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WORLD MAIZE FACTS AND TRENDS

Meeting World Maize Needs:

Technological Opportunities and Priorities for the Public Sector

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Part 2

Assessing the Benefits of International Maize Breeding Research: An Overview of the Global Maize Impacts Study

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Introduction

During the early 1990s, researchers at CIMMYT conducted a study to document the global impacts of international maize breeding research. The results, published in 1994 in the monograph *Impacts of International Maize Breeding Research in the Developing World, 1966–1990*, provided a wealth of information about the germplasm products of maize breeding programs in developing countries and sketched a compelling picture of the widespread dissemination of improved maize varieties and hybrids (López-Pereira and Morris 1994). In subsequent years, the data generated by CIMMYT's global maize impacts study came to be recognized as definitive and were widely used to inform research investment and research management decision-making.

Efforts to update and extend CIMMYT's maize impacts database were initiated in 1997. Given the enormity of the data collection task, the global study was divided into three regional studies—one each for Latin America, eastern and southern Africa, and Asia (see Morris and López-Pereira 1999; Hassan et al. 2001; Gerpacio 2001). The specific objectives of the follow-up study were to

- estimate the level of public and private sector investment in maize breeding research in developing countries;
- document the germplasm outputs of public and private maize breeding programs in developing countries;
- document the use of CIMMYT materials by public and private maize breeding programs in developing countries; and
- estimate farm-level adoption of improved germplasm in developing countries.

Information for the follow-up study was collected through a survey of maize breeding organizations in 37 developing countries (Table 1). Questionnaires were completed by the directors of 104 public breeding institutes and seed production agencies and by representatives of 267 private seed companies. In terms of geographical coverage, the survey concentrated on countries targeted by the CIMMYT Maize Program. All of the important maize-producing regions in the developing world were included, except for West and Central Africa (where the CGIAR mandate for maize genetic improvement is held by CIMMYT's sister institute, IITA), northern China (where farmers grow mainly temperate materials that are not targeted by CIMMYT), and West Asia and North Africa (omitted for logistical reasons). Collectively, the countries included in the survey account for about 95% of the area planted to maize in nontemperate production environments of Latin America, eastern and southern Africa, and Asia.[1]

Table 1. Countries participating in the CIMMYT maize research impacts survey

Latin America	East and Southern Africa	East, South, and Southeast Asia
Caribbean	*East Africa*	*East Asia*
Cuba	Ethiopia	China
Dominican Republic	Kenya	
Haiti	Tanzania	*South Asia*
	Uganda	India
Mexico & Central America		Nepal
	Southern Africa	
Costa Rica	Angola	*Southeast Asia*
El Salvador	Lesotho	Indonesia
Guatemala	Malawi	Philippines
Honduras	Mozambique	Thailand
Mexico	South Africa	Vietnam
Nicaragua	Swaziland	
Panama	Zambia	
	Zimbabwe	
Andean Zone		
Bolivia		
Columbia		
Ecuador		
Peru		
Venezuela		
Southern Cone		
Argentina		
Brazil		
Paraguay		

Source: CIMMYT maize research impacts survey.

[1] In China, the survey covered only the five southern provinces in which maize is grown in nontemperate production environments (Guangxi, Guizhou, Hunan, Sichuan, and Yunnan).

Why Maize is Different from Other Crops

Distinctive Characteristics of Maize

Maize differs from other crops in a number of respects that affect the way international breeding efforts are organized and the process by which modern varieties[2] are taken up by farmers and diffused across the countryside. Before assessing the impacts of international breeding efforts, it is important to understand the characteristics of maize that differentiate it from other crops.

Open Pollination

Maize is an open pollinating crop, unlike other leading cereals such as wheat and rice, which are self-pollinating. When self-pollinating crops reproduce, the pollen that fertilizes a given ovary to produce a viable seed almost always comes from a stamen of the same plant. Because the plant fertilizes itself, each generation of plants retains the essential genetic identity of the preceding generation. By contrast, when maize reproduces, genetic material is exchanged between neighboring plants. Consequently, unless pollination is carefully controlled, all of the maize plants in a given field will differ from the preceding generation and from each other.

