crop. True, private-sector maize breeding efforts are focused primarily on commercial producers in industrialized countries, but seed companies are quick to take advantage of market opportunities in developing countries. Public maize breeding programs, including CIMMYT's, consequently face much stiffer competition than do public breeding programs that work on other crops.

Future Prospects for International Maize Breeding Research

International maize breeding research clearly has been successful in the past. Will it continue to be as successful in the future? Looking ahead, there is little doubt that maize breeding programs, public as well as private, will be called upon to help bring about the substantial productivity gains that will be needed if maize production is to keep pace with projected strong growth in demand. Maize breeders will be expected to push forward the yield frontier by developing varieties with more efficient metabolisms, enhanced resistance to biotic and abiotic stresses (especially drought), and shorter growth cycles. In addition, they will face increased demand for non-yield benefits, such as enhanced nutritional content and improved industrial quality.

Will the international maize breeding system be able to meet these expectations? Future progress in maize improvement research will come in part from continued use of tried-and-true conventional breeding methods, which thus far show few signs of reaching the stage of diminishing returns. Traditional selection strategies continue to produce steady genetic gains, and those gains continue to be disseminated widely through global testing and evaluation networks.

While traditional methods will no doubt remain popular, emerging technologies meanwhile will provide new opportunities for making plant breeding cheaper and faster. Biotechnology, after a longer-than-expected gestation period, is beginning to pay real dividends. Recent advances in functional genomics and proteomics have greatly improved scientists' understanding of the molecular basis for many plant metabolic processes, opening the door to rapid progress in overcoming challenges that thus far have defied solution. Molecular marker-assisted selection methods are introducing greater precision into breeding and could significantly accelerate rates of progress. Genetic engineering, despite lingering questions surrounding its safety and appropriateness, holds great promise as a way of producing novel cultivars with economically valuable traits.

These technological advances are taking place against a backdrop of institutional changes that have significant implications for the way plant breeding research is organized and carried out. In an effort to reduce fiscal deficits, governments in many countries have implemented policy reforms designed to scale back the role of public breeding programs and to stimulate increased investment by private firms in crop improvement research. Typically these reforms have included significant strengthening of intellectual property rights (IPR) laws relating to ownership of plant genetic resources, research technology, and scientific information.

Recent growth in the numbers of maize breeders working in the private sector suggest that these reforms have succeeded in paving the way for greater participation by the private sector in the maize seed industries of many developing countries. Increased privatization has brought generally positive results, but at the same time there are grounds for concern. The accelerating cost of crop improvement research, coupled with the growing importance of IPRs, is rapidly changing the rules of the plant breeding game (Falcon 2000). Fearful of conceding advantages to potential competitors, many of the large multinational corporations that currently dominate the global seed industry are becoming less enthusiastic about sharing germplasm, technology, and information. As a result, maize breeding is rapidly being transformed from a collaborative activity undertaken for the common good into a competitive activity undertaken for shareholder profit.

Since most public breeding organizations (including CIMMYT) depend heavily on the free exchange of germplasm, technology, and information, these developments raise troubling questions about the future role of the international breeding system. In coming years, public breeding organizations will face a number of challenges, including:

- how to maintain access to genetic resources,
- how to maintain access to cutting edge technologies,
- how to maintain access to genomic databases and other sources of information needed for biotechnology-assisted crop improvement research, and
- how to maintain and stabilize funding.

The privatization of national seed industries also raises questions about the distributional impacts of technical change. The MV adoption data presented in this report show that it is simply wrong to argue—as many policymakers and development agency officials continue to do—that the best way to get improved germplasm to farmers is by relying on the magic of the market. Market liberalization measures have indeed opened the door to greater participation in national maize seed industries, but despite the proliferation of private companies, during the past 10 years the area planted to maize MVs in developing countries has increased very slowly in percentage terms. The sad reality is that significant numbers of small-scale, subsistence-oriented farmers have been ignored because they do not represent attractive customers for profit-oriented firms. Market-based solutions clearly do not work for these farmers who lack the resources needed to pay for improved seed and the information needed to manage it properly.

Despite the encouraging progress that has been achieved, considerable challenges remain to be overcome if the products of the international maize breeding system are to reach the poorest of the poor. Over one-third of the developing world's maize area (nearly one-half of the maize area in non-temperate environments) is still planted to farm-saved seed of uncertain genetic background and variable quality. In many instances, farmers continue to use farm-saved seed not because MVs are unavailable; rather, the problem is that small-scale, subsistence-oriented farmers located in isolated rural areas are not well integrated into the market economy. As CIMMYT and its partners look to the future, they will be challenged to come up with creative approaches to reaching the millions of non-commercial farmers who still do not enjoy full access to the fruits of the international breeding system.

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