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Impacts of International Maize Breeding Research in the Developing World, 1966-1990

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CIMMYT is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a research program for maize, wheat, and triticale, with emphasis on improving the productivity of agricultural resources in developing countries. It is one of several nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of some 40 donor countries, international and regional organizations, and private foundations.

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Abstract. The impacts of maize breeding research for non-temperate environments in the developing world by national agricultural research systems (NARSs) and the International Maize and Wheat Improvement Center (CIMMYT) over 1966-90 are analyzed. Collaborative maize breeding by NARSs and CIMMYT resulted in the development and release of 842 maize varieties and hybrids by public research organizations in developing countries during 1966-90. Of these materials, 53% contained CIMMYT germplasm. Although the share of hybrid releases rose substantially following increased emphasis on hybrids by NARSs, for the period as a whole hybrids comprise just 35% of releases. Maize releases are distributed fairly evenly between tropical lowlands (53%) and tropical mid-altitudes, tropical highlands, and the subtropics (47%). In non-temperate ecologies an estimated 24.6 million hectares were planted to improved maize in 1990 (43% of the 57.7 million hectares under maize in the countries under study). Public sector materials accounted for 19.9 million hectares (81%) of the area under improved maize; 4.7 million hectares (19%) were under proprietary materials. Improved maize containing CIMMYT germplasm was planted on 13.5 million hectares in 1990 (55% of the area under improved materials), mostly open-pollinated varieties in tropical lowlands. The fact that more than half (33 million hectares) of the developing world's maize area is still planted to unimproved varieties suggests that significant barriers continue to slow adoption of improved maize germplasm. To reach farmers who do not plant improved maize, breeders must continue developing varieties and hybrids adapted to marginal growing conditions, especially materials tolerant to biotic and abiotic stresses and low levels of external inputs. The still modest use of improved maize germplasm in some regions of the developing world also reflects farmers' difficulty in obtaining seed and points to the need for more effective maize seed industries, especially better seed production and distribution. Finally, to obtain more accurate estimates of the economic impacts of maize breeding research, researchers must monitor 1) the flow of germplasm from public research organizations, especially the use of this germplasm by private sector organizations; 2) farmers' adoption of improved maize; and 3) the yield effects of using improved maize at the farm level.

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Executive Summary

This study analyzes and estimates the impacts of maize breeding research in the developing world by national agricultural research systems (NARSs) and the International Maize and Wheat Improvement Center (CIMMYT) for the period 1966-90. It documents numbers and types of maize varieties and hybrids released by public sector organizations, examines trends in the extent to which public NARSs have used CIMMYT germplasm, and estimates the adoption of improved maize varieties and hybrids in the developing world in 1990.

The analysis is based primarily on data collected from maize breeding programs in 45 developing countries through a survey eliciting information on maize varieties and hybrids that they had released over the years. The survey responses made it possible to develop a detailed database on the 1,039 maize varieties and hybrids reported to have been released since 1966, including the year each material was released, the origin of the germplasm from which the material was developed, its ecological adaptation, the type of material (open pollinated variety or hybrid), its grain color, and the estimated area planted to the material in 1990. This database provides comprehensive information on maize improvement research in all developing countries with non-temperate maize growing environments (with the exception of Angola, Afghanistan, and Somalia, which have a significant area of maize but were unable to respond to the survey). A few developing countries/regions with mostly temperate maize growing ecologies were also excluded from the analysis, notably Argentina, Turkey, and northern China.

Trends in maize varieties and hybrids released

Public sector breeding programs in developing countries released 842 maize varieties and hybrids between 1966 and 1990. Of these materials, 545 (65%) were improved open pollinated varieties (OPVs) and 297 (35%) were hybrids; 448 (53%) were adapted to tropical lowland growing environments, and the rest (394 or 47%) to tropical mid-altitudes, tropical highlands, and the subtropics. This distribution of materials by ecology is congruent with the distribution of non-temperate maize across growing ecologies.

The pace of releases by public sector programs has intensified in recent years, so that by 1986-90 developing countries released an average of 46 public maize varieties and hybrids each year, more than double the number of releases (20 per year) in 1966-70.

Origins of maize varieties released by NARSs

Of the 842 public maize varieties and hybrids released in 1966-90, 445 (53%) contained at least some CIMMYT germplasm in their genetic backgrounds. Fifty-one percent carried some CIMMYT germplasm; 23% were varieties selected from CIMMYT trials, which thus contained a good deal of CIMMYT germplasm; and 26% were released directly by the breeding program, so they may be considered 100% CIMMYT germplasm.

A large proportion of the releases containing CIMMYT germplasm consisted of OPVs (62%), reflecting CIMMYT's emphasis on this type of germplasm until the late 1980s, although in recent years hybrids have come to account for a greater proportion of releases containing CIMMYT germplasm. Most of the releases containing CIMMYT germplasm are adapted to tropical lowland environments, a result of CIMMYT's marked emphasis on breeding for this growing ecology.

Adoption of improved maize varieties and hybrids

An estimated 25 million hectares of non-temperate maize area were planted to improved varieties and hybrids in 1990 in developing countries. This represents about 43% of the maize area in these countries that year. Of the total area covered by improved maize, 20 million hectares (81%) were estimated to be planted to public varieties and hybrids and 5 million hectares (19%) to proprietary materials.

About 14 million hectares of improved maize area were planted in the tropical lowlands, of which 8.8 million hectares (63%) were OPVs and 5.1 million hectares (37%) were hybrids. Of the 11 million hectares of improved maize in the tropical mid-altitudes, tropical highlands, and the subtropics, only 2.8 million hectares (26%) were planted to OPVs, where 7.9 million hectares (74%) were planted to hybrids, indicating a clear specialization between ecologies in OPVs and hybrids.

Of the 25 million hectares under improved maize varieties and hybrids, 13.5 million hectares (or 55%) were planted to maize possessing at least some CIMMYT germplasm. Materials developed and released by the public sector accounted for 12.1 million of the 13.5 million hectares planted to CIMMYT-related materials, whereas proprietary materials accounted for 1.4 million hectares.

CIMMYT germplasm is used by public sector breeding programs in all regions of the developing world. Farmers in sub-Saharan Africa planted two million hectares to maize containing CIMMYT germplasm in 1990, which represents 33% of the area planted to improved maize in the region. In Asia 5.3 million hectares — 65% of the area planted to improved maize — were covered by maize varieties and hybrids derived from CIMMYT germplasm, whereas Latin American countries reported planting 5.7 million hectares (58% of the improved maize area) to CIMMYT-derived materials. Materials containing CIMMYT germplasm covered virtually all (0.6 million hectares or 96%) of the area planted to improved maize in West Asia and North Africa.

The area under materials containing CIMMYT germplasm is substantially higher in tropical lowland environments compared to the other non-temperate ecologies, reflecting CIMMYT's emphasis on this ecology in its breeding objectives. The impact of CIMMYT-related materials released in the late 1980s was not yet felt in 1990, because most of the area under materials containing CIMMYT germplasm in 1990 was planted to materials released in 1985 or earlier (83%). However, given the higher numbers of maize releases in recent years (including releases containing CIMMYT germplasm) and the normal lag between release and peak adoption, impacts of the collaboration between CIMMYT and the public NARSs should increase substantially in the next 10-20 years as farmers adopt these newer releases.

Conclusions

Most of the varieties and hybrids released by public NARSs contain CIMMYT germplasm, and farmers are adopting them. More than half of the area under improved maize in the developing world is planted to varieties and hybrids containing CIMMYT germplasm, attesting to the success of collaborative breeding by public NARSs and CIMMYT. The full impact of this collaboration is still to come. The adoption of improved maize in the next 10-20 years is likely to accelerate as a result of the increased number of improved, higher yielding varieties and hybrids released annually.

One of the original objectives of this study was to estimate the economic impacts of the collaborative maize breeding research done by NARSs and CIMMYT. Whereas it was possible to obtain estimates of the area planted to improved maize varieties and hybrids for this study, it was not possible to estimate the economic impacts of breeding research at the global level because some of the key information necessary to derive such estimates was not available. Information on the yield gains attributable to maize breeding under farmers' conditions and data on private companies' use of public germplasm are especially scarce. Future studies of the impact of maize research would benefit from careful documentation of 1) materials containing public germplasm, 2) the adoption of improved materials by farmers, and 3) the on-farm yield gains associated with adoption of improved varieties.

The fact that more than half (33 million hectares) of the developing world's maize area is still planted to unimproved varieties suggests that significant barriers continue to slow adoption of improved maize germplasm. The still modest use of improved maize germplasm in some regions of the developing world reflects farmers' persistent difficulty in obtaining seed and points to the need for more effective maize seed industries, especially better seed production and distribution. Major efforts to improve the effectiveness of commercial seed production and distribution are in evidence in many developing countries, especially though modifications in agricultural policies, seed legislation, and seed trade. These changes are undoubtedly a step in the right direction toward achieving higher adoption rates of improved maize varieties and hybrids.

Increases in maize production probably will depend almost entirely on increases in productivity. One of the easiest ways to increase productivity is through the use of improved seed. Breeders thus face the formidable task of continually developing varieties adapted to local conditions, with tolerance/resistance to important biotic and abiotic stresses, especially where maize is produced under marginal conditions and under low levels of purchased inputs and drought stress. The continued collaboration between CIMMYT and public and private sector organizations is expected to be a key factor in meeting this challenge.

Chapter 1

Introduction

In mid-1990, the International Maize and Wheat Improvement Center (CIMMYT) initiated a major effort to evaluate the impacts of its maize and wheat breeding programs. This effort was undertaken to provide feedback to CIMMYT researchers on the level of acceptance of improved maize and wheat germplasm developed with the help of CIMMYT scientific staff. A secondary goal was to generate information on how that germplasm might best be modified to better meet the needs of the intended users.

This report presents results of the effort to evaluate the impacts of CIMMYT's maize breeding program. (Results of the parallel study of the impacts of CIMMYT's wheat breeding program appear in Byerlee and Moya, 1993.) Evaluating the impacts of the CIMMYT maize breeding program is challenging for at least three reasons. First, the scope of the task is truly daunting. Because CIMMYT has a global mandate for maize germplasm improvement in non-temperate production environments, the impacts of its research must be assessed over more than 60 million hectares. Second, the boundaries of the study are imprecise. Because CIMMYT does not release commercial maize varieties and hybrids directly to farmers but rather provides improved germplasm for use by national programs, by other international centers, and by private companies, no clear line indicates precisely where the work of CIMMYT maize breeders ends and that of their collaborators begins. Largely for this reason, maize breeding at the global level must be considered a joint effort between CIMMYT, national agricultural research systems (NARSs), other international agricultural research centers, and private companies. Third, because maize is an open-pollinating crop, the genetic constitution of improved maize varieties grown in farmers' fields changes continually, making these varieties much more difficult to identify and to track than improved varieties of self-pollinating crops such as wheat and rice.

This study updates and greatly extends work done in the mid-1980s by Timothy, Harvey, and Dowswell (1988) to assess the spread of improved maize varieties and hybrids in developing countries. In addition to updating earlier estimates on the adoption of improved materials, this study documents the extent to which CIMMYT germplasm has made its way into materials released in developing countries.[1]

Sources of Information

The information presented in this report was compiled from many sources:

1. Data showing genetic gains achieved in CIMMYT breeding materials were obtained directly from CIMMYT maize breeders as well as from published and unpublished sources (e.g., journal articles, the *CIMMYT Research Highlights* and *CIMMYT Review* series, and unpublished internal reports).

2. Data on the composition and global distribution of maize varieties and hybrids were generated through a global survey of national maize breeding programs undertaken in 1990 (Appendices A and B). Through this survey, which included all major maize-producing countries in the developing world (except those where maize is produced primarily in temperate environments), a

[1] Throughout this report, "improved maize materials" denotes "improved open pollinated maize varieties and hybrids."

comprehensive database was assembled containing information on maize varieties and hybrids released by public sector breeding institutions from 1966 to 1990. Some private sector releases are also included in this database.

3. Data on the area planted to different types of improved maize materials in different production environments throughout the developing world were obtained from the global survey and from FAO's AGROSTAT database. Figures reported in this study relating to area planted to maize correspond to the 1990 crop year. Data from various surveys carried out by the CIMMYT Economics Program as part of the *CIMMYT World Maize Facts and Trends* series were also used to estimate the total area under improved maize materials in developing countries.

The CIMMYT Maize Program

The mission of the CIMMYT Maize Program is to "help the poor in developing countries by increasing the productivity of resources committed to maize, while protecting natural resources. This will be accomplished through the preservation, improvement, and dissemination of genetic resources; the development of environmentally compatible crop management practices; the provision of research methodologies and information; and through training and consulting" (CIMMYT Maize Program 1994). Because the overwhelming majority of poor farmers in developing countries are located in non-temperate (i.e., tropical and subtropical) production environments, CIMMYT concentrates its germplasm improvement efforts on these environments. As will become evident, the explicit emphasis on poverty, developing countries, and non-temperate production environments has clear implications for CIMMYT's maize breeding strategy.

Under its current structure, the CIMMYT Maize Program comprises three main subprograms: 1) Lowland Tropical Maize, 2) Subtropical and Mid-altitude Maize, and 3) Physiology, Agronomy, and Stress Resistant Maize (Figure 1). Several units operate across subprograms, including the Maize Germplasm

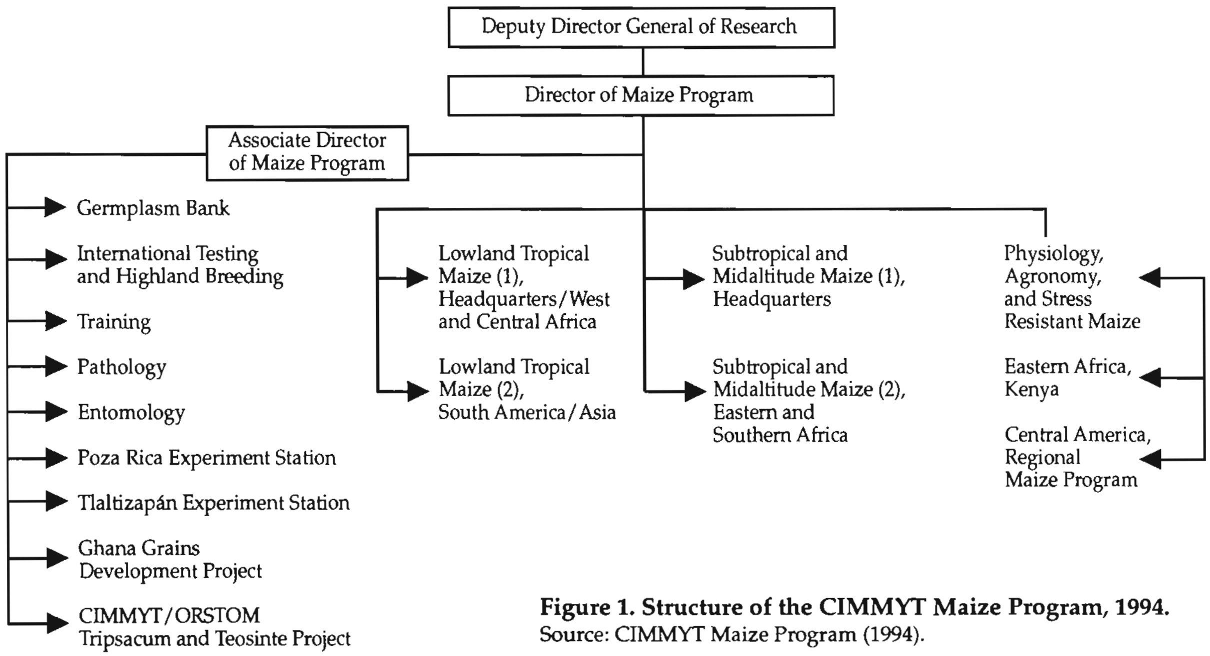

Figure 1. Structure of the CIMMYT Maize Program, 1994.
Source: CIMMYT Maize Program (1994).

Bank, International Testing,[2] and Training, Pathology, and Entomology. In 1994, the Maize Program had 36 maize scientists, 24 of them based at CIMMYT headquarters in Mexico. The rest worked out of regional offices located in Central America (Guatemala), South America (Colombia), West Africa (Ghana, Côte d'Ivoire), East Africa (Kenya), southern Africa (Zimbabwe), and Asia (Thailand). Figure 2 provides an idea of trends in the resources used by the CIMMYT Maize Program with respect to total budgets and numbers of maize scientists. The figure reflects the expanding support for international agricultural research (including maize improvement) throughout the 1970s and much of the 1980s, which was countered by reduced support in the 1990s and declining numbers of scientists conducting maize research.

Since CIMMYT was founded in 1966, the breeding activities of its Maize Program have rested on the belief that recurrent selection represents an effective method for producing a wide range of source materials which national breeding programs can use, either directly (as improved varieties) or indirectly (as source materials for locally developed improved varieties and hybrids).[3] Recurrent selection permits systematic accumulation of favorable alleles and combinations of alleles that provide superior populations, useful as sources of new varieties as well as new inbred lines for use in developing hybrids. Although various types of recurrent selection programs have proved successful for improving maize varieties or germplasm complexes, for reasons of efficiency, practicality, and economy, the CIMMYT Maize Program traditionally has emphasized population improvement through half-sib, full-sib, and (more recently) S1 and S2 recurrent selection.

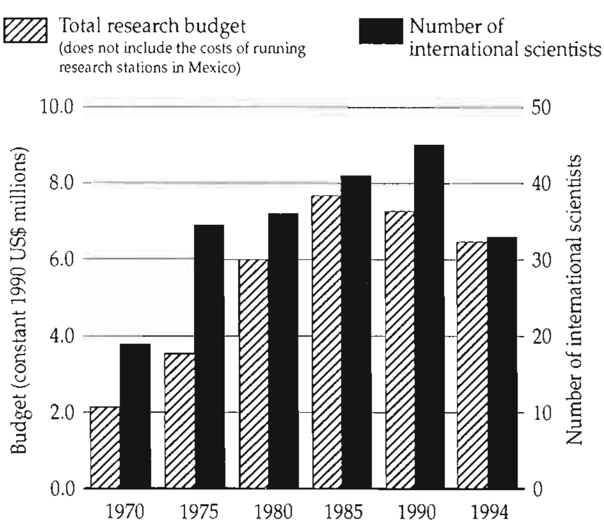

Figure 2. Trends in resources allocated to the CIMMYT Maize Program, 1970-94.

In earlier years, CIMMYT maize breeders emphasized intra-population recurrent selection, since this provided a steady source of new varieties at each cycle of selection. This was the main emphasis in maize breeding between 1970 and 1985. More recently, as national breeding programs have increased their ability to work with hybrids, and as seed industries have been liberalized to allow greater private sector participation in seed production and distribution as well as germplasm development, increased attention has been focused on developing inbred lines and other hybrid products.[4] The allocation of CIMMYT Maize Program resources in 1994 by discipline and product is presented in Figure 3. The Program currently devotes almost half of its resources (44%) to maize breeding; 30% of its products are improved populations, 13% are open pollinated varieties (OPVs), and 18% are inbred lines and hybrids.

2 Breeding for tropical highlands is done by the breeder in charge of International Testing.
3 Throughout this report, "national programs" is used in a broad sense to denote both public national agricultural research institutions, as well as private companies engaged in research and development.
4 For additional information on the development of breeding populations and the integration of population improvement with the development of open pollinated varieties and hybrids, see Pandey and Gardner (1992); Pandey et al. (1987); Gardner (1986); and Timothy et al. (1988). Information on inbred lines and other germplasm products can be also obtained by writing to International Maize Trials, CIMMYT.

CIMMYT and the International Maize Breeding System

CIMMYT's maize breeding program constitutes only one small part of a larger international system whose purpose is to generate improved maize germplasm and deliver that germplasm to farmers (Figure 4). Before turning to CIMMYT's maize breeding activities, it is useful to describe the larger system in order to develop a sense of CIMMYT's role.

The activities of the larger system can be divided into five stages. CIMMYT maize breeding activities (Stage 1) take place primarily at five research stations in different regions of Mexico, as well as at a number of breeding stations outside of Mexico (e.g., the CIMMYT Mid-Altitude Research Station in Zimbabwe, Farm Suwan in Thailand, the CIMMYT/International Institute of Tropical Agriculture [IITA] Research Station in Côte d'Ivoire). Scientists working at these stations engage in a continual process of developing and improving CIMMYT breeding materials, which include pools, populations, synthetics, inbred lines, partially inbred lines, and special purpose materials (for a description of the breeding activities of the Maize Program, see any of the CIMMYT International Maize Testing Program Annual Reports).

