The presence or absence of incentives to produce and sell hybrid seed may be related to the stage of development of the local seed industry. Several authors have advanced life cycle theories of seed industry development in which national seed industries are described as evolving in a path-dependent manner through successive growth stages (Douglas 1980, Pray and Ramaswami 1991; Rusike 1995; Dowswell, Paliwal, and Cantrell 1996; Morris and Smale 1997; Morris, Smale, and Rusike 1998). According to the various life cycle theories, the characteristics associated with the initial stages of seed industry development mitigate against the diffusion of hybrid maize, because incentives to produce and sell hybrid maize are not yet present. In the early stages of seed industry development, maize producers consist mainly of small-scale, subsistence oriented farmers who use mostly farm-saved seed retained from their own harvest or obtained from neighbors. Under these circumstances, there is no adequate market capable of sustaining firms looking to generate profits through the production and sale of commercial seed. Not until the seed industry reaches more advanced stages of development, when farmers understand the benefits of improved germplasm and are willing to purchase seed on a regular basis, does the effective demand for hybrid seed become strong enough to support a commercial seed industry—thereby paving the way for widespread diffusion of hybrids. In short, the production and delivery of hybrid maize seed go hand-in-hand with the existence of well-developed commercial seed industries.

## Economic Benefits Associated with MV Adoption

As more and more demands are placed on the limited pool of funds available for agricultural research, research organizations face increasing pressure to show that resources are being used efficiently. In today's highly competitive funding environment, scientists must not only demonstrate that their work is having an impact, but frequently they are also required to quantify the economic benefits that have been generated.

What have been the economic benefits generated by international maize breeding research? More specifically, what have been the economic benefits generated by CIMMYT's maize breeding program? For reasons that are discussed extensively in the investment literature, estimating economic benefits generated by agricultural research organizations is often difficult (for a comprehensive summary, see Alston, Norton, and Pardey 1995). In the case of plant breeding programs, economic benefits include not only benefits received by farmers in the form of increased production, but also benefits received by consumers (who pay lower prices for grain and fodder), by food and feed processors (who experience increased demand for their services), by agricultural laborers (who derive increased employment opportunities), and by other groups that benefit via price- or income-transmitted multiplier effects. Quantification and valuation of these indirect benefits is a major undertaking requiring multi-market or general-equilibrium modeling and large amounts of data (for an example involving the economic benefits generated by wheat breeding research, see Renkow 1993).

The economic benefits estimates presented below were not generated using a formal modeling approach. Instead, they were derived through "back-of-the-envelope" calculations involving a number of simplifying assumptions. Furthermore, they refer only to the benefits received by developing-country maize farmers in the form of increased grain production; no attempt was made to account for indirect benefits received by consumers, food and feed processors, agricultural laborers, and other groups. Despite these limitations, however, the estimates provide useful information about the value of additional production attributable to international maize breeding efforts in general and to CIMMYT's maize breeding program in particular.

## Economic Benefits Not Reflected in Yield Gains

The following discussion regarding the economic benefits generated by international maize breeding research focuses on the value of additional grain production associated with adoption of MVs. Mainly because of data limitations, benefits from plant breeding research that are not reflected in the form of yield gains are ignored. Examples of traits that confer non-yield benefits include:

- ***improved grain quality*** (benefits: easier processing, better storability, improved nutritional status of humans and livestock)
- ***improved fodder quality*** (benefits: easier processing, better storability, faster growth, and improved nutritional status of livestock) and
- ***shorter growth cycle*** (benefit: additional crops can be accommodated in multi-crop rotations without compromising maize yields).

While non-yield benefits associated with MV adoption can be extremely important, quantifying and valuing them tends to be difficult. In contrast, yield gains associated with MV adoption are more easily measured, and since the price of maize grain is usually available, the economic value of the additional production can be readily estimated.

## Parameters Needed to Calculate Value of Additional Production

In order to calculate the value of the additional maize grain production attributable to international maize breeding efforts, three key parameters must be estimated: (1) the area planted to maize MVs, (2) the productivity gains attributable to adoption of maize MVs, and (3) the price of maize grain. Using a simple economic surplus model, these three parameters can be combined to calculate the value of additional production in a given period ($t$):

$$B_t = A_t \quad y_t \quad P_t$$

where:

$B$ = value of additional production attributable to maize breeding research,
$A$ = area planted to maize MVs,
$y$ = yield gain attributable to maize breeding research,[13] and
$P$ = price of maize grain.

### AREA PLANTED TO MVS

Estimates of the area planted to maize MVs ($A$) have been presented earlier in this report (see Sections 5.2 and 5.3).