Contrary to the widely held view, the goal of CIMMYT's maize breeding program is not to produce finished materials that can be delivered directly to farmers. In fact, CIMMYT maintains a firm policy of not releasing its own varieties or hybrids. Rather, CIMMYT's maize breeding program produces intermediate products — a complete range of improved germplasm showing high yield potential, good agronomic characteristics, and resistance to important diseases and pests — for use by national breeding programs. Private seed companies also make extensive use of CIMMYT germplasm in their breeding efforts, although first priority is given by CIMMYT to meeting the needs of public sector breeding programs.

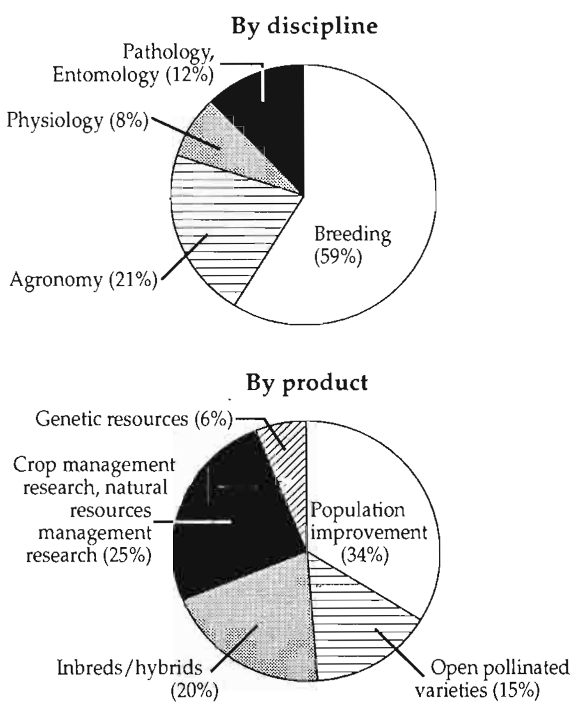

Figure 3. CIMMYT Maize Program research resource allocation by discipline and products, 1994.

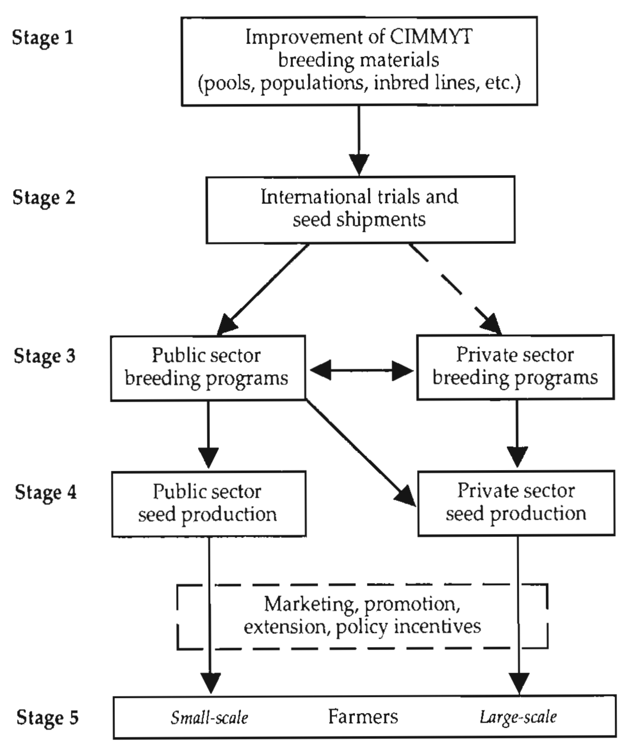

Figure 4. Flows of CIMMYT maize germplasm.

The products of CIMMYT's maize breeding research are distributed to the national programs via two channels (Stage 2). International trials are sent to cooperators throughout the developing world, providing them with an opportunity to evaluate experimental germplasm; if they so choose, the cooperators may then request seed of promising materials. In addition, seed is shipped to maize breeders in national programs and private companies in response to direct requests. (See the box, "Dissemination of CIMMYT Germplasm").

Once germplasm from CIMMYT is received by breeders working in national programs or private companies, it is used as an input into local breeding efforts (Stage 3). Depending on numerous factors, including the performance of the material when it first arrives, the objectives of the national breeding program, and the strength of the national program, the CIMMYT material may be released almost immediately (usually after being renamed), or it may undergo additional cycles of selection and improvement. Depending on the nature and duration of the additional breeding work done by the local breeders, by the time a variety or hybrid is officially released, it may contain varying amounts of CIMMYT germplasm.

After they have been officially released, improved varieties and hybrids enter into seed production (Stage 4). Because maize is a cross-pollinated crop, the performance of the seed industry, whether the industry is public or private, plays an especially important role in disseminating improved maize seed to farmers. Since maize plants in one field often cross with plants in nearby fields if both crops flower at the same time, farmers require reliable sources of high quality seed. In the case of hybrids, which do not "breed true," seed must be replaced every

Dissemination of CIMMYT Germplasm

The main vehicle for distributing CIMMYT germplasm is the system of international trials. Each trial consists of a set of materials sent to local cooperators. These materials are grown under carefully controlled levels of management (for a more detailed description, see Vasal, Ortega, and Pandey 1982). In return for growing the trial and reporting the results to CIMMYT, the cooperators have an opportunity to observe (and, if they choose, request seed of) a set of promising experimental materials. International trials thus serve as an important two-way conduit through which germplasm moves from CIMMYT to cooperating countries and information moves from cooperating countries to CIMMYT.

In addition to moving through the international trial system, germplasm is also distributed directly from the Maize Germplasm Bank in response to specific requests for breeder seed. The Germplasm Bank currently contains more than 10,000 accessions, many of them collected during the 1940s and 1950s.

Maize breeders from developing as well as industrialized countries may request seed, either seed of CIMMYT materials (e.g., pools, populations, experimental varieties, inbred lines) or seed of non-CIMMYT materials maintained in the Germplasm Bank. From 1975 to 1990, seed shipments averaged about 350 per year. Maize germplasm has been distributed to all regions of the developing world, with Latin America the heaviest user, followed by Asia and sub-Saharan Africa. It is interesting to note that not only developing countries, but also industrialized countries, make extensive use of this service.

year to avoid segregation in the F2 and subsequent generations. In the case of OPVs, seed should be replaced at least every five years if high levels of genetic purity are to be maintained.[5]

After these four stages have been completed, seed of improved varieties and hybrids becomes available to farmers. Assuming farmers receive adequate information about the material, and if economic incentives for maize production are favorable, the seed is planted (Stage 5). Depending on agroclimatic conditions, farmers' management practices, and/or other factors, the improved material may or may not perform better than farmers' previous variety or hybrid. Performance is usually measured in terms of increased grain yield, although often this is not the only criterion of interest to farmers. Other important characteristics sought by farmers may include earliness, drought tolerance, pest resistance, stover quantity or quality, and grain quality.

It is important to understand this complex, multistage process through which the products of CIMMYT's maize breeding program make their way to farmers. Just as a chain is only as strong as its weakest link, so CIMMYT germplasm can be expected to deliver benefits to farmers only if all stages in this process work effectively. Rather than focusing exclusively on what many perceive to be the only meaningful measure of research impact — the yield gains in farmers' fields that can be attributed to the use of improved germplasm — this report considers each of the five stages in the process. The five stages are treated independently because the most widely used indicator of breeding impacts (yield gains achieved in farmers' fields) is an inadequate measure of the performance of CIMMYT's maize breeding program. Yield gains achieved in farmers' fields ultimately depend not only on the availability of superior germplasm but also on many other factors that have little to do with plant breeding *per se*. For example:

- *Government policies* affect the yield gains achieved in farmers' fields by influencing the economic incentives associated with maize production. No matter how good the available germplasm is, farmers will not plant maize if production remains economically unattractive because of low producer prices or high input costs. Even when maize production is economically attractive, yield levels will be depressed if government policies fail to ensure the timely availability of complementary inputs, such as fertilizer, pesticides, and irrigation water.

- *The strength of national plant breeding programs* can affect the yield gains achieved in farmers' fields by influencing the way in which CIMMYT germplasm is evaluated, further improved, and promoted in individual countries. CIMMYT materials may not be ready to be released directly to farmers; frequently, breeders working in the national program make additional selections to identify materials that are well adapted to local production conditions and conform to local producer and consumer preferences. If the national program cannot perform these functions effectively, even the best CIMMYT germplasm may not find its way into farmers' fields.

- *The strength of local crop management research* can affect the yield gains achieved in farmers' fields by influencing the level of knowledge about how improved maize varieties and hybrids should be managed. If crop

[5] Although the generally accepted rule of thumb states that seed of OPVs should be replaced once every five years, in fact the optimal rate of seed replacement will vary depending on farmers' seed management practices, which affect the rate of genetic contamination. Evidence from a number of empirical studies suggests that many farmers do not replace seed of OPVs with sufficient frequency to maintain genetic purity (for example, see Longmire and Mohammed, 1994).

management research is weak, farmers may lack adequate information for managing improved materials so as to exploit their higher yield potential.

- *The effectiveness of the local extension service* can affect the yield gains achieved in farmers' fields by influencing the amount and quality of information about how to manage improved maize varieties and hybrids. Even if crop management researchers have generated sound recommendations for the management of improved materials, these recommendations may not reach farmers if the extension service is ineffective.

- *The strength of local seed industries and seed trade regulations* can affect the yield gains achieved in farmers' fields by affecting the availability, quality, and cost of seed. If farmers cannot obtain pure, high quality, affordable seed of the varieties they desire, they are not likely to adopt improved materials. Even if they do, poor seed quality will result in depressed yields. Similarly, bottlenecks in seed production can prevent timely replacement of seed, leading to deterioration of genetic purity and yields, especially in the case of hybrid seed.

Chapter 2

Gains in Genetic Potential of CIMMYT Breeding Materials

CIMMYT breeders have sought to develop a range of diverse materials showing broad adaptation across different environments. In some instances, they have also worked on specialized materials possessing traits desired by national breeding programs within a given region, such as resistance to a particular local disease or pest. These breeding objectives differ from those typically pursued by breeders working for national programs, who tend to concentrate on maximizing yield potential in specific, narrowly defined production environments. Although yield potential remains the single most important objective of the CIMMYT breeding program, gains in yield potential *per se* represent only a partial measure of the progress achieved by CIMMYT breeders. In fact, in some of the special-purpose pools and populations, yield potential is considered a secondary objective.

To show the progress achieved in raising the yield potential of CIMMYT's breeding materials, average annual percentage rates of yield gain were calculated for selected CIMMYT pools and populations. Results are reported only for pools and populations that have been maintained intact and that have been worked on more or less continuously for at least 10 years.[6] The data presented in Tables 1 and 2 indicate that the rates of yield gain achieved in CIMMYT's breeding pools and populations have varied.[7] Progress generally has been more rapid in the pools (average annual yield gain of 2.5%), largely because two breeding cycles are completed each year and selection pressure usually is higher. Progress has been modest in the populations (average annual yield gain of 1.1%), where each cycle takes two years on average to complete. These rates of yield gain appear to fall well within the range reported for maize breeding programs with similar objectives (e.g., Eberhart, Harrison, and Ogada 1967, Darrah 1986).

Further evidence of increased yield potential in CIMMYT breeding materials is available from a number of sources. Most of this evidence comes from analyses done by CIMMYT breeders to monitor progress. Results of such analyses are sometimes published formally (for example, see Bolaños and Edmeades 1993; Ceballos, Deutsch, and Gutiérrez 1991; Pandey et al. 1986, 1987; Pandey, Vasal, and Deutsch 1991; Pandey and Gardner 1991; Crossa and Gardner 1989; de León and Pandey 1989; Fischer, Edmeades, and Johnson 1987; Johnson et al. 1986). More frequently they appear in CIMMYT publications, such as the CIMMYT *Research Highlights* and CIMMYT *Annual Reports*, or in unpublished reports prepared for use within the CIMMYT Maize Program (e.g., Lothrop 1988).

[6] Whereas strictly speaking no population undergoing improvement remains intact since it changes through time, at various points certain CIMMYT populations were radically transformed through introgression of large amounts of new material; these populations were not included in the analysis.

[7] Differences in the rates of yield gain achieved within individual pools and populations can be attributed to a number of factors. Of primary importance is the genetic diversity of the pool or population when it was originally formed. In general, the narrower the genetic base at the time of formation, the slower the rate of subsequent yield gains that can be achieved through intra-population recurrent selection. This partly explains the generally more rapid progress in the pools compared to the populations; the pools included more genetic diversity at the time of formation. Differences in rates of yield gain between individual pools and populations may also be explained by periodic introgressions of new germplasm to introduce desired genetic traits (e.g., resistance to a specific disease or insect pest). Such periodic introgressions have affected some pools and populations more than others. Finally, differences in rates of yield gain between pools and populations can be explained by differences in breeding objectives. While increased yield potential is usually a primary objective, in some pools and populations yield has occasionally been sacrificed to achieve other objectives that are considered more important, such as protein quality or drought tolerance. (See Appendix C for a discussion of alternative procedures for measuring yield gains in breeding materials.)

Table 1. Average annual percentage gain in yield potential for selected CIMMYT tropical and subtropical pools

Pool	Number of cycles evaluated	Year first cycle formed	Year last evaluated cycle formed	Yield, initial cycle (t/ha)	Yield, last cycle evaluated (t/ha)	Average gain per year (%)	Average gain per cycle (%)
19	15	1973B	1980 B	5.1	5.6	1.4	0.7‡
20	15	1973B	1980 B	3.7	4.4	2.2	1.1†
21	15	1973B	1980 B	5.4	5.7	0.8	0.4‡
22	16	1973B	1981 A	4.6	5.4	2.0	1.0†
23	15	1973B	1980 B	5.1	5.2	0.5	0.2†
24	15	1973B	1980 B	5.1	5.7	1.4	0.7‡
25	14	1973B	1980 A	3.5	4.1	2.6	1.3†
26	14	1973B	1980 A	5.4	5.4	0.1	0.0‡
27	16	1973B	1981 A	3.1	4.0	3.2	1.6‡
32	16	1973B	1981 A	3.9	6.4	6.5	3.2‡
33	16	1973B	1981 A	3.2	3.9	2.6	1.3†
34	16	1973B	1981 A	2.9	4.8	6.7	3.3†

Sources: † = CIMMYT (1987b); ‡ = CIMMYT (1982).

Table 2. Average annual percentage gain in yield potential for selected CIMMYT populations

Population	Number of cycles evaluated	Year first cycle formed	Year last evaluated cycle formed	Yield initial cycle (t/ha)	Yield last evaluated cycle (t/ha)	Average gain per year (%)	Average gain per cycle (%)
21	5	1974	1983A	6.0	6.3	0.7	1.2[a]
22	4	1974	1982A	6.1	6.5	0.9	1.8[a]
23	5	1974	1982A	5.1	5.3	0.4	0.7[b]
24	5	1974	1982A	5.7	5.8	0.2	0.3[a]
26	5	1974	1983A	5.0	5.4	0.9	1.7[b]
27	5	1974	1982A	5.3	5.8	1.1	1.8[a]
28	4	1975	1983A	6.0	6.4	0.7	1.5[a]
29	5	1974	1983A	6.2	6.	0.0	0.0[a]
32	4	1975	1982A	4.8	5.5	1.7	3.1[b]
33	4	1979	1989A	4.4	5.0	1.3	3.2[d]
34	5	1974	1983A	6.2	7.3	1.9	3.4[c]
35	4	1975	1982A	4.7	5.1	1.4	2.4[b]
36	5	1974	1983A	5.7	6.2	1.0	1.8[a]
42	4	1974	1983A	7.2	8.0	1.5	2.6[c]*
43	4	1974	1982A	6.1	6.6	0.9	1.8[a]
44	7	1974	1989A	4.7	6.1	2.1	3.8[d]*
45	5	1977	1989A	4.6	5.5	1.5	3.6[d]
48	7	1974	1989A	3.2	4.1	2.0	3.8[d]*

* Breeding discontinued for two years.
Sources: a = Pandey et al. (1986); b = Pandey et al. (1987); c = CIMMYT (1984); and d = Eaton, Byrne, and Renfro (1991).

Chapter 3

Patterns in Varietal Releases

After being distributed through international trials or via direct seed shipments, CIMMYT's experimental maize germplasm is taken up by public and private organizations and used in developing improved varieties and hybrids for local release. To assess the impact of international maize breeding efforts, locally released varieties and hybrids must be examined to determine the amounts and types of germplasm they contain from different sources. Data on the composition and distribution of maize varieties and hybrids released by national programs were collected through a questionnaire distributed in 1990 to the major maize-producing countries of the developing world. Since CIMMYT does not work with temperate maize germplasm, a few developing countries (or regions within countries) where virtually all maize is produced in temperate environments were excluded from the survey (e.g., Argentina, Chile, Turkey, northern and central China). Forty-five countries responded to the survey (see Appendix A).

Collecting data on the genetic background (pedigrees) of maize varieties and hybrids is made difficult by the complex and highly variable nature of maize breeding. Because maize is a cross-pollinating crop, maize breeders are able to produce a wide array of materials, including inbred lines, full-sib and half-sib families, composites, synthetics, and a wide range of conventional and non-conventional hybrids (for a discussion of the major types of maize materials, see CIMMYT 1987a; Sprague and Dudley 1988; Vasal and Srinivasan 1991). By the time a maize variety or hybrid is certified for official release, typically it contains materials from many different sources.

Because maize pedigrees are often complex, classifying germplasm is difficult. In classifying materials released by national programs, a major problem lay in deciding how to distinguish between materials based on their CIMMYT germplasm content, which can range from 0% to 100% but is rarely known with precision. For wheat, definitions have been based on reasonably clear-cut genealogical criteria. For example, wheat varieties resulting from crosses made at CIMMYT in Mexico are classified as "mostly CIMMYT," whereas wheat varieties from crosses made by national programs using at least one CIMMYT parent are classified as "containing some CIMMYT germplasm" (Byerlee and Moya 1993). However, the complex nature of maize breeding makes the use of equivalent genealogical criteria virtually unworkable, since maize breeding often involves numerous cycles of topcrossing, backcrossing, or selfing to introduce or eliminate specific traits. Although it was not possible to develop clear-cut genealogical criteria for classifying maize materials, survey respondents were asked to classify materials into the following five classes:

- Class 1 = Public materials, containing no CIMMYT germplasm
- Class 2 = Public materials, using some CIMMYT germplasm
- Class 3 = Public materials, selection from CIMMYT trials
- Class 4 = Public materials, direct use of CIMMYT variety or hybrid
- Class 5 = Private materials (proprietary hybrids)

In several cases in which CIMMYT's contribution was debatable, specific decision rules were applied. For example, all maize landraces were considered Class 1, unless they had been transformed into an identifiable CIMMYT breeding population through selection and improvement (e.g., Tuxpeño, ETO). Materials developed in Mexico and elsewhere during the early 1960s by Rockefeller Foundation-supported scientists (notably Suwan-1 in Thailand and materials derived from Suwan-1 in other countries) also were considered Class 2 (containing some CIMMYT germplasm).[8] Most of the materials developed at IITA using CIMMYT source germplasm were also conservatively classified as Class 2. A few IITA materials for which the direct use of CIMMYT germplasm was not in doubt were classified as Class 3 (e.g., the TZPB-SR series developed from the Tuxpeño Planta Baja population).

Private sector releases proved particularly difficult to classify. Private companies were usually willing to indicate whether or not CIMMYT germplasm had been used in developing a particular OPV or hybrid, but since they were usually not willing to identify the specific source material or indicate its importance in the finished OPV or hybrid, all private sector materials included in the survey were categorized as Class 5 and further subdivided into one of two categories (containing CIMMYT germplasm or containing no CIMMYT germplasm).

We emphasize that these classifications do not imply attribution of credit for breeding. Because maize materials distributed by CIMMYT are not intended for direct release to farmers, CIMMYT materials used by national programs often require additional screening, selection, and improvement. Varieties and hybrids that contain CIMMYT germplasm and have been released by a national program (Classes 2, 3, or 4) are in a very real sense products of that program. In classifying materials for this study, the intention was simply to identify materials that CIMMYT breeders had worked on at some point, so that the movement of these materials could be tracked. We consider this to be a conservative approach in determining whether maize releases contain germplasm of CIMMYT origin, and one that gives due credit to the national programs for further improvement of CIMMYT materials prior to release.

The sections that follow will examine patterns in the varieties and hybrids released by national programs (for example, the types of material released, their ecological adaptation, and their grain color), focusing first on patterns encountered among all improved materials and second on patterns in CIMMYT-related materials.

Patterns in All Improved Materials

The 1990 survey generated information on 1,039 varieties and hybrids released in 45 developing countries between 1920 and 1990.[9] These materials include nearly all varieties and hybrids officially released by the public sector during that period in those countries, with the exception of China. As indicated earlier, in the case of China only materials released for the lowland tropical, subtropical, mid-altitude, and highland zones of southern China were inventoried (i.e., the maize growing zones of Yunnan, Guizhou, and Guangxi Provinces). In addition to varieties and hybrids released by

[8] CIMMYT had not been founded when development of these materials began. However, since the Rockefeller Foundation plant breeding program essentially was transformed into CIMMYT in 1966, it is reasonable to classify these materials as CIMMYT materials. A similar approach was used in classifying wheat varieties for a study of the impacts of wheat research (Byerlee and Moya 1993).

[9] Questionnaires were sent to most developing countries with at least 100,000 ha planted to maize in non-temperate environments during 1988-90. A few countries with less maize area were also included (e.g., Costa Rica), and a few countries with more than 100,000 ha were excluded due to extraordinary circumstances that made collecting data impossible (e.g., Angola). Total non-temperate maize area in 1990 for the 45 countries included in the survey was 57.4 million hectares, representing 95% of the approximately 60.7 million hectares of non-temperate maize area in the developing world that year.

public institutions, approximately 45 hybrids developed and released by private companies were included in the database.[10]

Of the more than 1,000 varieties and hybrids inventoried during the 1990 survey, 842 were released between 1966 and 1990, the period during which CIMMYT's Maize Program has been in existence.[11] Since the main objective of the study was to assess the impact of CIMMYT's contribution to international maize breeding efforts, the analysis that follows is restricted to materials released between 1966 and 1990. Also, although the analysis presented here emphasizes public sector releases, information from a survey of private company maize releases is presented in a later section.

Geographical distribution — Tables 3 and 4 provide data on the number of maize varieties and hybrids released by public sector institutions in developing countries during 1966-90. Considerable variability is evident in the number of releases per country, which range from four in

Table 3. Public maize varieties and hybrids released in developing countries, 1966-90

Region/country	Total maize releases	Maize area, 1990 (000 ha)	Total releases per million ha per year[a]	Region/country	Total maize releases	Maize area, 1990 (000 ha)	Total releases per million ha per year[a]
Sub-Saharan Africa				**South, East, and Southeast Asia**			
Burundi	11	124	3.7	Myanmar	15	125	5.7
Ethiopia	16	1,050	0.8	India	44	5,954	0.3
Kenya	19	1,500	0.6	Nepal	12	758	1.0
Madagascar	6	153	2.0	Pakistan	21	845	1.2
Malawi	16	1,344	0.6	Indonesia	16	3,158	0.2
Mozambique	14	1,015	0.9	Philippines	14	3,820	0.2
Tanzania	13	1,630	0.4	Thailand	7	1,545	0.2
Uganda	4	389	0.5	Vietnam	22	432	2.7
Zambia	16	760	0.8	China			
Zimbabwe	27	1,150	1.1	(Southern Provinces)[b]	20	2,246	0.4
Benin	9	454	0.9	Taiwan	11	84	5.2
Burkina Faso	18	216	5.3				
Cameroon	22	200	2.3	**Latin America**			
Côte d'Ivoire	8	690	0.7	Costa Rica	14	41	10.6
Ghana	12	465	1.2	El Salvador	13	282	2.3
Mali	10	170	4.4	Guatemala	44	634	2.9
Nigeria	37	1,500	1.5	Honduras	23	367	2.9
Senegal	12	117	7.3	Mexico	83	7,339	0.5
Togo	4	296	1.0	Nicaragua	15	194	3.0
Zaire	16	1,200	0.9	Bolivia	16	256	2.6
				Colombia	42	837	2.7
West Asia and North Africa				Ecuador	10	459	1.4
Egypt	13	830	0.7	Peru	17	323	1.9
Morocco	15	376	1.4	Venezuela	24	462	2.1
				Brazil	26	11,389	0.1
				Paraguay	15	518	2.0
				All developing countries	**842**	**57,697**	**0.7**

Source: CIMMYT maize varietal releases database, FAO AGROSTAT diskettes.
[a] Based on average maize area over 1966-90.
[b] Yunnan, Guizhou, and Guangxi.

[10] Efforts are underway to expand the database to include all private sector releases.
[11] The other 197 releases included 126 public materials released before 1966, 45 materials released by private companies during 1966-90, and 26 materials for which the year of release is unknown.

Togo and Uganda to 83 in Mexico. This variability reflects the level of activity of public sector maize breeding institutions, the number of production environments targeted, differences among national seed certification procedures and regulations, and (perhaps indirectly) the level of research activity of private seed companies, among other factors.

There appears to be an inverse relationship between the number of releases per year and the size of the maize area within a given country (Tables 3-5). The number of releases per million hectares per year is a standard measure of the rate of varietal release that allows comparisons to be made between large and small countries. In general, the number of releases per million hectares decreases as maize area increases.[12] Rates of release in Latin America and Asia (0.5 releases per million hectares per year) are half those in sub-Saharan Africa and West Asia and North Africa (1.0 releases per million hectares per year). These different rates of release are a reflection of many factors. For example, in China, where there are no private seed companies, maize-producing regions are relatively more homogeneous than those in most African countries, and thus fewer varieties and hybrids are released annually per unit of maize area. The very low rate of releases in Brazil seems to be related more to the presence of an active private seed sector that has strong breeding programs than to the relatively homogeneous production environment, which reduces the need for the public sector to release a great number of materials (private sector materials are excluded in this analysis). Interestingly, some of the countries that have released the fewest maize varieties per million hectares per year possess some of the most accomplished national breeding programs (e.g., China, India, Thailand, Brazil, and Mexico). This suggests that success in maize breeding should not be measured in terms of the number of varietal releases *per se*.

Table 4. Maize varieties and hybrids released in developing countries, by region, 1966-90

Region	Total maize releases	Total 1990 maize area (million ha)	Total releases per million ha per year[a]
Sub-Saharan Africa	290	14.4	1.0
West Asia and North Africa	28	1.2	1.0
South, East, and Southeast Asia	182	19.0	0.4
Latin America	342	23.1	0.6
All developing countries	**842**	**57.7**	**0.7**

Source: CIMMYT maize varietal releases database, FAO AGROSTAT diskettes.
[a] Based on average maize area over 1966-90.

Table 5. Rate of varietal releases in developing countries, classified by 1990 maize area

Maize area (million ha)	Number of countries in category[a]	Total 1990 maize area (million ha)	Number of releases, 1966-90	Total releases per million ha per year[b]
< 0.25	10	1.4	134	3.2
0.25 - 0.50	12	4.6	169	1.6
0.50 - 1.00	8	5.9	171	1.3
1.00 - 2.00	9	11.9	165	0.6
2.00 - 5.00	3	9.2	50	0.2
> 5.00	3	24.7	153	0.3
Total	**45**	**57.7**	**842**	**0.7**

Source: CIMMYT maize varietal releases database, FAO AGROSTAT diskettes.
[a] Data for China include only the three southern provinces of Yunnan, Guizhou, and Guangxi.
[b] Based on average maize area over 1966-90.

[12] This pattern was also found in the rate of wheat varietal releases (Byerlee and Moya 1993).

Types of material — In the past, public breeding programs (including the CIMMYT Maize Program) focused much of their attention on developing OPVs, which were assumed to be easier for small-scale farmers to manage because they could be grown without the need for annual seed replacement. This emphasis on OPVs is reflected in their predominance among the different types of materials released during the past 25 years; OPVs constitute 65% of all public sector releases since 1966 (Table 6).

Beginning in the mid-1980s, maize breeders in many public breeding programs began to reassess the benefits of hybrids. To a considerable extent, this reassessment was motivated by the realization that in many countries the spread of improved germplasm was obstructed by the lack of effective mechanisms for producing and distributing high quality seed of OPVs. At the same time, evidence began to accumulate that, despite the conventional wisdom, hybrids in some cases represent an appropriate technology even for small-scale, resource-constrained farmers. The public sector breeders' growing awareness of the potential advantages of hybrids under small-scale, low-management farming conditions has led to an increased emphasis on hybrid development and a greater proportion of hybrids released (Figure 5). Relatively more hybrids are expected to be released in the future as the emphasis on hybrids becomes stronger and CIMMYT's hybrid program makes more inbred lines available.[13]

An additional factor that has accelerated the shift into hybrid development is the increasing participation of private seed companies in maize research and development. Although only limited data are available on varieties released by private

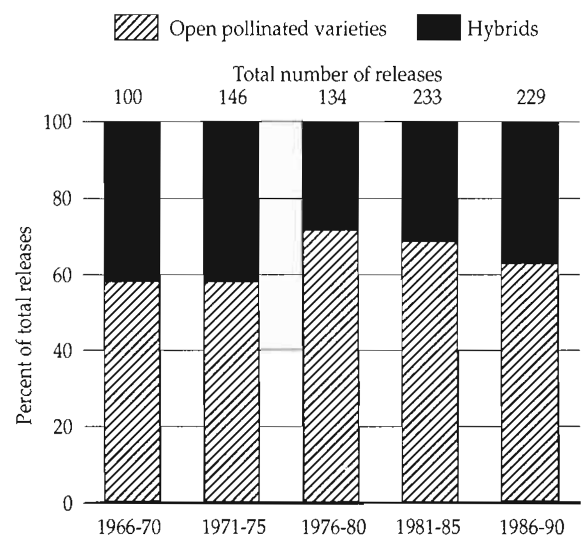

Figure 5. Trends in types of public sector maize materials released in developing countries, 1966-90.

Table 6. Types of maize materials released in developing countries, 1966-90

Region	Open pollinated varieties	Conventional hybrids	Non-conventional hybrids	Total number of releases in region
	(% of regional total)			
Sub-Saharan Africa	62	23	15	290
West Asia and North Africa	14	68	18	28
South, East, and Southeast Asia	78	15	7	182
Latin America	64	30	6	342
All developing countries	**65**	**25**	**10**	
Total releases by type	**545**	**214**	**83**	**842**

Source: CIMMYT maize varietal releases database.

[13] As of early 1994, the CIMMYT Maize Program had officially released 310 inbred lines, of which 193 (62%) are for tropical environments, 109 (35%) for the subtropics and tropical mid-altitudes, and 8 (3%) for tropical highlands (CIMMYT Maize Program 1994).

companies, all of the private sector releases listed in the CIMMYT database are hybrids, mostly conventional hybrids (Table 7). The private sector's heavy concentration on hybrids is logical, because hybrid technology can be protected from potential competitors.

Ecological adaptation — It is important to recognize the fundamental differences between the environments where maize is produced in industrialized and developing countries. In industrialized countries almost all maize is grown in temperate environments, whereas in developing countries more than three-quarters of the maize is grown in tropical environments. Since maize germplasm adapted to temperate production conditions rarely performs well under tropical conditions (and vice versa), many of the materials grown in industrialized countries are unsuitable for the production conditions that prevail throughout most of the developing world. By the same token, many of the materials grown in tropical developing countries are unsuitable for the production conditions prevailing throughout most of the industrialized world. Environmental factors thus represent an important barrier to the direct flow of improved maize germplasm between industrialized and developing countries.

Table 7. Types of maize materials released in developing countries by public and private organizations, 1966-90

Sector	Open pollinated varieties	Conventional hybrids	Non-conventional hybrids[a]	Total number of releases in sector
	(% of sector total)			
Public	65	25	10	842
Private[b]	0	93	7	45
Total	**61**	**29**	**10**	
Total releases by type	**545**	**256**	**86**	**887**

Source: CIMMYT maize varietal releases database.
[a] Non-conventional hybrids include primarily top-cross and varietal hybrids.
[b] Includes only those proprietary materials reported in the impacts survey in some countries. The actual number of maize materials released by the private sector is unknown but is certain to be much higher than this figure.

CIMMYT maize breeders recognize five major maize growing ecologies: 1) lowland tropics, 2) subtropics, 3) tropical mid-altitudes, 4) tropical highlands, and 5) temperate environments. Tables 8 and 9 present information on these five ecologies and show the area planted to maize in each one in developing and industrialized countries. Only the first four are targeted by CIMMYT's maize breeders.

Table 8. Maize production ecologies in developing and industrialized countries, 1990

	Developing countries			Industrialized countries	
Ecology	Total maize area (million ha)	Percent of total	Percent of non-temperate[a]	Total maize area (million ha)	Percent of total
Lowland tropics	34.5	43	57	0.0	..
Subtropics	13.0	16	21	4.2	9
Tropical mid-altitudes	7.6	9	12	0.0	..
Tropical highlands	6.0	8	10	0.0	..
Temperate regions	19.6	24	..	44.3	91
Total	**80.7**	**100**	**100**	**48.5**	**100**

Source: CIMMYT maize megaenvironments database and FAO AGROSTAT files.
[a] Based on 61.1 million hectares of non-temperate maize in all developing countries.

Table 10 presents data on the ecological adaptation of maize materials released by public sector organizations during 1966-90. Materials adapted to lowland tropical environments account for slightly over half of the total (53%). The pattern of varietal releases is roughly congruent with the area planted to maize in each of these four non-temperate environments, with two notable exceptions. In Asia the number of releases for the subtropics has been disproportionately high (47% of total releases versus 21% of the total maize area), probably because Chinese breeders have been adept at adapting temperate materials from northern China to subtropical production environments. In Latin America, the number of subtropical releases has been disproportionately low (4% of releases versus 23% of total maize area), which can be attributed to the relatively strong presence of private companies whose materials are not included in this analysis. Also, somewhat of a specialization by type of material is found in the different growing environments (Figure 6). Hybrid releases have been much more important, in both absolute and relative terms, in the subtropical, mid-altitude, and highland ecologies. This circumstance reflects CIMMYT's traditional emphasis on OPVs and tropical lowlands and the relatively greater emphasis on hybrids by NARSs with important maize areas in the three other ecologies (López-Pereira 1993).

Grain color — White materials outnumbered yellow materials among all public sector releases during 1966-90, although differences are evident between regions (Table 11). White materials predominated in sub-Saharan Africa and Latin America, reflecting the relatively

Table 9. Distribution of non-temperate maize area in developing countries by region and ecology, 1990[a]

Region	Lowland tropics (%)	Sub-tropics (%)	Tropical mid-altitude (%)	Tropical highland (%)	All (%)	Total maize area (million ha)
Sub-Saharan Africa	49	2	38	11	100	14.4
West Asia and North Africa	0	99	0	1	100	1.2
Asia	71	21	3	5	100	19.0
Latin America	59	23	3	14	100	23.1
Total	**59**	**19**	**12**	**10**	**100**	**57.7**

Source: CIMMYT maize megaenvironments database and FAO AGROSTAT files.
[a] Includes only countries participating in CIMMYT's Maize Research Impacts Survey.

Table 10. Maize varieties and hybrids released in developing countries, by ecological adaptation, 1966-90

Region	Lowland tropics	Sub-tropics	Tropical mid-altitude	Tropical highland	Number of releases in region
	(% of regional total)				
Sub-Saharan Africa	51	1	43	5	290
West Asia and North Africa	0	100	0	0	28
South, East, and Southeast Asia	42	47	8	3	182
Latin America	65	4	13	18	342
All developing countries	**53**	**15**	**22**	**10**	
Total releases in environment	448	129	183	82	842
Percent of 1990 maize area located in environment	59	19	12	10	100

Source: CIMMYT maize varietal releases database; CIMMYT Maize Program (1988); FAO AGROSTAT files.

greater importance of maize as human food in these regions and stronger preferences for white grain (FAO AGROSTAT files 1990). The figures for Latin America are biased towards white materials because private sector hybrids, which are mostly yellow grained, are not included in the analysis. Yellow materials have predominated in Asia, where maize is relatively more important as feed than as food and color preferences for food maize are less pronounced. The aggregate regional figures also conceal considerable variability at the individual country level. For example, the figures for Latin America are influenced heavily by Mexico and the Central American countries, where consumers prefer white maize, whereas in most South American countries yellow grain is preferred.

Over the entire period of analysis, no clear pattern is evident in the distribution of grain color by production environment. The overall proportion of white and yellow releases has been similar across environments, with white-grained materials accounting for 59% of total tropical lowland releases and 55% of total subtropical, mid-altitude and highland releases. However, changes have occurred within individual environments. White materials continue to dominate lowland tropical environments, but releases in the other three environments are increasingly yellow-grained materials (Figure 7). For 1986-90, 61% of all releases for subtropical, mid-altitude and highland environments were yellow, compared to only 43% of all releases for tropical lowlands. Interestingly, there seems to have been some degree of interaction between type of material and grain color (Figure 8). Open pollinated varieties have been more or less equally divided between white and yellow materials, while hybrids have been

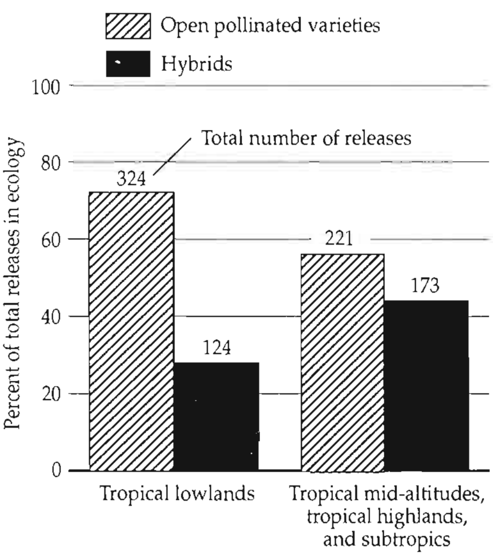

Figure 6. Public NARS maize releases by type of germplasm and ecology, 1966-90.

Table 11. Maize varieties and hybrids released in developing countries, by grain color, 1966-90

Region	Percent releases white	Percent releases yellow	Total number of releases by region
Sub-Saharan Africa	72	28	199
West Asia and North Africa	65	35	26
South, East, and Southeast Asia	21	79	169
Latin America	66	34	318
All developing countries	**57**	**43**	**712**

Source: CIMMYT maize varietal releases database.

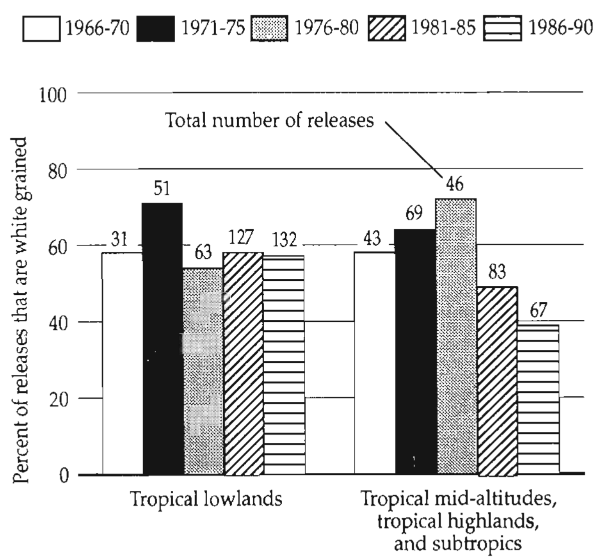

Figure 7. Trends in white maize releases by public NARSs, by ecology, 1966-90.

predominantly white. However, yellow grain color appears to be growing in importance across all types of material, perhaps reflecting the increasing share of maize consumed as animal feed (Byerlee and Saad 1993).

Commercial success rate — Because some varieties and hybrids are never taken up and used by farmers after they are released, the number of releases is an imperfect measure of a breeding program's performance. Recipients of the survey were therefore asked to identify commercially successful releases. A variety or hybrid was defined as a commercial success if it had been planted on a minimum of 25,000 ha in 1990 or before (or, for countries with small maize areas, planted on at least 5% of the national maize area). While this definition is somewhat arbitrary, it is unlikely that the benefits generated by a variety planted on less than 25,000 ha or 5% of the national maize area would justify the costs of development and distribution. By these standards, about 40% of releases were judged commercially successful, with the rate similar for OPVs and hybrids and for materials of different origin and ecologies (Table 12). This success rate is virtually identical to that reported for wheat varieties (Byerlee and Moya 1993).

Patterns in Materials Containing CIMMYT Germplasm

To what extent is CIMMYT germplasm present in the OPVs and hybrids released in developing countries? Of the 842 public materials released between 1966 and 1990, and whose genetic backgrounds are known, 445 (53%) contain CIMMYT germplasm (Table 13).[14] More than 50% of the materials known to contain CIMMYT germplasm (Classes 2, 3, and 4 in Table 13) were characterized as Class 2 materials (containing some CIMMYT germplasm), suggesting that national programs use CIMMYT germplasm mainly as a basis for further improvement, combining it with other materials to develop OPVs and hybrids adapted to local conditions. Only 14% of the materials known to contain CIMMYT germplasm were characterized as Class 4 materials (containing 100% CIMMYT germplasm); in some cases, these materials were released under the names used at CIMMYT.