### YIELD GAIN ATTRIBUTABLE TO MAIZE BREEDING RESEARCH

At the farm level, the yield gain attributable to maize breeding research ($y$) is the difference between the yield obtained with a farmer's current variety (which depending on the circumstances may be a landrace or an older MV) and the yield obtained with a newly adopted MV, holding

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[13] The productivity gains associated with MV adoption are conventionally measured in terms of the yield increase per unit land area achieved when input costs are held constant. An alternative approach is to measure cost savings at a given yield level.

constant inputs and management. In practice, this difference is difficult to estimate for at least two reasons:

1. ***Genotype by environment (GxE) interactions*****:** The genetic potential of any cultivar interacts with environmental factors, so the yield difference between the same variety will tend to vary across locations and between cropping seasons because of agro-climatic effects. Case study evidence suggests that yield gains associated with adoption of the same MV can vary widely (Morris, Risopoulos, and Beck 1999). To further complicate matters, where farmers are recycling seed, the genetic composition of their cultivars may change from generation to generation due to GxE interactions, which further affects the yield difference.
2. ***Germplasm vs. crop management effects:*** Yield gains achieved in farmers' fields come not only from adoption of MVs; yield gains come also from adoption of improved crop management practices, which frequently interact with MVs. In estimating the economic benefits attributable to plant breeding research, it is therefore necessary to distinguish between the germplasm effect on yields and the crop management effect (Figure 10). Relatively little empirical research has been done on this topic, but it is reasonable to assume that improved germplasm and improved management practices each have contributed about 50% to observed yield gains in cereal crops (Bell et al. 1995, Thirtle 1995, Fuglie et al. 1996).

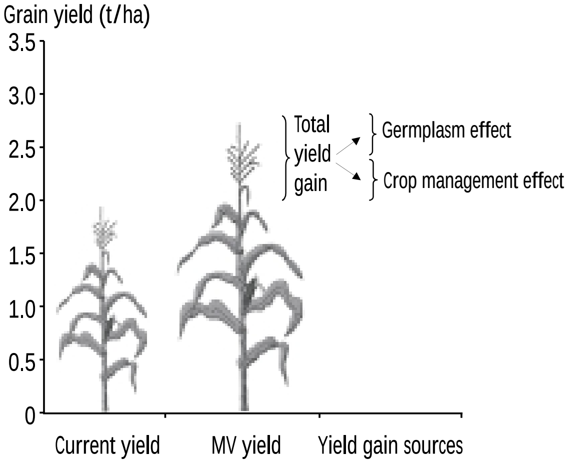

**Figure 10. Yield gain components: Germplasm vs. crop management effect.**
Source: Author.

The practical difficulties inherent in measuring the yield gains attributable to MV adoption are compounded by a conceptual problem. Many plant breeding impacts studies implicitly assume that in the absence of the breeding program being evaluated, farmers' yields would have remained unchanged. This assumption is often unrealistic, as usually there are alternative sources of improved technologies. Thus the relevant comparison is not between current yields and yields being achieved at the time the breeding program was established, but rather between current yields and yields that farmers would currently be achieving had the breeding program being evaluated not been established.[14]

Figure 11 illustrates this problem. The horizontal dashed line represents the average yield achieved by farmers prior to the establishment of the breeding program being evaluated. The upper solid line represents average yields achieved by farmers as the result of growing a total of seven MVs produced by the breeding program; since MV replacement occurs at irregular intervals, the line is stepped. A common mistake in many impacts studies is to assume that the yield gain attributable to the breeding program is the difference between the farmers' original yield and their current yield, represented by the vertical distance (a + b). A more realistic estimate would take into account the fact that yield gains would likely have been realized even in the absence of the breeding program being evaluated, because farmers would have grown MVs obtained from other sources. This so-called counterfactual scenario is represented in Figure 11 by the lower solid line; the yield gains that would have been achieved under the counterfactual scenario are represented by the vertical distance (b). The yield gain attributable to the breeding program being evaluated thus should be estimated as something less than the difference between farmers' original

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[14] This concept is well-known in the literature on benefit:cost analysis, in which it is referred to as the "with and without project" comparison (see Gittinger 1982: 47-50).

yields and their current yields; a more realistic estimate might be the yield gain represented by the vertical distance (a). Although it is impossible to know what would have happened to farmers' yields had the breeding program being evaluated not existed, some sort of subjective judgment is needed to account for the yield gains that would have been achieved under the counterfactual scenario.