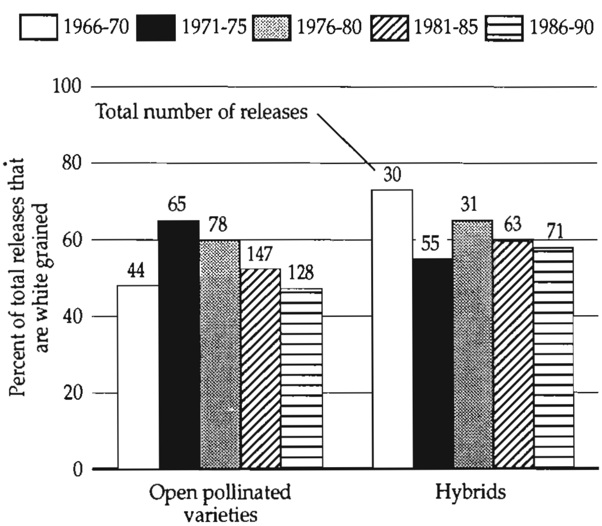

Figure 8. Trends in white maize releases by public NARSs, by type of germplasm, 1966-90.

Table 12. Commercial success rate of maize varieties and hybrids released, by type of material, ecological adaptation, and origin of germplasm, 1966-90

	Success rate (%)	Total number of releases
By ecology		
Lowland tropics	44	441
Subtropical, mid-altitude, highland	38	374
By type		
Open pollinated varieties	40	535
Hybrids	43	280
By origin of germplasm		
Non-CIMMYT origin	40	378
CIMMYT origin	42	437

Source: CIMMYT maize varietal releases database.

[14] Since information provided on individual varieties is sometimes incomplete, slight discrepancies may occur between tables, depending on the total number of varieties for which information on specific variables is available.

The data in Table 13 indicate that CIMMYT germplasm has made a large impact in the developing world's three most important maize-producing regions, appearing in 44% of releases in sub-Saharan Africa, 57% of releases in Asia, and 59% of releases in Latin America. The use of CIMMYT germplasm has been somewhat more modest in West Asia and North Africa, where only 36% of releases were classified as containing CIMMYT germplasm.[15] These aggregate figures conceal great variation among individual countries. The percentage of releases containing CIMMYT germplasm ranges all the way from 0% in Uganda to 100% in Thailand, southern China, Costa Rica, El Salvador, Honduras, and Ecuador. Use of CIMMYT germplasm does not appear to be related to the size of the national area planted to maize, indicating that it has been used by small as well as large national programs.

Characteristics of CIMMYT-derived materials — The use of CIMMYT germplasm by NARS breeders has been much higher in tropical lowland environments, where CIMMYT has traditionally focused its maize breeding efforts (Table 14). Fully 75% of the public maize releases adapted to tropical lowlands contain CIMMYT germplasm, compared to only 28% of public maize releases adapted to the other non-temperate environments. The relative lack of penetration of CIMMYT germplasm in the subtropical, mid-altitude, and highland production environments can be attributed to greater competition in the supply of germplasm adapted to these cooler environments (for example, breeders working in subtropical and mid-altitude environments often obtain 50% or more of their source material directly from the US Corn Belt). The varying extent to which CIMMYT germplasm appears

Table 13. Maize varieties and hybrids released in developing countries, by origin of germplasm, 1966-90

Region	No CIMMYT (Class 1)	Some CIMMYT (Class 2)	Mostly CIMMYT (Class 3)	All CIMMYT (Class 4)	Total number of releases
	(% of regional total)				
Sub-Saharan Africa	56	20	12	12	290
West Asia and North Africa	64	32	4	0	28
South, East, and Southeast Asia	43	38	5	14	182
Latin America	41	27	16	16	342
All developing countries	**47**	**27**	**12**	**14**	**842**
Number of releases	**397**	**227**	**102**	**116**	

Source: CIMMYT maize varietal releases database.
Note: See Appendix B for definitions of germplasm classes.

Table 14. Ecological adaptation of maize varieties and hybrids containing CIMMYT germplasm, 1966-90

Region	Tropical lowland materials containing CIMMYT germplasm		Subtropical, mid-altitude, highland materials containing CIMMYT germplasm	
	Number of releases	Percent of total	Number of of releases	Percent of total
Sub-Saharan Africa	108	73	20	14
West Asia and North Africa	..	..	10	36
South, East, and Southeast Asia	56	73	48	46
Latin America	171	77	32	27
All developing countries	**335**	**75**	**110**	**28**

Source: CIMMYT maize varietal releases database.

[15] Only two countries in West Asia and North Africa (Egypt and Morocco) were included in the survey, which explains the low number of releases reported in this region.

in public releases in different environments is also apparent in the absolute number of releases: 335 for the lowland tropics compared to 110 for the other three environments.

The number of releases containing CIMMYT germplasm accelerated in all environments in the 1980s (Figure 9). Materials with CIMMYT germplasm were released at an average rate of 34 per year in the 1980s (25 for the lowland tropics and nine for the other environments), compared to an average of eight per year in the 1970s (six for tropical lowlands and two for other environments). Given the substantial lag between release of a variety and peak adoption, this suggests that public releases containing CIMMYT germplasm have yet to reveal their full impact in farmers' fields.

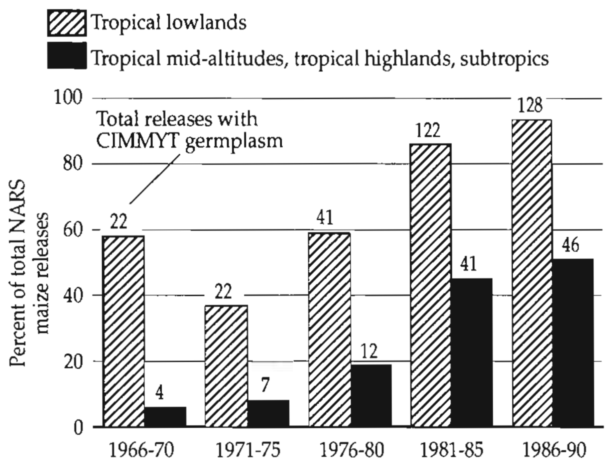

Figure 9. Public maize releases containing CIMMYT germplasm, by ecology, 1966-90.

CIMMYT germplasm has been used extensively to develop OPVs. Over three-quarters of all public releases containing CIMMYT germplasm have been OPVs (Table 15). This suggests that CIMMYT germplasm is particularly well suited for the development of OPVs, which is perhaps not surprising considering that CIMMYT breeders concentrated almost exclusively on OPVs until the late 1980s.

The grain color of releases containing CIMMYT germplasm closely resembles the patterns in white- and yellow-grained releases in the overall data set (Table 16). In other words, among materials containing CIMMYT germplasm, neither white nor yellow germplasm has been disproportionately successful.

Table 15. Maize releases containing CIMMYT germplasm, by type (open pollinated varieties or hybrids), 1966-90

	OPVs containing CIMMYT germplasm		Hybrids containing CIMMYT germplasm	
Region	Number of releases	Percent of total	Number of releases	Percent of total
Sub-Saharan Africa	105	58	23	21
West Asia and North Africa	2	50	8	33
South, East, and Southeast Asia	91	64	13	32
Latin America	140	64	63	51
All developing countries	**338**	**62**	**107**	**36**

Source: CIMMYT maize varietal releases database.

Table 16. Grain color of maize releases containing CIMMYT germplasm, 1966-90

	White materials containing CIMMYT germplasm		Yellow materials containing CIMMYT germplasm	
Region	Number of releases	Percent of total	Number of releases	Percent of total
Sub-Saharan Africa	81	57	31	55
West Asia and North Africa	9	53	1	11
South, East, and Southeast Asia	19	54	74	55
Latin America	122	58	68	64
All developing countries	**231**	**57**	**174**	**57**

Source: CIMMYT maize varietal releases database.

Historical trends in the release of CIMMYT-derived materials — Table 17 presents data on the numbers of CIMMYT-derived materials that have been released, expressed as percentages of all varieties and hybrids released during 1966-90, and Figure 10 illustrates historical trends in the percentage of public releases (OPVs and hybrids) by the extent to which CIMMYT germplasm was used in their development. The considerable time lags involved in plant breeding are evident. Among materials released in the first decade after CIMMYT's founding, few contained CIMMYT germplasm. (However, the proportion of releases containing CIMMYT germplasm was actually quite high in certain production environments: for example, about half of the varieties released for tropical lowlands during 1966-76 contained CIMMYT germplasm.) As CIMMYT began to offer a more complete range of improved germplasm, CIMMYT materials were gradually picked up by breeders in national programs, and CIMMYT germplasm appeared with increasing frequency in national program releases.[16] Meanwhile, many national breeding programs strengthened their breeding capacity and the composition of releases evolved. Subsequent periods show an increasing proportion of hybrids released (Figure 11). In 1986-90, almost 60% of all public hybrids released contained CIMMYT germplasm, compared to only 11% in 1971-75.

Table 17. Trends in maize releases containing CIMMYT germplasm, 1966-90

Period	Total number of public releases	Releases with CIMMYT germplasm	
		Number	Percent of total
1966-70	100	26	26
1971-75	146	29	20
1976-80	134	53	40
1981-85	233	163	70
1986-90	229	174	76
1966-90	**842**	**445**	**53**

Source: CIMMYT maize varietal releases database.

Breeding activities undertaken at CIMMYT during the past two-and-a-half decades continue to make an impact, as evidenced by an ever-increasing number of public releases containing CIMMYT germplasm. During the most recent period of analysis (1986-90), 174 public varieties and hybrids released in developing countries contained CIMMYT germplasm, over three-fourths of the 229 public materials released during that period (Table 17).

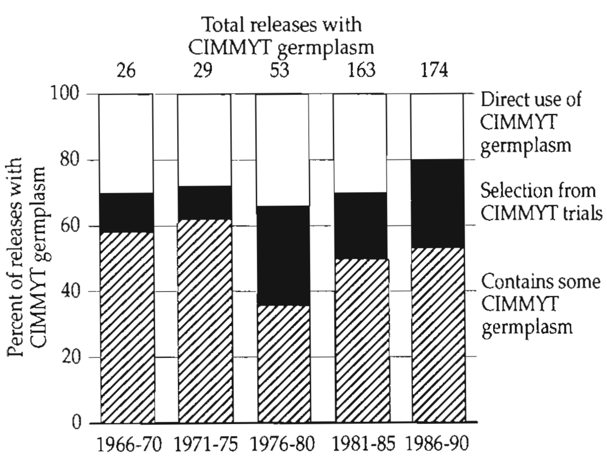

Figure 10. Public maize releases containing CIMMYT germplasm, 1966-90.

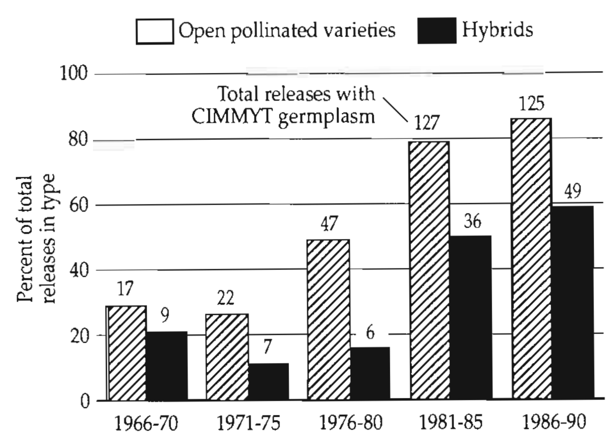

Figure 11. Public maize releases containing CIMMYT germplasm, by type of germplasm, 1966-90.

[16] The fact that the CIMMYT Maize Program grew during the 1970s and 1980s no doubt also contributed to the increasing proportion of releases containing CIMMYT germplasm.

Importance of the strength of national programs — To determine whether the use of CIMMYT germplasm has varied depending on the strength of local maize breeding capacity, the countries responding to the survey were subjectively divided into two groups, relatively strong and relatively weak national breeding programs.[17] As expected, countries considered to have strong breeding programs have made less direct use of CIMMYT germplasm (reflected in a lower proportion of Class 4 releases), while countries with weaker breeding programs have relied much more heavily on direct use of CIMMYT germplasm (a higher proportion of Class 4 releases) (Table 18). If the countries with the five strongest and the five weakest national programs are compared, the differences are more marked (Figure 12). Upon receiving CIMMYT source germplasm, countries with strong national breeding programs are much more likely to do further selection and/or crossing, whereas countries with weaker programs tend to release varieties or hybrids containing CIMMYT germplasm with little additional improvement. NARSs with strong breeding programs also tend to use CIMMYT germplasm more intensively, as

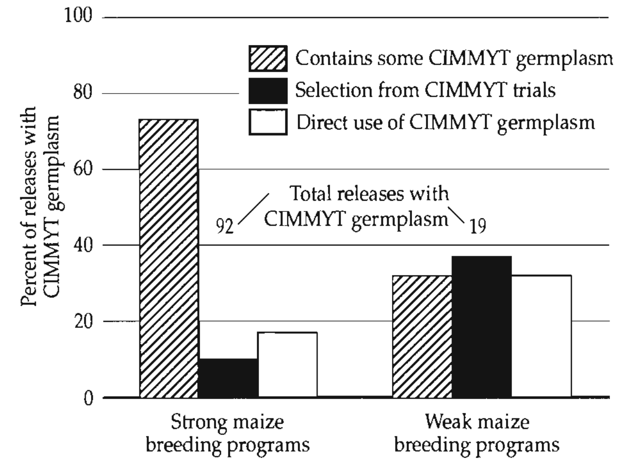

Figure 12. Public maize releases containing CIMMYT germplasm, by strength of breeding programs, 1966-90.

Table 18. Trends in the use of CIMMYT germplasm, by strength of national breeding program, 1966-90

	Percent of releases containing some CIMMYT germplasm (Class 2)	Percent of releases containing mostly CIMMYT germplasm (Class 3)	Percent of releases containing only CIMMYT germplasm (Class 4)	Number of releases (Classes 2-4)
Countries with strong maize breeding programs				
1966-70	57	7	36	14
1971-75	60	13	27	15
1976-80	38	42	21	24
1981-85	61	15	24	110
1986-90	65	22	13	80
1966-90	**60**	**19**	**21**	**243**
Countries with weak maize breeding programs				
1966-70	58	16	25	12
1971-75	64	7	29	14
1976-80	34	21	45	29
1981-85	28	32	40	53
1986-90	44	31	26	94
1966-90	**41**	**27**	**32**	**202**
All countries, 1966-90	**51**	**23**	**26**	**445**

Source: CIMMYT maize varietal releases database.
Note: Classification of national maize breeding programs based on subjective assessment by CIMMYT Maize Program staff (see text).

[17] The definitions were based on the number, educational level, and experience of the maize breeders working in the national program; the research resources available per researcher; and the number of commercially successful varieties and hybrids released by the program.

indicated by the number of releases with CIMMYT germplasm. Finally, hybrids constitute a greater proportion of the total releases by NARSs with strong maize breeding programs (Figure 13). As noted earlier, the clear decline in the proportion of hybrids released during the late 1960s and early 1970s, followed by the upward trend during the 1980s, reflects the changes in emphasis on hybrid development in national programs and at CIMMYT.

Patterns in Materials Released by Private Companies

CIMMYT strives to maintain a policy of free distribution for its germplasm, meaning that all requests for materials are met, regardless of whether these requests emanate from public breeding programs or private companies. However, if supplies are limited, first priority is given to requests from public sector institutions in developing countries. In practice, sufficient germplasm is normally available to fill all requests. Since many private seed companies routinely screen CIMMYT materials, this means that a considerable amount of CIMMYT germplasm makes its way into the private sector.

In the past, use of CIMMYT germplasm by private seed companies has not been well documented, partly because seed companies have not been considered priority clients for CIMMYT and partly because seed companies are reluctant to disclose pedigrees of proprietary materials (disclosure provides important information to potential competitors). More recently, a growing appreciation of the private sector's role in disseminating improved germplasm has encouraged efforts to monitor private seed companies' use of CIMMYT maize germplasm. CIMMYT is seeking to identify the major seed companies operating in its mandate regions, especially companies with active maize breeding programs. Once these companies are identified, they will be contacted about their use of CIMMYT materials so that the varietal database can be more complete.

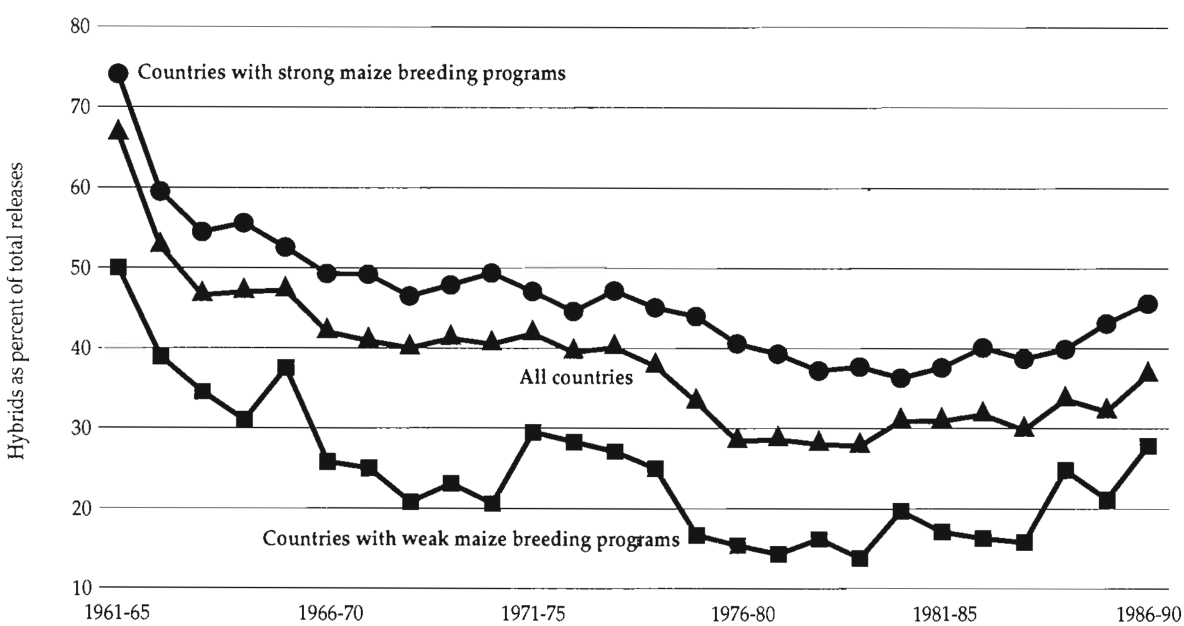

Figure 13. Hybrids as a percentage of all public maize releases in developing countries, by strength of maize breeding programs, five-year moving averages, 1961-90.

To gain a preliminary impression of the extent to which CIMMYT germplasm is used by private seed companies, as part of the 1990 survey a brief questionnaire was distributed to approximately 50 seed companies that had requested seed from CIMMYT in recent years. The questionnaire did not solicit detailed information on pedigrees; instead, it requested general information on how much CIMMYT germplasm was used (see Appendix B). Twenty-nine companies responded to the questionnaire, and Table 19 summarizes the information they provided on the source germplasm constituting their commercial releases. Due to the non-random and incomplete nature of the sample, the data presented in Table 19 may not be representative of the materials released by all seed companies.

Of the 201 proprietary hybrids developed by the companies responding to CIMMYT's survey, 35% contained CIMMYT germplasm. While this number is lower than the equivalent number for public sector releases (53%), it is still significant, especially since many of the companies reporting extensive use of CIMMYT germplasm are located in the largest maize-producing countries in the developing world (e.g., Brazil, India, the Philippines, and Mexico). Based on this limited sample, private sector use of CIMMYT germplasm appears to be highest in Asia (55%) and somewhat more modest in Latin America (28%).[18] Caution should be exercised in interpreting these regional figures, however, because they are likely to be biased.[19]

Table 19. Private company maize releases containing CIMMYT germplasm

Region and country (period covered)	Number of companies responding	Number of maize releases	Number of releases containing CIMMYT germplasm	Percent of releases containing CIMMYT germplasm
Sub-Saharan Africa	**1**	**2**	**0**	**0**
Nigeria (1990)	1	2	0	0
Asia	**10**	**58**	**32**	**55**
India (1971-90)	4	27	14	52
Indonesia (1985)	1	1	1	100
Pakistan (1991)	1	1	1	100
Philippines (1980)	1	9	4	44
Thailand (1981-85)	3	20	12	60
Latin America	**18**	**141**	**39**	**28**
Argentina (1968-84)	3	26	1	4
Brazil (1960-82)	4	46	18	39
Colombia (1979-81)	3	6	0	0
Mexico (1959-80)	4	49	16	33
Peru (1976)	1	5	0	0
Venezuela (1979-90)	3	9	4	44
Total	**29**	**201**	**71**	**35**

Source: CIMMYT maize varietal releases database.

[18] Only one African company responded, so it is impossible to generalize about Africa.

[19] For example, since only a handful of private companies in Africa support breeding programs, few have developed proprietary hybrids; rather, most private companies in Africa still concentrate on producing and distributing seed of varieties and hybrids developed by the public sector (López-Pereira and Filippello 1994). For most countries the number of private companies with breeding programs is higher than the number reported here. In addition, the period covering the reported releases varies across countries, and many companies failed to report recent releases. These factors indicate that many private sector materials are not included in this analysis.

CHAPTER 4

EVIDENCE OF IMPACTS AT THE FARM LEVEL

For practical purposes, the easiest way to measure a plant breeding program's impact is to estimate the incremental production resulting from farmers' use of improved germplasm developed by the program. Incremental production is conventionally measured by calculating the area planted to improved materials and multiplying this area by the average yield gain realized by farmers when they switch from their previous variety to an improved variety or hybrid. This chapter presents estimates of the area planted to improved maize varieties and hybrids in the developing world and reviews the available evidence on the size of the yield gains associated with adoption.

Before estimates of the area planted to improved maize varieties and hybrids are presented, a caveat is necessary concerning the quality of the data. Because of the tremendous diversity in maize production environments and the many different kinds of maize-based farming systems, it is difficult to estimate with precision the area planted to improved maize. The problem is compounded by the fact that it is often very difficult to identify improved germplasm in the field. When improved maize is introduced into areas where unimproved maize is grown, mixtures often result, and it is not always possible to distinguish between the two. Many so-called "unimproved local" materials may include substantial amounts of improved germplasm, which implies that conventional estimates of the area planted to improved varieties may understate the true extent (and impact) of the use of improved germplasm. The estimates reported in this study are based on conservative, conventional estimation procedures, and thus the impacts of CIMMYT's and NARSs' breeding efforts are likely to be underestimated, not overestimated.

ADOPTION OF ALL IMPROVED MATERIALS

Respondents to the 1990 survey provided estimates of the area planted to improved varieties and hybrids in 1990. Since few formal studies have been done of the adoption of maize varieties, particularly at the national level and for specific varieties, in many cases survey respondents found it necessary to make subjective estimates of the area planted to individual varieties or hybrids. Typically these estimates were based partially on survey data and partially on seed sales data, often complemented by direct observation of farmers' fields.[20] Table 20 presents data on the estimated non-temperate maize area planted in 1990 to improved varieties and hybrids released by national programs and private companies. Overall, of the 57.7 million hectares planted to maize in 1990 in the countries covered by the survey,[21] an estimated 24.6 million hectares (43%) were planted to improved varieties and hybrids. This is a significant increase over the equivalent figure for 1985-86, when it was estimated that 28% of the developing world's maize area was planted to improved materials (CIMMYT 1986, Timothy, Harvey, and Dowswell 1988).

The fact that 25 million hectares of non-temperate maize were planted in 1990 to improved varieties and hybrids represents no small achievement and testifies to the effectiveness of global maize improvement efforts.

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[20] While formal survey data would of course have been preferable, the estimates presented here are believed to be reasonably accurate.

[21] These countries represent over 95% of the non-temperate maize area in the developing world.

It is nevertheless sobering to note that the use of unimproved local maize varieties remains extensive in many developing countries. In 1990, approximately 57% of the developing world's non-temperate maize area was still planted to unimproved local materials, a significantly higher percentage than the equivalent estimates for wheat (30%) and rice (41%) (Byerlee 1993). The finding that well over half of the non-temperate maize area in developing countries has yet to benefit from international breeding efforts highlights the significant challenge facing researchers, extension agents, and policy makers in moving improved germplasm into farmers' fields.

In addition to showing the extensive use of improved maize materials throughout the developing world, the data presented in Table 20 highlight differences in the relative importance of public and private research organizations in the development of improved maize germplasm. Of the 24.6 million hectares of non-temperate maize area planted to improved varieties in 1990, 19.9 million hectares (81%) were under materials developed by public breeding programs, while only 4.6 million hectares (19%) were under hybrids developed by private companies. At the global level, these figures point to the dominance of public maize breeding programs in developing countries up to 1990.

The aggregate data on the diffusion of improved maize varieties and hybrids conceal considerable variability among regions and countries (for a complete listing by country, see Appendix D). In Latin America, 43% of the 1990 non-temperate maize area was planted to improved materials; of this area, 60% was under public varieties and hybrids. Public sector releases in Latin America were grown almost exclusively in the Central American countries, whereas proprietary hybrids accounted for a significant proportion of the maize area in Brazil (49% of the maize area planted to improved materials), Colombia (45%), Peru (33%), and Ecuador (25%). Proprietary hybrids were also common in Mexico, where seed regulations introduced in the late 1980s meant that an increasing share of the improved maize area was planted to private sector hybrids (López-Pereira and García 1994). In sub-Saharan Africa, 42% of the 1990 maize area was planted to improved materials; virtually all of this area was under public materials. Private sector materials were grown in very few African countries (e.g., Côte d'Ivoire, Malawi). In Asia, improved materials covered 43% of the 1990 maize area; of this, over 90% was under public materials. No private sector releases were grown in Myanmar, Nepal, Pakistan, China, Taiwan, and Vietnam, whereas proprietary releases accounted for about 15% of the improved maize area in India, Thailand, Indonesia, and the Philippines.

Table 20. Non-temperate maize area planted to improved varieties and hybrids in developing countries, by region, 1990

Region	Maize area, 1990 (million ha)	Area under public sector materials		Area under private sector materials		Total area under improved maize	
		(million ha)	(%)	(million ha)	(%)	(million ha)	(%)
Sub-Saharan Africa	14.4	5.9	41	0.1	0[a]	6.0	42
West Asia and North Africa	1.2	0.6	47	0.0	0	0.6	47
South, East, and Southeast Asia	19.0	7.5	39	0.8	4	8.2	43
Latin America	23.1	5.9	26	3.9	17	9.9	43
Total	**57.7**	**19.9**	**35**	**4.7**	**8**	**24.6**	**43**

Source: CIMMYT Maize Research Impacts Survey.
[a] Less than 0.5%.

Adoption by ecological adaptation and type of material — Although improved maize materials cover a larger absolute area in lowland tropical production environments (13.9 million hectares) than they do in subtropical, mid-altitude, and highland production environments combined (10.7 million hectares), the impact of these materials is similar in the sense that they cover about 40% of the maize area in each ecology. However, while the proportion of maize area planted to improved materials is similar across ecologies, the types of materials being grown differ. In lowland tropical environments, the area planted to improved materials tends to be under OPVs, while in the other three environments the area planted to improved materials is mostly under hybrids (Table 21). This pattern does not necessarily prevail, however, within individual regions. In sub-Saharan Africa, OPVs dominate the improved maize area in lowland tropical environments and hybrids are dominant in other environments, but in Asia all environments are dominated by OPVs, and in Latin America hybrids clearly dominate in all environments. In West Asia and North Africa, where there are no lowland tropical production environments, OPVs dominate the improved maize area (Table 21).

Rate of varietal replacement in farmers' fields — In examining varietal adoption patterns, it is important to note not only the extent to which improved OPVs and hybrids have been adopted, but also the rate at which farmers replace improved materials. Farmers need to replace improved materials regularly to take advantage of the increased genetic potential of newer materials, as well as to avoid yield declines resulting from loss of resistance to diseases and pests in older materials.

For any given area, the rate of varietal replacement can be measured by estimating the weighted average age (WAVA) of all materials grown at a particular time. The WAVA is calculated as the average age since the materials were released, weighted by the area planted to each material (Brennan and Byerlee 1991). Subject to certain restrictive assumptions, the WAVA can be used to gauge the rate at which a country's breeding program develops and releases varieties, as well as the rate with which new releases replace older releases in farmers' fields. *Ceteris paribus*, a high WAVA indicates that many of the materials grown by farmers are older (implying a low rate of varietal replacement), while a low WAVA indicates that many of the materials being grown are newer materials (implying a high rate of varietal replacement).

It should be noted, however, that the interpretation of WAVAs is not always straightforward. Although a high WAVA usually indicates that a breeding program has been

Table 21. Area planted to improved maize varieties and hybrids, by ecology and type of material, 1990

Region	Lowland tropics			Subtropical, mid-altitude, highland ecologies		
	Total improved maize area (million ha)	Percent area sown to: OPVs	Percent area sown to: Hybrids	Total improved maize area (million ha)	Percent area sown to: OPVs	Percent area sown to: Hybrids
Sub-Saharan Africa	2.4	96	4	3.6	18	82
West Asia and North Africa	0.0	..	..	0.6	85	15
South, East, and Southeast Asia	5.7	74	26	2.5	63	37
Latin America	5.8	38	62	4.1	3	97
All developing countries	**13.9**	**63**	**37**	**10.7**	**26**	**74**

Source: CIMMYT Maize Research Impacts Survey.

unsuccessful at developing new improved OPVs and hybrids that clearly outperform older materials, a high WAVA can also arise when the national program "recycles" materials by introducing new germplasm into existing seed stocks, so that a variety or hybrid retains its name though it is genetically different. (This is more likely to occur with improved OPVs, which may be improved periodically and released several times under the same name).[22] Similarly, although a low WAVA usually indicates a high rate of varietal replacement (suggesting that the national program has successfully developed and promoted improved OPVs and hybrids), a low WAVA can also arise when farmers have only recently adopted improved materials for the first time.

Although WAVAs for maize in developing countries have not been estimated, WAVAs calculated for wheat would lead us to expect a minimum of 10 years, given normal lags in seed multiplication and adoption by farmers (Brennan and Byerlee 1991, Byerlee and Moya 1993).

For this study, WAVAs were calculated separately for improved OPVs and hybrids. As of 1990, there was still a substantial area under old OPVs, resulting in an overall WAVA for OPVs of 10 years for the sample as a whole (Table 22). Considerable differences can be observed between countries. Virtually all of the largest maize producing countries fall in the range of 5-15 years, while smaller countries tend to have somewhat lower WAVAs for OPVs. Many countries in Latin America and West Africa have WAVAs for OPVs of less than 10 years, indicating either that effective public breeding programs and extension services are fostering relatively rapid varietal turnover or that improved OPVs have only recently been adopted for the first time.

Table 23 presents data on the WAVAs for hybrids. As of 1990, there was still a substantial area under old hybrids, resulting in a WAVA for hybrids of 11 years for the sample as a whole. This figure is rather surprising; one would expect the overall WAVA for hybrids to be lower than the overall WAVA for OPVs, since hybrid seed has to be replaced annually (which should encourage

Table 22. Weighted average age (WAVA) for improved open pollinated varieties of maize planted in developing countries in 1990

Age (years)	Country
0 - 5	Burundi, Benin, Côte d'Ivoire, Togo, Vietnam, Costa Rica, El Salvador, Nicaragua, Venezuela
> 5 - 10	Mozambique, Tanzania, Zambia, Burkina Faso, Cameroon, Ghana, Egypt, India, Nepal, Philippines, Southern China, Mexico, Bolivia, Colombia, Ecuador, Peru, Brazil
> 1 - 15	Mali, Nigeria, Senegal, Zaire, Myanmar, Indonesia, Thailand
> 15 - 20	Ethiopia, Kenya, Malawi, Uganda, Morocco, Pakistan, Guatemala, Honduras

Source: CIMMYT maize varietal releases database, Maize Research Impacts Survey.
Note: The overall WAVA for OPVs is 10 years.

Table 23. Weighted average age (WAVA) for maize hybrids planted in developing countries in 1990

Age (years)	Country
0 - 5	Ethiopia, Malawi, Burkina Faso, Côte d'Ivoire, Egypt, Indonesia, Costa Rica, Nicaragua, Ecuador, Brazil
> 5 - 10	Kenya, Zambia, Togo, Southern China, Taiwan, Guatemala, Honduras, Mexico, Colombia, Venezuela
> 10 - 15	Mozambique, Tanzania, Peru
> 15 - 20	Zimbabwe, Zaire, Colombia
> 20	India, El Salvador

Source: CIMMYT maize varietal releases database, Maize Research Impacts Survey.
Note: Overall WAVA for hybrids is 11 years.

22 This probably explains the high WAVAs for hybrids and OPVs in some countries where a small number of improved OPVs (Thailand, Guatemala) and hybrids (Zimbabwe, India, El Salvador) have been used for many years.

more frequent replacement of older hybrids with newer hybrids). At the level of individual countries, patterns in WAVAs for hybrids are less obvious. The WAVAs for hybrids are surprisingly high in many countries considered to have strong breeding programs. The extreme cases are India and El Salvador, where hybrids released 20 or more years ago are still widely used. Exceptionally high WAVAs for hybrids reflect the continuing dominance of one or two "super hybrids" which have remained popular for more than two decades. In Brazil, the WAVA for hybrids is very low (3 years), presumably owing to the presence of a highly competitive private seed sector with strong breeding programs, which have actively developed and promoted hybrids.[23] In Burkina Faso and Malawi, the WAVAs for hybrids are relatively low because efforts to promote hybrids began quite recently, and the hybrids grown there are all relatively new.

Table 24 compares the WAVAs for improved OPVs and hybrids grown in 1990, classified according to whether or not they contain CIMMYT germplasm. Most of the area under materials that do not contain CIMMYT germplasm was under very old releases, reflecting the growing influence of CIMMYT germplasm in recent releases, as well as the increased popularity of these releases. With the exception of hybrids in Latin America, the overall WAVAs for OPVs and hybrids that do not contain CIMMYT germplasm exceeded 10 years, whereas the WAVAs for OPVs and hybrids containing CIMMYT germplasm were 8.6 and 7.8 years, respectively. In sub-Saharan Africa and in West Asia and North Africa, the very low WAVAs for hybrids that contain CIMMYT germplasm reflect the recent introduction of CIMMYT materials in these regions.

Adoption of CIMMYT-derived Materials

Of the 24.6 million hectares planted in 1990 to improved varieties and hybrids, at least 13.5 million hectares (55%) were planted to materials containing CIMMYT germplasm (Table 25). This figure almost certainly understates the area planted to CIMMYT-derived materials, since the use of CIMMYT germplasm by private companies remains unknown.[24] Even without fully accounting for the use of CIMMYT germplasm in proprietary hybrids, it is impressive that well over half the area under improved maize varieties and hybrids in the developing world in 1990 was planted to materials containing at least some CIMMYT germplasm.

Table 24. Weighted average ages (WAVAs) for maize varieties and hybrids planted in 1990 in developing countries, by origin of germplasm

	WAVAs of materials containing no CIMMYT germplasm		WAVAs of materials containing CIMMYT germplasm	
Region	OPVs (yr)	Hybrids (yr)	OPVs (yr)	Hybrids (yr)
Sub-Saharan Africa	15.7	11.5	8.5	1.7
West Asia and North Africa	22.0	..	9.8	3.2
South, East, and Southeast Asia	16.0	20.4	8.9	5.6
Latin America	14.4	7.7	7.8	8.4
Overall	**15.8**	**12.2**	**8.6**	**7.8**

Source: CIMMYT maize varietal releases database, Maize Research Impacts Survey.
Note: Overall average age of OPVs is 10 years; hybrids, 11 years.

[23] Brazil's public breeding program has also promoted hybrids.
[24] For some countries it was possible to obtain estimates of area under proprietary materials that contain CIMMYT germplasm, notably Mexico, Brazil, India, and Thailand.

At the individual country level, the impact of CIMMYT germplasm varies considerably (see Appendix D). As of 1990, none of the public materials used in Malawi, Uganda, or Zimbabwe contained CIMMYT germplasm; in contrast, CIMMYT germplasm was present in all public materials used in Madagascar, Côte d'Ivoire, Senegal, Egypt, Nepal, Thailand, Vietnam, Ecuador, and all the countries in Central America.

Adoption by ecological adaptation and type of material — CIMMYT germplasm has had its greatest impact in the lowland tropics. Of 13.5 million hectares planted to CIMMYT-based materials in 1990, 10.2 million hectares were located in lowland tropical environments (Table 26). The use of CIMMYT germplasm has been more modest in the other three environments. The extensive use of CIMMYT-derived materials in the lowland tropics does not merely reflect the relatively large size of this production environment; CIMMYT-derived materials were planted on a greater proportion of total improved maize area in the lowland tropics than in the other ecologies.

Table 25. Area planted to maize containing CIMMYT germplasm, 1990

	Area under public materials containing CIMMYT germplasm		Area under private materials containing CIMMYT germplasm		Area under all materials containing CIMMYT germplasm	
Region	**(million ha)**	**(%)**	**(million ha)**	**(%)**	**(million ha)**	**(%)**
Sub-Saharan Africa	2.0	34	0.0 [a]	3	2.0	33
West Asia and North Africa	0.5	96	0.0	0	0.5	96
South, East, and Southeast Asia	5.0	67	0.3	43	5.3	65
Latin America	4.6	77	1.1	28	5.7	58
All developing countries	**12.1**	**61**	**1.4**	**30**	**13.5**	**55**

Source: CIMMYT Maize Research Impacts Survey.
[a] Less than 50,000 ha.

Table 26. Area planted to maize containing CIMMYT germplasm, by production ecology, 1990

Ecology	Sub-Saharan Africa	West Asia and North Africa	South, East, and Southeast Asia	Latin America	Total
Tropical lowlands					
Million ha	1.8	..	4.1	4.4	10.2
Percent of improved maize area	74	..	71	75	74
Tropical mid-altitudes					
Million ha	0.2	..	0.1	0.1	0.3
Percent of improved maize area	6	..	46	27	9
Tropical highlands					
Million ha	0.0 [a]	..	0.0 [a]	0.1	0.1
Percent of improved maize area	2	..	100	73	22
Subtropics					
Million ha	0.0 [a]	0.5	1.2	1.2	2.9
Percent of improved maize area	77	96	49	32	43
Regional totals					
Million ha	**2.0**	**0.5**	**5.3**	**5.7**	**13.5**
Percent of improved maize area	**33**	**96**	**65**	**58**	**55**

Source: CIMMYT Maize Research Impacts Survey.
[a] Less than 50,000 ha.

The considerable impact of CIMMYT-derived materials in lowland tropical environments has resulted in large part from the success of the Tuxpeño germplasm complex, a set of materials that trace a common ancestry to the Mexican landrace Tuxpeño. Developed during many hundreds of years of selection by farmers in eastern Mexico, Tuxpeño is believed to have resulted from the hybridization of two other landraces, Olotillo and Tepecintle (CIMMYT Maize Staff 1986). A white dent material, Tuxpeño is distinguished by its tallness (averaging 3-4 m), its good resistance to ear rots and foliar diseases, and its inherent disposition to respond to high fertility (Morris, Clancy, and López-Pereira 1992, CIMMYT Maize Staff 1986). The Mexican national research system and the CIMMYT Maize Program have developed many improved populations and pools using Tuxpeño sources. Population 21 (Tuxpeño 1), Population 43 (La Posta), Population 49 (Blanco Dentado-2), Population 63 (Tuxpeño O2), and Population 75 (Tuxpeño Sequía) were all developed directly from advanced cycles of improvement of the Tuxpeño race. Many other populations at CIMMYT contain lesser amounts of Tuxpeño. Several CIMMYT populations containing Tuxpeño germplasm have been used by IITA in Nigeria; the popular populations TZPB and TZPB-SR, developed directly from Tuxpeño germplasm, have been used extensively by many NARSs in sub-Saharan Africa.

According to the CIMMYT Global Maize Impacts Survey, 255 varieties and hybrids released in developing countries between 1966 and 1990 contain Tuxpeño germplasm. Of these, 152 varieties and hybrids contain at least one of the populations directly derived from Tuxpeño. The countries with the largest number of released varieties and hybrids containing Tuxpeño germplasm are Guatemala (20 releases), Nigeria (12), Honduras (12), Venezuela (11), and Mexico (10). The use of these materials has been extensive. In 1990, about 4.4 million hectares in 34 countries were planted to varieties and hybrids containing CIMMYT germplasm derived from the Tuxpeño race. Countries with the largest area under Tuxpeño-derived materials in 1990 included Mexico (0.8 million hectares), Brazil (0.6 million hectares), Nigeria (0.5 million hectares), Egypt (0.4 million hectares), and Venezuela (0.4 million hectares). The regions with the largest area under Tuxpeño-derived materials were Latin America (2.4 million hectares) and sub-Saharan Africa (1 million hectares).

In sub-Saharan Africa and Asia, the area planted to improved materials containing CIMMYT germplasm tends to be under OPVs, whereas in Latin America, the area planted to CIMMYT-derived materials tends to be under hybrids (this pattern is consistent with the generally greater use of hybrids in Latin America) (Table 27). These data once again illustrate how public breeding programs working on materials for lowland tropical environments have emphasized OPVs and have made greater use of CIMMYT germplasm, whereas breeding programs working on the other three environments have emphasized hybrids and have made less use of CIMMYT germplasm.