One final point must be made concerning yield gain estimates. Many published impacts studies have used annual yield gain parameters that when considered in a temporal dimension imply yield growth far exceeding actual historical yield growth. According to FAO data, maize yields in developing countries grew at an average annual rate of 2.5% from 1966-98, the period covered by this study (FAOSTAT online database). This growth rate, which reflects both the germplasm effect and the crop management effect, is consistent with yield data suggesting that long-term growth in genetic potential has averaged 1-2% per year in maize (Duvick 1992; Troyer 1996, 1999). Yield gains attributed to MV adoption that implicitly would have led to aggregate yield growth in excess of actual observed growth rates are clearly unrealistic.

In view of these practical and conceptual difficulties, estimating a single average global annual yield gain parameter (*y*) is problematic. Calculation of such a parameter would require time-series data on MV adoption, disaggregated by environment, by level of management, and by type of adoption behavior (initial adoption of an MV to replace a landrace, replacement of an older MV by a newer MV). In the absence of such data, the approach used here is to estimate economic benefits generated under a range of plausible yield gain estimates (15%, 25%, 35%, 45%).[15] Estimates on this order of magnitude imply that since CIMMYT was founded in 1966, international maize breeding efforts have boosted average maize yields gains realized in developing countries by 0.25 – 1% per year.

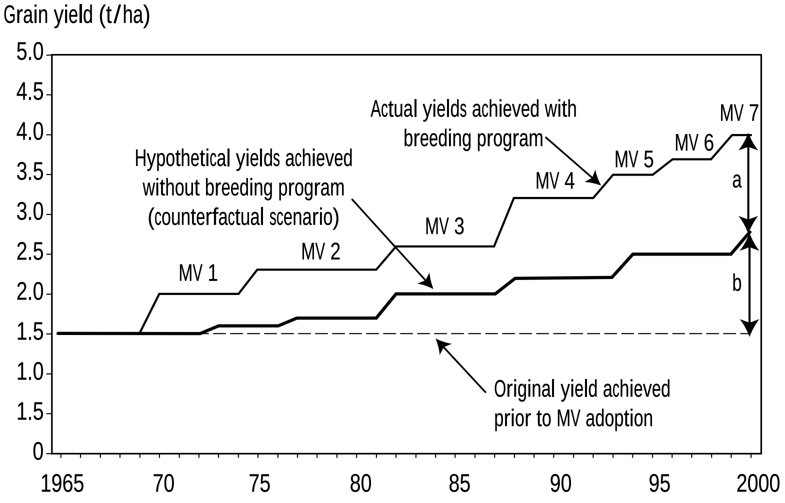

**Figure 11. Estimating MV yield gains: Accommodating the counterfactual scenario.**
Source: Author.

### PRICE OF MAIZE GRAIN

The price of maize grain (*p*) is conservatively valued at US$ 120/ton. During the late 1990s, the main international reference price of maize (#2 Yellow, FOB US Gulf ports) varied between US$ 60/ton and US$ 105/ton. Since most developing countries are net importers of maize, the appropriate price to use in valuing incremental production is the

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[16] In order to calculate the additional amount of grain produced as a result of MV adoption, the percentage yield gain (*y)* must be multiplied by the average MV yield (Y). Farm survey data suggest that maize MV yields in developing countries range from 2.5 t/ha to more than 10 t/ha. For purposes of this study, the average maize MV yield is assumed to be 3.5 t/ha.

import parity price. The figure of US$ 120/ton was derived by adding representative international transport and handling costs to the reference price.

If there were any evidence that the additional production attributable to adoption of maize MVs in developing countries influences international maize prices (for example, by shifting out the global supply curve and depressing world markets), then some sort of adjustment to the international reference price would be needed. Such an adjustment is unnecessary in the present context, however, because international maize prices are determined mainly by supply and demand conditions in industrialized countries. With very few exceptions (for example, unusually severe global weather disruptions), changes in the quantity of maize produced in developing countries are unlikely to have a significant effect on international reference prices. Also, to the extent that changes in production in developing countries do affect international prices, these changes would normally occur in large countries such as Argentina, China, and South Africa, which grow mainly temperate varieties produced by breeding programs that are not being considered in this study.

## Gross Benefits Associated with MV Adoption

The value of additional maize grain production attributable to the adoption of MVs in developing countries is shown in Table 16. Depending on the average yield gain associated with MV adoption (Columns 1 and 2), gross benefits are estimated to range between US$ 3.7 billion and US$ 11.1 billion per year (Column 3). Assuming that 50% of the yield gain is attributable to the germplasm effect and 50% is attributable to the crop management effect, gross benefits attributable to the germplasm effect alone are estimated to range between US$ 1.9 billion and US$ 5.6 billion per year (Column 4).