Lags in adoption — When the area planted in 1990 to OPVs and hybrids containing CIMMYT germplasm is disaggregated by their date of release, the time lag associated with the adoption of improved materials is apparent (Table 28). In 1990, the greatest proportion of area was planted to OPVs and hybrids released during 1981-85, indicating that adoption of materials released 5-10 years earlier was at or near peak levels. The area planted to OPVs and hybrids released during 1986-90 was somewhat smaller, indicating that adoption of these newer materials had not yet peaked by 1990. Finally, area under OPVs and hybrids released before 1970 was very small, a sign that farmers had already replaced these older materials.

Adoption of materials containing CIMMYT germplasm: selected examples — Aggregate data such as those summarized above provide important quantitative measures of the overall impacts of international maize breeding efforts. However, despite their obvious usefulness, aggregate data are finally limited in the sense that they provide little or no detailed information about the forces determining farm-level impacts of improved germplasm. Underlying the macro-level statistics on varietal releases and area planted to improved materials are countless individual stories about what actually happens when improved OPVs and hybrids are developed and released. Valuable insights into the forces influencing the success of international maize breeding efforts can be gained only by examining specific case studies to understand the factors that have led to the successful adoption of improved materials in some instances and to their rejection in others.

Table 27. Area planted to maize containing CIMMYT germplasm, by production ecology and type of material, 1990

Production ecology and type of material	Sub-Saharan Africa	West Asia and North Africa	South, East, and Southeast Asia	Latin America	Total
Lowland tropics					
Improved OPVs (000 ha)	1.8	..	3.5	2.1	7.3
Percent improved OPV area	75	..	83	93	83
Hybrids (000 ha)	0.0 [a]	..	0.6	2.3	2.9
Percent hybrid area	40	..	40	64	57
Subtropics and mid-altitude and highland environments					
Improved OPVs (000 ha)	0.2	0.5	1.0	0.1	1.7
Percent improved OPV area	23	95	64	94	61
Hybrids (000 ha)	0.1	0.1	0.2	1.2	1.6
Percent hybrid area	2	100	25	31	20
Total					
Improved OPVs (000 ha)	1.9	0.5	4.5	2.2	9.0
Percent improved OPV area	64	95	78	93	78
Hybrids (000 ha)	0.1	0.1	0.8	3.5	4.5
Percent hybrid area	3	100	34	47	34

Source: CIMMYT Maize Research Impacts Survey.
[a] Less than 50,000 ha.

Table 28. Area planted in 1990 to maize varieties and hybrids containing CIMMYT germplasm, by release date

	Area (million ha) planted in 1990 to CIMMYT-derived materials				
Period of release	Sub-Saharan Africa	West Asia and North Africa	South, East and Southeast Asia	Latin America	Total
1966-70	0.0[a]	0.0[a]	0.0[a]	0.3	0.3
1971-75	0.2	0.0[a]	1.0	0.3	1.5
1976-80	0.2	0.4	1.0	0.1	1.7
1981-85	0.7	0.0[a]	0.5	1.6	2.8
1986-90	0.3	0.1	1.1	0.8	2.3
Unknown release year	0.6	0.0[a]	1.7	2.6	5.0
Total	**2.0**	**0.5**	**5.3**	**5.7**	**13.5**

Source: CIMMYT Maize Research Impacts Survey.
[a] Less than 50,000 ha.

Hybrids in Malawi. Most of the area planted to maize in Malawi is cultivated by small-scale farmers. Until recently, despite extensive efforts to develop high-yielding hybrids, adoption of improved maize materials was very low. Studies showed that an important factor contributing to farmers' reluctance to adopt improved materials was grain type: despite Malawian consumers' strong preference for flinty grain, most of the hybrids released in Malawi during the 1970s and 1980s were soft-grained dents. In 1990, following years of intensive testing under farmers' management, two high-yielding semi-flint hybrids were released (Smale et al. 1993). These hybrids, MH17 and MH18, were developed in part from CIMMYT Population 32 (ETO Blanco). Both have been readily accepted by farmers, and adoption is accelerating rapidly. Their relative performance under low input conditions and in on-farm trials over several years was better than that of local varieties even in the drought year of 1992 (Figure 14). The widespread popularity of these hybrids gives them the potential to revolutionize the maize sector in Malawi. Hybrid seed sales jumped from about 2,000 t in 1987-88 to about 8,000 t in 1992-93 (enough seed to cover approximately 320,000 ha, or about 25% of the total maize area in the country).[25] Production of OPV seed has been discontinued. The success of the Malawi program in developing and delivering maize hybrids is the result of a strong public breeding program for developing materials adapted to farmers' needs, validation of the technology under farmers' conditions, and a strong link between public and private seed sectors for seed production and delivery (Byerlee and Heisey 1993, Smale 1992).

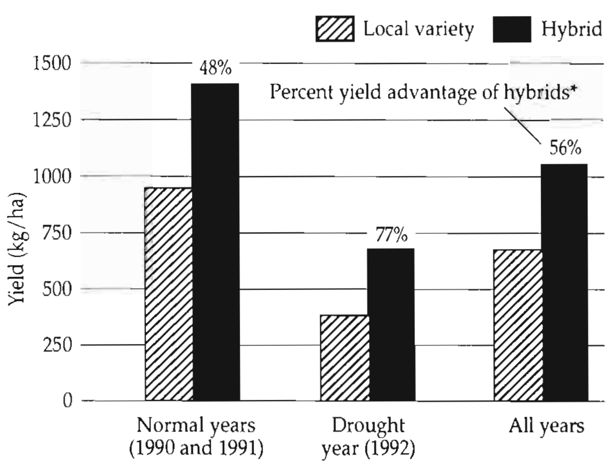

Figure 14. Yields of hybrid and local maize under low-input conditions (zero fertilizer and drought), on-farm trials in Malawi, 1990-92.

* The hybrids used in the trials are MH17 and MH18 (top crosses). Yields are averages of 110 sites in 1990 and 1991 and 102 sites in 1992.

Sources: Smale et al. (1993), Byerlee and Heisey (1993).

Improved OPVs in Ghana. The Ghana Grains Development Project (GGDP), established in 1979 with the objective of strengthening the national research and extension capacity in Ghana, has focused its efforts on maize research (GGDP 1991). One of the main achievements has been the development of several improved OPVs, most notably Dobidi, Okomasa (both developed from CIMMYT's Population 43), and Aburotia (developed from CIMMYT's Population Tuxpeño Planta Baja). Although these improved OPVs consistently yielded better than farmers' local varieties under experimental conditions, research indicated that changes were necessary in farmers' management practices to realize the OPVs' full potential. The GGDP's breeding activities were therefore complemented by a strong crop management research effort (including an important on-farm research component) designed to develop improved crop management practices. Following their release, the improved OPVs were promoted by the extension service as part of a seed-technology package. Farmers who adopted both components of the package achieved dramatic production increases, and the technology spread rapidly. By 1990, seed of the three OPVs was planted on about 115,000 ha, about 20% of the country's total maize area. The

25 Data obtained from a 1993 CIMMYT survey of maize seed production in developing countries (López-Pereira and Filippello 1994).

Ghana example shows how successful adoption of improved germplasm can depend to a large extent on the development of complementary crop management practices.

Short-season varieties in Ethiopia and Tanzania. Up until the mid-1980s, maize breeders working in the Bako region of Ethiopia emphasized the development of late maturing varieties (over 150 days) to take full advantage of the long rainy season. However, survey results indicated that many farmers were interested in obtaining an early maturing variety that could be harvested during the period of greatest maize deficit, since this would allow them to replenish their grain stocks well before the main harvest (Negassa et al. 1991). Following several years of trials, the short-season variety Guto (developed from CIMMYT's Population 21) was released in 1988. Guto matures about 20 days earlier than the most popular local variety, and about 35 days earlier than the late-maturing improved OPV Bako Composite (Asfaw Negassa et al. 1992). Although slightly lower yielding than the full-season varieties, Guto was readily accepted by farmers because it could be harvested during a crucial hungry period. Surveys carried out in 1989 indicated that after only one year of experience with the variety, most farmers (78%) planned to plant Guto in at least part of their fields the following year (Asfaw Negassa et al. 1992).

In Kilosa District of Tanzania, where rainfall is distributed bi-modally as in the Bako region, maize breeders traditionally focused their efforts on developing varieties adapted to the more reliable February-May rains. Years of breeding resulted in 1983 in the release of Kito, an improved OPV developed from CIMMYT's Population 30 (Lev n.d.). Although the extension service initially promoted Kito during the major February-May rainy season, producer surveys soon revealed that the variety frequently was planted during the minor November-February rainy season. Additional research revealed that in spite of a yield disadvantage of about 30% relative to the highest yielding minor-season material, Kito was preferred for two reasons. First, Kito could be harvested during the period of greatest maize shortage, thus allowing many households to alleviate seasonal food shortages. Second, Kito's short growth cycle allowed a better establishment of subsequent crops in the relay- or double-cropping systems common in the region (usually cotton and/or cassava), leading to higher yields for the associated crops and increasing returns to the cropping system as a whole (Lev n.d.).

Corn stunt resistant varieties in Nicaragua and El Salvador. A long-term collaboration involving maize breeders from CIMMYT and from the Nicaraguan national maize program culminated in the late 1980s with the release of two improved OPVs, NB-6 (developed from CIMMYT's Population 73) and NB-12 (developed from CIMMYT's Population 76). Both of these varieties showed strong resistance to corn stunt, a potentially devastating disease for Central American maize farmers. This resistance enabled farmers to harvest grain even in years when climatic conditions were favorable for the development of the disease, leading to devastating losses in susceptible varieties. An aggressive government campaign to promote NB-6 and NB-12, which included the production and distribution of certified seed, achieved rapid results; a 1991 survey conducted in Nicaragua's most important maize-growing region established that more than 90% of the region's total maize area was planted to these two varieties (Borbón and Sain 1992).

Following the success of the stunt-resistant varieties in Nicaragua, two hybrids resistant to the disease were released in El Salvador in 1991. The hybrid H-53 (developed from CIMMYT's Populations 73 and 43) and H-57 (containing germplasm from CIMMYT's Population 21 and Pool 23) yielded 20-25% more grain than the hybrids they replaced, primarily H-3 and H-5, which had been developed during the late 1960s and had become susceptible to corn stunt over the years (Aguilúz et al. 1991).

Maize varieties in Pakistan. During the late 1970s and early 1980s, diagnostic surveys were conducted in the Swat Valley of Pakistan to determine why improved production technologies developed by the national research program, including several maize varieties, were not adopted more widely. These surveys demonstrated that farmers needed varieties that could produce both grain and fodder, since maize fodder is crucial for feeding livestock when green fodder from other sources is unavailable (Byerlee, Khan, and Saleem 1991). Economic analysis revealed that the value of maize fodder comprises about 50% of the total value of the crop. Since the fodder characteristics of the improved varieties being promoted at that time did not measure up to those of the local varieties, farmers were reluctant to adopt the improved materials. Based on these findings, breeders began to select for tolerance to high plant density, reasoning that farmers would be able to improve fodder yields by increasing planting density. The variety Azam (developed from CIMMYT's Population 30) demonstrated consistently superior performance, both in grain and fodder yield. Azam was released in 1983. Adoption surveys conducted in 1988 indicated that within five years of its release, Azam had been adopted on more than 80% of the maize area in the villages participating in the program, and in about 50% of the area in neighboring villages (Figure 15) (Byerlee, Khan, and Saleem 1991).

Lessons from the case studies. In each of the cases described above, improved materials containing CIMMYT germplasm were introduced successfully in developing countries. Although the specific factors leading to adoption varied, many of the case studies have one or more features in common.

First, in most cases the improved OPV or hybrid clearly yielded better than the materials previously grown by farmers. The message is clear: with rare exceptions (such as Kito in Ethiopia), superior yield performance is fundamental to successful adoption.

Second, in addition to delivering substantial yield gains, the improved materials were highly compatible with farmers' needs and/or consumers' preferences. Factors such as fodder quantity and quality, early maturity, and grain quality often decisively influenced adoption. Since breeders are not likely to know about these non-yield characteristics without direct feedback from farmers and consumers, the importance of maintaining a strong end-user orientation in breeding research is clear.

Third, successful adoption of improved materials was nearly always preceded by effective promotional campaigns. Public extension services usually played a key role in paving the way for successful adoption by demonstrating new materials in farmers' fields and by educating farmers about proper crop management practices.

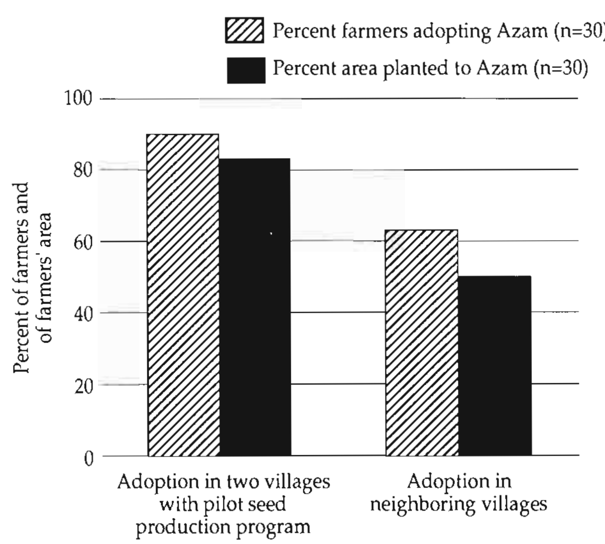

Figure 15. Adoption of the improved maize variety Azam in the Swat Valley, Pakistan, 1988.
Sources: Byerlee, Khan, and Saleem (1991).

Fourth, in most of the case studies an effective seed industry played a vital role in delivering high quality seed to farmers at affordable prices. It is not enough to develop improved materials and to educate farmers about their use if quality seed remains unavailable.

Finally, the case studies serve to reiterate the point made earlier that improved germplasm originating from CIMMYT's breeding program usually cannot be transferred directly to farmers. In many instances, CIMMYT materials must undergo additional cycles of testing and selection to meet local requirements; only then will they be acceptable to farmers and/or consumers. These cases highlight the essentially collaborative nature of germplasm improvement research, especially the value of strong links between NARSs, CIMMYT, other international agricultural research centers, and private companies.

Yield Gains Associated with Adoption of Improved Germplasm

What benefits do farmers receive when they adopt an improved maize variety or hybrid? Although reasons for adopting may vary, increased grain yield usually ranks as the single most important criterion.[26] In considering the yield gains realized through the adoption of improved materials, it is useful to distinguish two stages in the adoption process. When an improved OPV or hybrid is adopted for the first time (i.e., it replaces an unimproved local variety), a substantial one-off yield gain usually results, referred to here as a "Type 1" yield gain). As older improved materials are replaced periodically by newer improved materials, modest incremental yield gains are realized over time, referred to in this report as "Type 2" yield gains.

When thinking about the benefits attributable to the adoption of improved germplasm, most people think of Type 1 yield gains. This is only natural, considering that Type 1 yield gains tend to be highly visible. The so-called "Green Revolution" in wheat was the dramatic result of Type 1 yield gains associated with the initial adoption of modern semidwarf wheat varieties, whose rapid spread through well-watered production zones in Mexico, Turkey, and South Asia had a sudden and highly visible impact. Because production conditions in these zones were fairly homogeneous, and because wheat was generally monocropped, the yield gain associated with switching from old tall varieties to modern semidwarfs could be measured with a fair degree of accuracy; across large areas, yields rose an average of about 40% when the modern varieties were introduced along with modest amounts of fertilizer (CIMMYT 1989, Byerlee and Moya 1993).

What is not as widely appreciated, however, is the importance of Type 2 yield gains, which can be quite significant. Once again, the experience of wheat is instructive. In the years following the original Green Revolution period, yield gains in wheat resulting from the replacement of the first-generation semidwarfs by later generations of semidwarfs were less dramatic but nonetheless steady. Since the mid-1970s, wheat yields in Mexico, India, and Pakistan have risen at an average annual rate of about 1% due to genetic gains in yield potential (CIMMYT 1989, Byerlee and Moya 1993), resulting in cumulative yield increases of 25% or more in many areas.

Estimating equivalent figures for maize is problematic. Because of the diversity in maize production environments, as well as the wide range of maize-based farming systems, Type 1

[26] Many varietal characteristics taken into account by farmers in fact contribute directly or indirectly to higher, more stable grain yields (e.g., drought tolerance, resistance to diseases or insects, early maturity). In rare cases, farmers may adopt an improved OPV or hybrid with lower grain yield, usually because the new material allows them to achieve increased fodder yields or improved grain quality.

yield gains associated with the initial adoption of improved maize materials tend to be quite variable.[27] Furthermore, the size of Type 1 yield gains in maize depends on the nature of the improved materials being adopted (improved OPVs versus different types of hybrids). In cases where hybrids have replaced local varieties, several recent empirical studies suggest that yield gains under farmers' conditions have averaged around 40% in favored production environments and around 30% in marginal environments (Rohrbach 1989, Smale et al. 1993, Smith n.d.). Where hybrids have replaced improved OPVs, the yield gains are less pronounced, averaging around 20-25% across a wide range of production environments (Bolaños 1993, Chiduza et al. 1994, Wattanutchariya, Kao-ian, and Vonyordpun 1987). Where improved OPVs have replaced local varieties, the yield gains are more modest but still significant, averaging around 15-25% in most tropical regions.

It is even more difficult to generalize about Type 2 yield gains in maize, especially since adoption of improved maize germplasm in developing countries has rarely proceeded beyond the first generation of improved materials. The best available evidence on the potential yield gains associated with regular replacement of improved maize materials comes from the United States. Hybrid maize was introduced in the US during the 1930s and spread rapidly. Contrary to popular belief, the replacement of OPVs by hybrid maize did not lead to dramatic breakthroughs in yields. Most estimates of the yield gains achieved through the initial adoption of hybrid maize put the increase at about 10-15%, or about 200 kg/ha above prevailing yield levels (Iowa State Department of Agriculture 1935, Duvick 1992). However, the first-generation hybrids were soon replaced by newer generations, helping to fuel yield gains of about 2.7% per year between 1930 and 1955.[28] It is important to note that the main source of gains in genetic potential in the 25 years following the introduction of hybrids was not the switch to hybrids *per se* (Type 1 yield gains), but the increased genetic potential realized through periodic replacement of older hybrids with newer ones (Type 2 yield gains). Since 1930, maize breeders in the US have achieved gains in genetic potential averaging 50-60 kg/ha/year, nearly half of the yield gains realized in farmers' fields (Duvick 1992).

While the experience of the US is certainly instructive, it would of course be dangerous to extrapolate yield gains achieved in the US Corn Belt to the entire developing world. Given the significant differences between the US and most developing countries in agroclimatic conditions, cropping systems, production technologies, and policy incentives, there is no reason to assume that yield gains achieved in developing countries would mirror those achieved in the US. This points to the need for careful, farm-level studies to monitor the yield gains achieved from adopting and regularly replacing improved materials.

[27] For a review of the empirical evidence on yield gains associated with the initial adoption of improved materials, see Morris, Clancy, and López-Pereira (1992).

[28] The yield gains realized in the USA were not attributable to germplasm alone. Changes in crop management practices played an important complementary role in helping farmers to achieve these yield gains (Duvick 1992, Byerlee and López-Pereira 1994).

Chapter 5

Recommendations for Future Research Impact Studies

In the process of assembling and analyzing the data presented in this report, we have realized that large gaps still exist in our knowledge of maize breeding impacts, and it seems appropriate to offer a brief comment on the need for additional research on the global impacts of maize breeding. Substantial scope for improvement exists in the generation of information relevant for the assessment of maize breeding research at both the national and the international levels. One glaring deficiency relates to the source germplasm used in developing the improved materials released by national programs and private companies. In assembling the varietal database that is the primary source of information for this study, we have repeatedly been frustrated by the absence of documentation of the pedigrees of improved materials grown in the developing world. In the case of proprietary hybrids developed by private companies, the unavailability of pedigree information is understandable; with proprietary hybrids, the problem is not so much that the pedigrees are unknown, but rather that for strategic reasons they are not disclosed publicly. However, proprietary hybrids constitute a relatively small portion of CIMMYT's varietal database; the vast majority of the materials contained in the database are public materials, both improved OPVs as well as hybrids. Somewhat surprisingly, it has been difficult to obtain accurate, clear documentation of the source germplasm that went into producing these public materials. In the relatively small number of cases in which it has been possible to contact the breeder or breeders responsible for developing specific materials, it has usually been possible to piece together rough pedigree information, but in the vast majority of cases, pedigree information remains unavailable. The absence of reliable information about source germplasm is worrisome, because without such information, it will be difficult to track the impacts of international maize breeding efforts. And without the ability to track the impacts of international breeding efforts, it will be difficult to ensure that scarce breeding resources are used efficiently.

Information on pedigrees is not the only information that is lacking. Our efforts to calculate the impacts of international maize breeding research have been hampered by the difficulty of estimating two critical parameters needed to quantify the benefits attributable to international breeding efforts: 1) the global area planted to improved OPVs and hybrids, and 2) the yield gains associated with adopting improved materials.