## Benefits Attributable to CIMMYT's Breeding Program

What portion of the estimated gross benefits shown in Table 16 can be attributed to CIMMYT's maize breeding program? Estimated gross benefits attributable to the adoption of CIMMYT-derived maize MVs are shown in Table 17. Depending on the average yield gain associated with MV adoption (Columns 1 and 2), gross benefits realized on the area planted to CIMMYT-derived MVs (germplasm effect plus crop management

**Table 16. Value of additional production attributable to international maize breeding efforts, developing countries.**

| Yield gain attributable to adoption of maize MVs (germplasm effect plus crop management effect) |  | Gross economic benefits from MV adoption (US$ million/year) | Net economic benefits from germplasm effect (US$ million/year) |
|---|---|---|---|
| (%) | (t/ha) |  |  |
| 15 % | 0.53 | 3,705 | 1,852 |
| 25 % | 0.88 | 6,175 | 3,087 |
| 35 % | 1.23 | 8,644 | 4,322 |
| 45 % | 1.58 | 11,114 | 5,557 |

Assumptions:
Area planted to maize MVs in developing countries: 58.8 million ha
Average yield of MVs: 3.5 t/ha (implies average yield of non-MVs: 1.2 t/ha)
Proportion of yield gain attributable to germplasm effect: 50%
Average price of maize grain: 120 US$/t
Source: Calculated by author.

effect) range between US$ 1.3 billion and US$ 4.0 billion per year (Column 3). Assuming that 50% of the yield gain associated with MV adoption is attributable to the germplasm effect and 50% to the crop management effect, then gross benefits attributable to the germplasm effect alone range between US$ 668 million and US$ 2 billion per year (Column 4).

Although they have been adjusted to account for the crop management effect, the gross benefits estimates shown in Table 17, Column 4, still overstate the impacts of CIMMYT's maize breeding program because they include the contribution made by other research organizations. To isolate the benefits generated by CIMMYT's breeding program, it is necessary to estimate the proportion of germplasm effect associated with adoption of CIMMYT-derived MVs that can be credited directly to their CIMMYT germplasm content. This turns out to be difficult, since CIMMYT serves as the hub of a global breeding network consisting of CIMMYT's own breeding program, public-sector breeding programs, private sector breeding programs, and advanced research institutes. These organizations collaborate to various degrees and frequently share breeding materials, making it difficult to attribute credit among them.

To further complicate matters, maize breeding presents unusual attribution problems that are not found in other major cereals. As mentioned earlier, attribution of credit for maize breeding is made difficult by two factors. First, the pedigrees of most commercial maize hybrids are confidential, so it is not possible to assign breeding credit by examining selection histories to determine the role played by different organizations in the varietal development process. Second, breeding strategies for maize (especially hybrid maize) tend to be more variable than breeding strategies for self-pollinating cereals such as rice and wheat. Hybrid maize development schemes often involve a lengthy process of population improvement, extraction of inbred lines, improved and/or recycling of inbred lines, introgression of desirable alleles, repeated backcrossing with a recurrent parent, and finally test crossing with other inbred lines. The non-standardized and ad hoc breeding strategies followed by maize breeders defy easy description, and at the end of the day it is often very difficult to trace the germplasm contained in a finished hybrid back to a particular source. This means that with maize, even when pedigree information is available, application of formal attribution rules may still be very complicated.

**Table 17. Value of additional production attributable to CIMMYT's maize breeding program, developing countries.**

| Yield gain attributable to adoption of CIMMYT-derived maize MVs (germplasm + crop management effects) | | Gross benefits from adoption of CIMMYT-derived maize MVs US$ million/year) | Net benefits attributable to germplasm effect of MV adoption (US$ million/year) | Contribution of CIMMYT germplasm | | |
|---|---|---|---|---|---|---|
| | | | | 25% | 50% | 75% |
| (%) | (t/ha) | | | Net benefits generated by CIMMYT maize breeding program: | | |
| 15 % | 0.53 | 1,336 | 668 | 167 | 334 | 501 |
| 25 % | 0.88 | 2,227 | 1,114 | 278 | 557 | 835 |
| 35 % | 1.23 | 3,118 | 1,559 | 390 | 770 | 1,169 |
| 45 % | 1.58 | 4,009 | 2,004 | 501 | 1,002 | 1,503 |

Assumptions:
Area planted to maize CIMMYT-derived MVs in developing countries: 21.2 million ha
Average yield of MVs: 3.5 t/ha (implies average yield of non-MVs: 1.2 t/ha)
Proportion of yield gain attributable to "germplasm effect": 50%
Average price of maize grain: 120 US$/t
Source: Calculated by author.

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