Perhaps the single largest problem confounding the evaluation of impacts is the lack of consistent and reliable estimates of the area planted to improved maize varieties and hybrids. In the case of public materials, area estimates can sometimes be made based on seed sales data (although this approach presumes some knowledge about average seeding rates and seed replacement rates). Unfortunately, area estimates made on the basis of seed sales data are often inaccurate, because the data themselves are often unreliable.[29] Thus in most countries there is a need for regular, consistent reporting of the areas planted to specific varieties and hybrids. Farm surveys can provide periodic "snapshot" views from which varietal diffusion patterns can sometimes be interpolated, but often periodic

[29] In the case of proprietary materials, reliance on seed sales data is particularly problematic, because private companies often consider these data confidential.

surveys will not be sufficient. Accurate data on varietal diffusion patterns can best come from methodical monitoring of seed sales data, which are then verified using information obtained from regular surveys in important production zones.

Information on the area planted to improved materials is particularly difficult to obtain in the case of OPVs, since farmers typically plant seed of OPVs for a number of years before replacing seed stocks with newly purchased commercial seed. In addition to producing seed for their own use, farmers who plant improved OPVs may also provide seed to their neighbors, leading to additional changes in the area planted to improved materials which are not easily tracked via seed sales data. The fact that OPVs gradually become contaminated through outcrossing with other varieties only compounds the problem of devising accurate area estimates, since what farmers identify as a specific improved OPV may in fact comprise a wide range of materials, all related to varying degrees to the same original improved source material.

To derive consistent area estimates that can be compared between countries and aggregated across regions, it will be necessary to agree upon a consistent method for making area estimates for OPVs. One possible approach would be to base all area estimates on seed sales data (assuming they are available), using a standard seeding rate of 25 kg/ha for maize that is monocropped and lower seeding rates for maize that is intercropped.[30] In the case of OPVs, the resulting figure would then be multiplied by some adjustment factor to take into account farmers' local seed multiplication and recycling practices. Several recent surveys suggest that this adjustment factor ranges between 1 (in countries such as Thailand where farmers replace OPV seed annually) and 5 (in countries such as Pakistan, where farmers purchase small quantities of OPV seed, multiply it, and replant the same seed for several years) (see López-Pereira and Filippello 1994, for a discussion on OPV seed recycling). Given the tremendous variability in local seed management practices, it seems undesirable to propose a single, universally applicable adjustment factor; rather, the adjustment factor for any given region or country should be based on knowledge of local seed management practices obtained from farm-level surveys.

The second area in which additional research is urgently needed relates to the yield advantage offered by improved varieties and hybrids over materials currently being grown by farmers. Although varietal trials are done routinely to determine yield differences between improved materials and local checks, results from conventional varietal evaluation trials usually cannot be used to calculate research benefits because they do not reflect farmers' management practices. Conducted under tightly controlled experimental conditions which typically involve recommended management practices and levels of inputs, conventional varietal evaluation trials almost invariably overstate the *absolute* yield advantage conferred by improved materials when they are grown under the less-than-optimal levels of management typically provided by farmers. Although the *relative* yield advantage achieved in conventional varietal evaluation trials may provide a more reasonable approximation of the yield gains likely to be achieved in farmers' fields, even the assumption of the same relative increase in yield may not hold when the crop is subject to extreme moisture and/or temperature stress. Thus if the yield advantage of improved materials is to be estimated realistically, breeders will have to be much more systematic about including farmer-managed, on-farm yield trials in the varietal evaluation process.

[30] The suggested standard seeding rate of 25 kg/ha for monocropped maize is based on CIMMYT's experience in numerous developing countries. Although planting at a rate of 25 kg/ha will frequently result in excessive plant populations (especially in the case of small-grained materials, such as most single-cross hybrids), farm-level surveys have shown that many farmers in developing countries consistently overplant.

Chapter 6

Summary and Conclusion

What lasting impressions emerge from this assessment of the impacts of 25 years of international maize breeding research?

First, it seems fair to conclude that maize breeders have made significant progress. The collaboration between national programs and the CIMMYT Maize Program has been fruitful, resulting in improved materials encompassing a wide range of grain types, colors, and maturities for the lowland, mid-altitude, and highland tropics and for subtropical environments. Most of these materials have been selected not only for increased yield potential, but also for desirable phenotypic characteristics, including reduced plant height, reduced tassel size, improved husk cover, and increased rooting ability. In addition to the widely adapted pools and populations (and more recently inbred lines), special-purpose materials are available as sources for specific traits, including resistance to major diseases and insect pests, drought tolerance, and tolerance to acid soils.

Second, it is clear that improved maize germplasm developed by the public sector is being disseminated widely. CIMMYT International Trials have proved an effective mechanism for distributing experimental germplasm, backed up by direct seed shipments from the Maize Germplasm Bank. Although not documented in this report, there is evidence that national programs also exchange significant quantities of improved germplasm. Scientists in national programs have had ready access to improved materials, and they have responded by using them — particularly CIMMYT materials — in their breeding programs. According to the results of the survey reported here, more than 50% of the maize varieties and hybrids released since 1966 by public sector breeding institutes contain CIMMYT-derived germplasm. Although information on proprietary releases is much more difficult to obtain, there is strong evidence that CIMMYT germplasm is being used extensively by private sector breeding programs as well. Significantly, the proportion of releases containing CIMMYT germplasm has increased through time, especially in the last 10 years, indicating that the full impact of CIMMYT's work has not yet been felt.

Third, improved maize germplasm is making its way into farmers' fields. In 1990, at least 24.3 million hectares were planted to improved OPVs and hybrids (including proprietary hybrids), representing 42% of the total area planted to maize in the developing world outside the temperate regions. Of this, 13.5 million hectares were planted to materials containing CIMMYT germplasm. While this accomplishment is significant in and of itself, there is reason to believe that the main impacts of global breeding efforts have yet to be realized. Judging by the weighted average age of materials being grown in 1990, it is clear that improved germplasm reaches farmers' fields only after a considerable lag, usually a decade or more. Most varieties grown in 1990 were released during the late 1970s and early 1980s. Since the number of maize releases accelerated sharply during the late 1980s, presumably adoption of these materials will not peak until the late 1990s and beyond. Since the proportion of releases containing CIMMYT germplasm has also accelerated sharply in recent years, the impacts of CIMMYT's breeding efforts can also be expected to increase disproportionately in the next 10-20 years.

Finally, the fact that over half of the developing world's maize area is still planted to unimproved varieties suggests that significant barriers continue to slow adoption of improved maize germplasm. As emphasized repeatedly in this report, maize differs markedly from other cereals of major global importance in that maize farmers are dependent on reliable sources of high-quality, affordable seed. The relatively modest use of improved maize germplasm in the developing world attests to farmers' continuing difficulty in obtaining seed. By implication, maize seed industries — especially their seed production and distribution capacity — will have to be strengthened if adoption of improved maize germplasm is to accelerate significantly. Signs of improvement are becoming evident as many countries adopt seed laws that respond to new conditions in the seed sector, the trend toward greater privatization continues, and the maize sectors of many countries open up (see, for example, López-Pereira and Garcia 1994, López-Pereira and Filippello 1994). There is little doubt that these policy developments and the accelerating pace of maize varietal releases will result in substantial increases in the maize area under improved varieties and hybrids in the developing world in the year 2000 and beyond.

Appendix A

The CIMMYT Global Maize Research Impacts Survey

The prime source of information for the analysis presented in this study was a global survey of the impacts of maize breeding research carried out in 1990-91. The survey was designed to establish a baseline set of maize research indicators. Two questionnaires were used (see Appendix B). The first questionnaire was sent to coordinators of the national maize research programs in 45 developing countries, including most developing countries with at least 100,000 ha of maize, as well as a few countries with less maize area (Table A1, Table D1). This questionnaire focused on two specific issues: *research investment* (e.g., number of scientists engaged in maize research, level of research expenditures), and *research impacts* (e.g., varieties and hybrids developed and released, area planted to improved materials). The second questionnaire was sent to about 50 private maize seed companies active in developing countries. This questionnaire, intended to complement the questionnaire distributed to public sector research organizations, focused primarily on the germplasm sources that private sector companies have used to develop their maize hybrids, and whether or not CIMMYT's basic germplasm has been used.

Table A1. Countries participating in the CIMMYT Global Maize Research Impacts Survey

Sub-Saharan Africa	West Asia and North Africa	South, East, and Southeast Asia	Latin America
Benin	Afghanistan	China:	Bolivia
Burkina Faso	Egypt	Yunnan	Brazil
Burundi	Morocco	Guizhou	Colombia
Cameroon		Guangxi	Costa Rica
Côte d'Ivoire		India	Ecuador
Ethiopia		Indonesia	El Salvador
Ghana		Myanmar	Guatemala
Kenya		Nepal	Honduras
Madagascar		Pakistan	Mexico
Malawi		Philippines	Nicaragua
Mali		Taiwan	Paraguay
Mozambique		Thailand	Peru
Nigeria		Vietnam	Venezuela
Senegal			
Swaziland			
Tanzania			
Togo			
Uganda			
Zaire			
Zambia			
Zimbabwe			

The survey's coverage was extensive. Of the developing world's important maize producers, only Argentina, Chile, and Turkey were excluded from the analysis. In these three countries, virtually all maize is produced in temperate environments using germplasm that is very different from the germplasm used in tropical and subtropical environments. In the case of China, only the three southern provinces of Yunnan, Guizhou, and Guangxi were included in the analysis, as these provinces feature mostly subtropical and tropical maize growing environments. For a few important maize producing countries (notably Angola, Somalia, Afghanistan) it was not possible to obtain data because of special circumstances.

Overall, the response was excellent, both from national programs as well as from private companies. In addition to generating information on the level of human and financial resources invested in maize research, the questionnaires generated information on over 1,000 public maize varieties and hybrids and about 100 private sector hybrids. Although many countries reported all public varieties and hybrids released since the inception of the national breeding program (including some dating back to the early part of this century), the information of public varietal releases is considered complete only for the period 1966-90. The database on public materials created from this information is considered the most complete source of information of its kind to date. With some limitations imposed to protect confidential pedigree information provided by our collaborators, this database is available from CIMMYT upon request.

APPENDIX B

THE MAIZE RESEARCH IMPACTS QUESTIONNAIRES

Questionnaire for Public National Agricultural Research Systems

CIMMYT GLOBAL MAIZE RESEARCH IMPACTS STUDY

GLOBAL MAIZE VARIETAL RELEASES, 1966-90.

COUNTRY: ______________________________

____

RESPONDENT:
Name: ______________________________

Organization: ______________________________

Position: ______________________________

Address: ______________________________

____

____

____

The following information is being collected as part of a CIMMYT study which will attempt to quantify the global impacts of maize breeding research activities by National Agricultural Research Systems and by CIMMYT. It also aims to create, and periodically update, a comprehensive database of public maize varieties and hybrids released by public NARSs since 1966.

This questionnaire focuses on the following areas:

1) Maize varieties and hybrids released

2) Area planted to different maize varieties and hybrids

3) Maize research effort

Please return to: Research Impacts Study - Maize
CIMMYT Economics Program
Apdo. Postal 6-641
06600 Mexico, D.F.
MEXICO

Part I. Public maize varieties and hybrids released during the period since 1966 (excluding materials adapted to temperate regions).

(If full list of releases is unavailable, please give information for as many years as available. Information on public releases before 1966, and also on private sector releases, is optional.)

Code A.
1 = Public material, contains no CIMMYT germplasm
2 = Public material, contains some CIMMYT germplasm
3 = Public material, contains substantial CIMMYT germplasm
4 = Public material, contains 100% CIMMYT germplasm
5 = Private (proprietary) hybrid, contains no CIMMYT germplasm
6 = Private (proprietary) hybrid, contains some CIMMYT germplasm

Code B.
1 = Open pollinated variety (OPV)
2 = Conventional hybrid
3 = Non-conventional hybrid
4 = Other

Code C.
1 = Tropical lowlands (< 900 masl)
2 = Sub-tropics
3 = Tropical mid-altitudes (900-1500 masl)
4 = Tropical highlands (>1500 masl)

Code D.
1 = Yes (covered at least 5% of total national maize area, or 25,000 ha, in 1990 or before)
2 = No (did not meet criterion in 1)

Code E.
1 = White grain
2 = Yellow grain
3 = Other grain color (specify)

Maize varietal releases   Page No. _______ of _______ (total number of pages)

Name of material	Year of release	Name of source germplasm	Origin (Code A)	Type of material (Code B)	Ecological niche (Code C)	Commercial success (Code D)	Grain color (Code E)
e.g., ICTA B-5	1980	Pop 30 (Bl. Crist. - 2)	3	1	1	1	1

(Photocopy this page and add additional pages if necessary).

Part II. Percent area planted to major maize varieties and hybrids in most recent crop year. (Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total maize area reported adds up to national maize area in the country.)

Name of material	Total area planted to this variety or hybrid (thousand ha)	Percent of national maize area planted to this variety or hybrid
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
		%
Other public OPVs		%
Other public hybrids		%
Other proprietary hybrids		%
Local varieties		%
TOTAL		**100%**

Summary of national maize area under different types of materials.

Type of material	Total area planted to this type of material (thousand ha)	Percent of national maize area planted to this type of material
Hybrids[a]		%
Improved open pollinated varieties[b]		%
Local varieties and others[c]		%
TOTAL		**100%**

[a] Only estimated maize area planted with commercial hybrid seed purchased the same year that it was planted (please do not include estimated area under advanced generation hybrid seed).
[b] Only estimated maize area planted with commercial OPV seed, and with seed derived from such commercial seed (recycled OPV seed) *if it was originally purchased within the last five years.*
[c] Estimated maize area planted with local varieties, advanced generation hybrid seed, and seed derived from commercial OPVs (recycled OPV seed) *if it was originally purchased more than five years ago.*

Year corresponding to above estimates ________

Source of above estimates (check one or more):
- Official statistics ________
- Seed sales ________
- Breeders' estimates ________
- Farm surveys ________
- Other (specify) ________

Part III. Maize research effort. (Give data for most recent year available.)

1. Number of full-time equivalent scientists working on developing improved maize varieties in the public sector.

	Breeders	Agronomists	Seed technologist	Other*
B.Sc.	________	________	________	________
M.Sc.	________	________	________	________
Ph.D.	________	________	________	________
Other	________	________	________	________
TOTAL	________	________	________	________

* Other disciplines that support varietal improvement, such as pathologists, entomologists, etc.

2. Number of maize seed companies operating in the country:

   Government or parastatal seed company ________
   Private sector - international company ________
   Private sector - national (domestic) company ________

3. Approximate number of maize scientists in the private sector working on:

   Crop improvement research ________
   Varietal testing ________
   Seed production only ________

Questionnaire for Private Maize Seed Companies

Company: ______________________________

Date: ______________________________

Respondent: ______________________________

Please complete for each country in which your company operates.

Country	Year your first maize hybrid was released	Total number of hybrids released by you to date	Number of these hybrids with CIMMYT germplasm	Main CIMMYT populations, pools, or lines used	Total maize research staff in the country[a]

[a] Please include only staff with a minimum level of training of B.S. or equivalent in maize breeding and support activities (e.g., pathology, entomology, seed technology).

Appendix C

Measuring Yield Gains in Breeding Materials

Whether yield gains are best modeled as linear or curvilinear remains a controversial issue. Although the fact that any closed breeding population contains a finite amount of genetic variability implies that genetic variability within that population will eventually be exhausted, leading to a decrease in the rate of yield gains, some scientists argue that the genetic variability in any given maize population is so vast that for all intents and purposes, breeding gains can be modeled as linear (J. Crossa, personal communication). In contrast, many experienced breeders note that the yield gains achieved through intra-population recurrent selection appear to level off after about 15 cycles, suggesting that genetic progress should be modeled as curvilinear (A. Hallauer, personal communication). To complicate matters, the linear or curvilinear nature of yield gains is undoubtedly influenced by the relative importance given to yield in relation to other traits across different cycles of selection. Maize breeders almost never select for yield alone, and selection pressure for different traits — including yield — typically changes across cycles of selection (Pandey and Gardner 1992).

A conservative approach would be to model yield gains using a quadratic function, which allows for the possibility of a significant quadratic term indicating a decreasing rate of yield gains. However, in order to estimate such a quadratic function, it is usually necessary to have observations for a large number of consecutive cycles, which implies a much greater expense in conducting evaluation trials. Thus, in any given situation the appropriate method for evaluating yield gains will depend partly on the importance of having an exact estimate, as well as on the amount of resources available for planting evaluation trials (i.e., the amount and quality of available data).

In practice, yield gains are usually calculated using linear approximation methods. Although some authors report gains in absolute terms (average kilogram increase per breeding cycle or per year), such measures are not always helpful, because they provide no information on the range of yield levels over which the gains were achieved. This is an important omission, because yield levels vary significantly depending on management factors (e.g., a gain of 150 kg/ha/year recorded in a trial yielding 8,000 kg/ha in the first year is not nearly as impressive as the same gain of 150 kg/ha/year recorded in a trial yielding an average of 1,500 kg/ha in the first year).

More commonly, yield gains are expressed in relative terms (average percentage increase per breeding cycle or per year). This is often estimated as a simple linear average rate of gain per breeding cycle:

$$g_c = \{[(Y_n - Y_0) / Y_0] * 100\} / n,$$

where:

g_c = average percentage increase in yield potential per cycle,

Y_n = yield in latest selection cycle,

Y_0 = yield in first selection cycle, and

n = number of selection cycles.

One advantage of expressing breeding progress in terms of yield gains per cycle is that work on a particular pool or population does not always proceed uninterrupted. For any number of reasons, work may be suspended for one or more cycles, and this procedure allows for the estimation of average yield gains per cycle of improvement in these cases. On the other hand, since the duration of a breeding cycle can vary significantly (e.g., depending on the maturity of the material, the location in which the selection is performed, the breeding method used, the availability of off-season nurseries, and the number of sites and replications), in many instances progress can be evaluated more easily if it is expressed in terms of yield gains per year. The easiest way to calculate yield gains per year is by taking the unweighted or simple average annual percentage increase:

$$g = \{[(Y_n - Y_0) / Y_0] * 100\} / t,$$

where:

g = average percentage increase in yield potential per year, and

t = number of years between first and last selection cycles.

Although this simple method is adequate for calculating yield gains over a relatively short period, for longer periods a more accurate method for calculating growth rates is to use the formula for annual percentage compound growth:

$$g = \{[(Y_t / Y_0)^{1/t}] - 1\} * 100.$$

Which of the two measures — yield gains per cycle or yield gains per year — is better for reporting breeding progress? Casual observation of the crop science literature suggests that breeding progress is more frequently reported in terms of yield gains per cycle than in terms of yield gains per year, although the latter measure is also used.

Appendix D

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Adoption of Improved Maize Varieties and Hybrids in Developing Countries in 1990

Table D1. Non-temperate maize area in developing countries, by type of material, 1990

Country and region	Total maize area in 1990 (000 ha)	Area under local varieties (000 ha)	(%)[a]	Area under improved OPVs (000 ha)	(%)[a]	Area under hybrids (000 ha)	(%)[a]
Sub-Saharan Africa	**14,423**	**8,420**	**58**	**2,985**	**21**	**3,018**	**21**
Burundi	124	105	85	19	15	0	0
Ethiopia	1,050	830	79	168	16	53	5
Kenya	1,500	450	30	120	8	930	62
Madagascar	153	147	96	6	4	0	0
Malawi	1,344	1,156	86	40	3	148	11
Mozambique	1,015	832	82	173	17	10	1
Tanzania	1,630	1,337	82	196	12	98	6
Uganda	389	156	40	195	50	39	10
Zambia	760	175	23	38	5	547	72
Zimbabwe	1,150	46	4	0	0	1,104	96
Benin	454	368	81	82	18	5	1
Burkina Faso	216	120	56	92	42	5	2
Cameroon	200	111	56	87	44	2	1
Côte d'Ivoire	690	469	68	193	28	28	4
Ghana	465	316	68	149	32	0	0
Mali	170	97	57	73	43	0	0
Nigeria	1,500	653	43	818	55	30	2
Senegal	117	0	0	117	100	0	0
Togo	296	250	84	37	13	9	3
Zaire	1,200	804	67	384	32	12	1
West Asia and North Africa	**1,206**	**637**	**53**	**486**	**40**	**83**	**7**
Egypt	830	299	36	448	54	83	10
Morocco	376	338	90	38	10	0	0

Source: CIMMYT Maize Research Impacts Survey.

[a] Percent of total country or regional maize area.

Continued

Table D1. (continued)

Country and region	Total maize area in 1990 (000 ha)	Area under local varieties (000 ha)	(%)[a]	Area under improved OPVs (000 ha)	(%)[a]	Area under hybrids (000 ha)	(%)[a]
South, East, and Southeast Asia	**18,967**	**10,754**	**57**	**5,796**	**30**	**2,417**	**13**
India	5,954	3,692	62	1,523	26	739	12
Myanmar	125	83	66	43	34	0	0
Nepal	758	493	65	265	35	0	0
Pakistan	845	625	74	194	23	25	3
Indonesia	3,158	1,547	49	1,200	38	410	13
Philippines	3,820	2,770	72	859	23	191	5
Thailand	1,545	0	0	1,236	80	309	20
Vietnam	432	238	55	194	45	0	0
China (southern provinces)	2,246	1,307	58	276	12	663	30
Taiwan	84	0	0	4	5	80	95
Latin America	**23,101**	**13,425**	**57**	**2,322**	**10**	**7,534**	**33**
Costa Rica	41	28	68	9	21	5	11
El Salvador	282	109	38	18	7	155	55
Guatemala	634	473	74	131	21	31	5
Honduras	367	245	67	104	28	18	5
Mexico	7,339	5,658	77	871	12	810	11
Nicaragua	194	128	66	64	33	2	1
Bolivia	256	178	69	70	28	8	3
Colombia	837	711	85	42	5	84	10
Ecuador	459	248	54	102	22	110	24
Peru	323	136	42	42	13	146	45
Venezuela	462	0	0	41	9	421	91
Brazil	11,389	4,897	43	797	7	5,694	50
Paraguay	518	435	84	31	6	52	10
All countries above	**57,697**	**33,056**	**57**	**11,589**	**20**	**13,053**	**23**

Source: CIMMYT Maize Research Impacts Survey.
[a] Percent of total country or regional maize area.

Table D2. Non-temperate maize area planted to improved materials in developing countries, by origin of germplasm, 1990

	Total area under improved materials		Area under public sector materials		Area under private sector materials	
Country and region	(000 ha)	(%)[a]	(000 ha)	(%)[a]	(000 ha)	(%)[a]
Sub-Saharan Africa	**6,003**	**42**	**5,941**	**41**	**62**	**0[b]**
Burundi	19	15	19	15	0	0
Ethiopia	220	21	220	21	0	0
Kenya	1,050	70	1,050	70	0	0
Madagascar	6	4	6	4	0	0
Malawi	188	14	154	12	34	2
Mozambique	182	18	183	18	0	0
Tanzania	293	18	293	18	0	0
Uganda	233	60	233	60	0	0
Zambia	585	77	585	77	0	0
Zimbabwe	1,104	96	1,104	96	0	0
Benin	86	19	86	19	0	0
Burkina Faso	96	44	96	44	0	0
Cameroon	89	44	89	44	0	0
Côte d'Ivoire	221	32	193	28	28	4
Ghana	149	32	149	32	0	0
Mali	73	43	73	43	0	0
Nigeria	848	57	848	57	0	0
Senegal	117	100	117	100	0	0
Togo	46	16	46	16	0	0
Zaire	396	33	396	33	0	0
West Asia and North Africa	**569**	**47**	**569**	**47**	0	0
Egypt	531	64	531	64	0	0
Morocco	38	10	38	10	0	0
South, East, and Southeast Asia	**8,214**	**43**	**7,461**	**39**	**752**	**4**
India	2,263	38	1,983	33	280	5
Myanmar	43	34	43	34	0	0
Nepal	265	35	265	35	0	0
Pakistan	220	26	220	26	0	0
Indonesia	1,611	51	1,405	45	205	6
Philippines	1,051	28	907	24	143	4
Thailand	1,545	100	1,421	92	124	8
Vietnam	194	45	194	45	0	0
China (southern provinces)	939	42	939	42	0	0
Taiwan	84	100	84	100	0	0
Latin America	**9,856**	**43**	**5,944**	**26**	**3,912**	**17**
Costa Rica	13	32	13	32	0	0
El Salvador	173	62	173	62	0	0
Guatemala	162	25	161	25	1	0[b]
Honduras	122	33	117	32	5	1
Mexico	1,681	23	1,183	16	498	7
Nicaragua	66	34	64	33	2	1
Bolivia	78	31	70	28	8	3
Colombia	126	15	69	8	57	7
Ecuador	211	46	158	34	53	12
Peru	187	58	125	39	62	19
Venezuela	462	100	442	96	20	4
Brazil	6,492	57	3,317	29	3,175	28
Paraguay	83	16	52	10	31	6
All countries above[c]	**24,641**	**43**	**19,915**	**35**	**4,726**	**8**

Source: CIMMYT Maize Research Impacts Survey.
[a] Percent of total country or regional maize area.
[b] Less than 0.5%.
[c] Includes only countries participating in Maize Research Impacts Survey.

Table D3. Non-temperate maize area planted to improved materials containing CIMMYT germplasm in developing countries, by origin of germplasm, 1990

Country and region	Area under public materials with CIMMYT germplasm (000 ha)	(%)[a]	Area under private materials with CIMMYT germplasm (000 ha)	(%)[a]	Total area under materials with CIMMYT germplasm (000 ha)	(%)[a]
Sub-Saharan Africa	**1,992**	**34**	**2**	**3**	**1,993**	**33**
Burundi	15	81	..[b]	..	15	81
Ethiopia	72	33	..	..	72	33
Kenya	15	1	..	..	15	1
Madagascar	6	100	..	..	6	100
Malawi	0	0	2	5	2	1
Mozambique	173	94	..	..	173	94
Tanzania	175	60	..	..	175	60
Uganda	0	0	..	..	0	0
Zambia	38	6	..	..	38	6
Zimbabwe	0	0	..	..	0	0
Benin	52	61	..	..	52	61
Burkina Faso	44	46	..	..	44	46
Cameroon	64	72	..	..	64	72
Côte d'Ivoire	193	100	0	0	193	88
Ghana	136	91	..	..	136	91
Mali	20	27	..	..	20	27
Nigeria	497	59	..	..	497	59
Senegal	117	100	..	..	117	100
Togo	37	81	..	..	37	81
Zaire	339	86	..	..	339	86
West Asia and North Africa	**545**	**96**	**..**	**..**	**545**	**96**
Egypt	531	100	..	..	531	100
Morocco	14	38	..	..	14	38
South, East, and Southeast Asia	**4,981**	**67**	**326**	**43**	**5,307**	**65**
India	1,004	51	90	32	1,094	48
Myanmar	37	86	..	..	37	86
Nepal	265	100	..	..	265	100
Pakistan	45	20	..	..	45	20
Indonesia	1,074	76	103	50	1,177	73
Philippines	570	63	72	50	642	61
Thailand	1,421	100	62	50	1,483	96
Vietnam	194	100	..	..	194	100
China (southern provinces)	356	38	..	..	356	38
Taiwan	15	18	..	..	15	18
Latin America	**4,562**	**77**	**1,108**	**28**	**5,670**	**58**
Costa Rica	13	100	..	..	13	100
El Salvador	173	100	..	..	173	100
Guatemala	161	100	0	0	161	99
Honduras	117	100	0	0	117	96
Mexico	977	83	148	30	1,125	67
Nicaragua	64	100	0	0	64	97
Bolivia	67	95	0	0	67	86
Colombia	42	61	0	0	42	33
Ecuador	158	100	0	0	158	75
Peru	115	92	0	0	115	61
Venezuela	400	90	10	49	410	89
Brazil	2,224	67	950	30	3,174	49
Paraguay	52	100	0	0	52	62
All countries above	**12,080**	**61**	**1,436**	**30**	**13,516**	**55**

Source: CIMMYT Maize Research Impacts Survey.
[a] Percent of total maize area under improved materials in each category.
[b] .. indicates that there is no maize area under proprietary materials in the country or region.

Table D4. Non-temperate maize area planted to improved materials containing CIMMYT germplasm in developing countries, by type of germplasm, 1990

	Area under improved OPVs with CIMMYT germplasm		Area under hybrids with CIMMYT germplasm	
Country and region	(000 ha)	(%)[a]	(000 ha)	(%)[a]
Sub-Saharan Africa	**1,903**	**64**	**91**	**3**
Burundi	15	81	..[b]	..
Ethiopia	20	12	53	100
Kenya	0	0	15	2
Madagascar	6	100	..	..
Malawi	0	0	2	1
Mozambique	173	100	0	0
Tanzania	175	90	0	0
Uganda	0	0	0	0
Zambia	38	100	0	0
Zimbabwe	..	..	0	0
Benin	52	64	0	0
Burkina Faso	40	43	4	96
Cameroon	62	71	2	100
Côte d'Ivoire	193	100	0	0
Ghana	136	91	..	..
Mali	20	27	..	..
Nigeria	482	59	15	50
Senegal	117	100	..	..
Togo	37	100	0	0
Zaire	339	88	0	0
West Asia and North Africa	**462**	**95**	**83**	**100**
Egypt	448	100	83	100
Morocco	14	38	..	..
South, East, and Southeast Asia	**4,490**	**78**	**817**	**34**
India	859	56	235	32
Myanmar	37	86	..	..
Nepal	265	100	..	..
Pakistan	45	23	0	0
Indonesia	1,033	86	144	35
Philippines	570	66	72	38
Thailand	1,236	100	247	80
Vietnam	194	100	..	..
China (southern provinces)	251	91	105	16
Taiwan	0	0	15	19
Latin America	2,166	93	3,504	46
Costa Rica	9	100	5	100
El Salvador	18	100	155	100
Guatemala	131	100	30	97
Honduras	104	100	13	74
Mexico	862	99	263	32
Nicaragua	64	100	0	0
Bolivia	67	95	0	0
Colombia	42	100	0	0
Ecuador	102	100	56	51
Peru	42	100	73	50
Venezuela	42	100	368	88
Brazil	654	82	2,520	44
Paraguay	31	100	21	40
All countries above	**9,021**	**78**	**4,494**	**34**

Source: CIMMYT Maize Research Impacts Survey.
[a] Percent of total maize area under improved materials in each category.
[b] .. indicates that there is no maize area under this type of material in the country.

References

Aguilúz, A., R. Urbina, R. Celado, and H. Córdova. 1991. Efecto del mejoramiento para resistencia al achaparramiento sobre rendimientos de cultivares de maíz evaluados en siete ambientes de Centroamérica y el Caribe. In *Desarrollo y mejoramiento de germoplasma para resistencia a factores adversos bióticos y abióticos 1990*. Guatemala City, Guatemala: CIMMYT Regional Maize Program for Central America and the Caribbean. Pp. 67-72.

Asfaw Negassa, Benti Tolessa, S. Franzel, Gemechu Gedeno, and Legesse Dadi. 1992. Developing an early-maturing maize variety to solve seasonal food shortages. In S. Franzel and H. van Houten (eds.), *Research with Farmers: Lessons from Ethiopia*. CAB International for the Institute of Agricultural Research, Ethiopia. Melksham, UK: Redwood Press Ltd. Pp. 60-68.

Bolaños, J. 1993. Bases fisiológicas del progreso genético en cultivares del PRM. In *Síntesis de resultados experimentales del PRM 1992*. Guatemala City, Guatemala: CIMMYT Regional Maize Program for Central America and the Caribbean. Pp. 11-19.

Bolaños, J., and G.O. Edmeades. 1993. Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield, biomass, and radiation utilization. *Field Crops Research* 31: 233-252.

Borbón, C., and G. Sain. 1992. El uso de variedades resistentes al achaparramiento en la Región IV de Nicaragua. Managua, Nicaragua: Centro de Investigación en Granos Básicos. Unpublished paper. Mexico, D.F.: CIMMYT.

Brennan, J.P., and D. Byerlee. 1991. The rate of crop varietal replacement on farms: Measures and empirical results for wheat. *Plant Varieties and Seeds* 4: 99-106.

Byerlee, D. 1993. Technical change and returns to wheat breeding research in Pakistan's Punjab in the post-Green Revolution period. *Pakistan Development Review* 32(1): 69-86.

Byerlee, D. 1994. *Modern Varieties, Productivity, and Sustainability: Recent Experiences and Emerging Challenges*. Mexico, D.F.: CIMMYT.

Byerlee, D., and P. Heisey. 1993. Performance of hybrids under low-input conditions in Eastern and Southern Africa. Unpublished paper. Mexico, D.F.: CIMMYT.

Byerlee, D., and M.A. López-Pereira. 1994. *Technical Change in Maize: A Global Perspective*. CIMMYT Economics Working Paper 94-02. Mexico, D.F.: CIMMYT.

Byerlee, D., and P. Moya. 1993. *Impacts of International Wheat Breeding Research in the Developing World, 1966-1990*. Mexico, D.F.: CIMMYT.

Byerlee, D., and L. Saad. 1993. CIMMYT's economic environment to 2000 and beyond: A revised forecast. Unpublished paper. Mexico, D.F.: CIMMYT.

Byerlee, D., K. Khan, and M. Saleem. 1991. Revealing farmer rationality: On-farm maize research in Swat Valley, Northern Pakistan. In R. Tripp (ed.), *Planned Change in Farming Systems: Progress in On-Farm Research*. Chichester, UK: John Wiley. Pp. 169-190.

Ceballos, H., J.A. Deutsch, and H. Gutiérrez. 1991. Recurrent selection for resistance to *Exserohilum turcicum* in eight subtropical maize populations. *Crop Science* 31: 964-971.

CIMMYT. 1982. *CIMMYT's Maize Program: An Overview*. Mexico, D.F.: CIMMYT.

CIMMYT. 1984. *Research Highlights 1983-84*. Mexico, D.F.: CIMMYT.

CIMMYT. 1987a. *1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries*. Mexico, D.F.: CIMMYT.

CIMMYT. 1987b. *CIMMYT Report on Maize Improvement 1982-83*. Mexico, D.F.: CIMMYT.

CIMMYT. 1989. *1987/88 CIMMYT World Wheat Facts and Trends. The Wheat Revolution Revisited: Recent Trends and Future Challenges*. Mexico, D.F.: CIMMYT.

CIMMYT Maize Program. 1988. Maize production regions in developing countries. Mexico, D.F.: CIMMYT. Mimeo.

CIMMYT Maize Program. 1994. Overview of the Maize Program. Presentation to CIMMYT's Board of Trustees. Mexico, D.F.: CIMMYT.

CIMMYT Maize Staff. 1986. *Improving on Excellence: Achievements in Breeding with the Maize Race Tuxpeño.* Mexico, D.F.: CIMMYT.

Chiduza, C., S.R. Waddington, I.K. Mariga, and K. Mashingaidze. 1994. Grain yield and economic performance of open pollinated varieties and released hybrids of maize in a geographically isolated semi-arid area of Zimbabwe. Unpublished paper.

Crossa, J., and C.O. Gardner. 1989. Predicted and realized grain yield responses in full-sib family selection in CIMMYT maize (*Zea mays* L.) populations. *Theoretical and Applied Genetics* 77: 33-38.

Darrah, L.L. 1986. Evaluation of population improvement in the Kenya maize breeding methods study. In Bantayehu Gelaw (ed.), *To Feed Ourselves: A Proceedings of the First Eastern, Central, and Southern Africa Regional Maize Workshop, Lusaka, Zambia, March 10-17, 1985.* Mexico, D.F.: CIMMYT. Pp. 160-176.

de León, C., and S. Pandey. 1989. Improvement of resistance to ear and stalk rots and agronomic traits in tropical maize gene pools. *Crop Science* 29: 12-17.

Duvick, D.N. 1992. Genetic contributions to advances in yield of U.S. maize. *Maydica* 37: 69-79.

Eaton, D., P. Byrne, and B. Renfro. 1991. Progress from full-sib recurrent selection in four subtropical maize (*Zea mays* L.) populations. Unpublished paper. Mexico, D.F.: CIMMYT.

Eberhart, S.A., M.N. Harrison, and F. Ogada. 1967. A comprehensive breeding system. *Der Zuchter* 37: 167-174.

Fischer, K.S., G.O. Edmeades, and E.C. Johnson. 1987. Recurrent selection for reduced tassel branch number and reduced leaf area density above the ear in tropical maize populations. *Crop Science* 27: 1150-1156.

Ghana Grains Development Project (GGDP). 1991. *A Study of Maize Technology Adoption in Ghana.* Mexico, D.F.: GGDP.

Iowa State Department of Agriculture. 1935. *1934 Iowa Yearbook of Agriculture.* Ames, Iowa: Iowa State Department of Agriculture.

Johnson, E.C., K.S. Fischer, G.O. Edmeades, and A.F.E. Palmer. 1986. Recurrent selection for reduced plant height in lowland tropical maize. *Crop Science* 26: 253-260.

Lev, D. (n.d.) The Kito story. Unpublished paper. Tanzania Farming Systems Project.

Longmire, J.L., and F. Mohammed. 1994. Assessing maize varietal deterioration using on-farm and on-station research: Azam maize in the Swat Valley, North West Frontier Province, Pakistan. Unpublished paper. Mexico, D.F.: CIMMYT.

López-Pereira, M.A. 1993. Impacts of research on maize for subtropical, midaltitude, and highland regions and prospects for the future. Paper presented at the External Review of CIMMYT's Subtropical, Midaltitude, and Highland Maize Subprogram, 7-10 September, 1993, Mexico City, CIMMYT.

López-Pereira, M. A., and M. Filippello. 1994. *Maize Seed Industries, Revisited: Emerging Roles of the Public and Private Sectors.* Part 1 of *CIMMYT 1993/94 World Maize Facts and Trends. Maize Seed Industries, Revisited: Emerging Roles of the Public and Private Sectors.* Mexico D.F.: CIMMYT. 1994.

López-Pereira, M.A., and J.C. García. 1994. The maize seed industries of Brazil and Mexico: Evolution and future prospects. Unpublished paper. Mexico, D.F.: CIMMYT.

Lothrop, J. 1988. Annual percentage responses for grain yield of CIMMYT breeding populations in recurrent selection programs. Unpublished paper. Mexico, D.F.: CIMMYT.

Morris, M.L., C. Clancy, and M.A. López Pereira. 1992. *Maize Research Investment and Impacts in Developing Countries.* Part 1 of *1991-92 CIMMYT World Maize Facts and Trends: Maize Research Investment and Impacts in Developing Countries.* Mexico, D.F.: CIMMYT.

Negassa, A., B. Tolessa, S. Franzel, G. Gedeno, and L. Dadi. 1991. The introduction of an early maturing maize (*Zea mays* L.) variety to a mid-altitude farming system in Ethiopia. *Experimental Agriculture* 27: 375-383.

Pandey, S., and C.O. Gardner. 1992. Recurrent selection for population, variety, and hybrid improvement in tropical maize. *Advances in Agronomy* 48: 1-85.

Pandey, S., A.O. Diallo, T.M.T. Islam, and J. Deutsch. 1986. Progress in selection in eight tropical maize populations using international testing. *Crop Science* 26: 879-884.

Pandey, S., A.O. Diallo, T.M.T. Islam, and J. Deutsch. 1987. Response to full-sib selection in four medium maturity maize populations. *Crop Science* 27: 617-622.

Pandey, S., S.K. Vasal, and J. Deutsch. 1991. Performance of open pollinated maize cultivars selected from 10 tropical maize populations. *Crop Science* 31: 285-290.

Smale, M. 1992. Risk, disaster avoidance, and farmer experimentation: The microeconomics of HYV adoption in Malawi. Ph.D. dissertation. College Park, Maryland: University of Maryland.

Smale, M., Z.H.W. Kaunda, H.L. Makina, M.M.M.K. Mkandawire. 1993. *Farmers' Evaluation of Newly Released Maize Cultivars in Malawi: A Comparison of Local Maize, Semi-Flint and Dent Hybrids.* Lilongwe, Malawi and Harare, Zimbabwe: CIMMYT.

Sprague, G.F., and J.W. Dudley (eds.). 1988. *Corn and Corn Improvement.* No. 18 in the series *Agronomy.* Madison, Wisconsin: American Society of Agronomy.

Smith, J. (n.d.) Targeting hybrid maize to appropriate agricultural systems in the Northern Guinea Savanna of West Africa. Unpublished paper. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Timothy, D.H., P. Harvey, and C. Dowswell. 1988. *Development and Spread of Improved Maize Varieties and Hybrids in Developing Countries.* Washington, D.C.: Bureau for Science and Technology, United States Agency for International Development.

Vasal, S., A. Ortega, and S. Pandey. 1982. *CIMMYT's Maize Germplasm Management, Utilization, and Improvement Program.* Mexico, D.F.: CIMMYT.

Vasal, S., and G. Srinivasan. 1991. Breeding strategies to meet changing trends in hybrid maize development. Paper presented at the Golden Jubilee Symposium of the Indian Society of Genetics and Plant Breeding, February, New Delhi, India.

Wattanutchariya, S., S. Kao-ian, and M. Vonyordpun. 1987. Economic analysis of hybrid and open pollinated corn production. Paper presented at the 18th Thai National Corn and Sorghum Reporting Session, 4-8 May, Kamphaengphet, Thailand.

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