Importance of Hybrid Vigor

When maize reproduces, much depends on whether the pollen grain used to fertilize a given kernel comes from the same plant or from a different plant. When maize plants self-fertilize, the resulting progeny are often characterized by undesirable traits, such as reduced plant size and low yield. But when maize plants cross-fertilize, some of the resulting progeny have desirable traits, such as increased plant size and high yield. Commonly referred to as "hybrid vigor," this phenomenon is attributable to the complementary action of favorable alleles and is exploited by plant breeders in their efforts to develop commercial varieties.

Multiple End Uses

No other cereal can be used in as many ways as maize. Virtually every part of the maize plant has economic value, including the grain, the leaves, the stalks, the tassels, and in some cases, even the roots. In view of the multiple end uses, it is not surprising that farmers grow thousands of varieties featuring unique combinations of desirable traits. Although many crops are genetically diverse, maize is notable for the extent to which genetic diversity is actively managed at the household level. In developing countries, it is not uncommon to find the same household growing three, four, or even more distinct maize varieties, each carefully selected to satisfy a specific food, feed, or industrial use.

Variability of Maize Production Environments

Maize is the world's most widely grown cereal. It is cultivated at latitudes ranging from the equator to approximately 50° North and South, at altitudes ranging from sea level to more than 3,000 m elevation. It is grown in extremely cool, moderate, and very hot climates, under moisture regimes ranging from extremely wet to semiarid, on flat terrain as well as precipitously steep hillsides, in many different types of soil, and using a profusion of production technologies.

Implications for Breeding Research

The distinctive characteristics of maize have important implications for crop genetic improvement efforts.

Farmer Breeding

Because maize is an open pollinating crop, new genetic combinations are continuously generated in farmers' fields through natural outcrossing. In many parts of the world, farmers understand that the genetic composition of their varieties changes with every cropping cycle, and when the time comes to select seed for replanting, they are careful to choose materials that exhibit desirable traits. Some farmers take this process a step further and deliberately generate new genetic combinations by planting seed of different varieties within the same plot or in adjacent plots to encourage cross-pollination. Alternatively, through a process known as *rustification* or *creolization*, farmers may acquire seed of modern varieties and apply selection pressure to alter their characteristics and thereby better meet local production and/or consumption requirements. Although maize is not the only crop subjected to farm-level selection pressure, few other species can be manipulated as rapidly as maize.

Emphasis on Hybrids

The distinctive biological characteristics of maize have not only encouraged farm-level breeding activity, but they have also had an important influence on institutional breeding efforts. Because the physical separation of the male and female flowers in maize makes controlled cross-pollination relatively easy, and because hybrid vigor in maize is so pronounced, formal maize improvement programs have concentrated almost exclusively on development of hybrids. This approach to achieving genetic gains

2 Throughout this report, the term *varieties* is used in a generic sense to refer to both open pollinated varieties of maize as well as hybrids. The term *modern varieties* is used to refer to open pollinated varieties and hybrids that have been improved by a formal breeding program.

makes sense from both a scientific and an economic point of view. Since hybrids are a much more attractive business proposition than open pollinated varieties (OPVs), a great deal of formal maize breeding work has been conducted by profit-oriented companies.

Location Specificity of Improved Germplasm

Most of the maize produced in the industrialized world is grown in temperate environments, while in developing countries, most of the maize is grown in nontemperate environments. This fact has important implications for the flow of improved technology. Maize germplasm that performs well in temperate regions generally cannot be introduced into nontemperate regions without undergoing extensive local adaptation. This means that unlike most other major food crops, modern varieties of maize developed for use in the United States, Western Europe, and northern China offer little direct benefit to developing countries.

Implications for Germplasm Diffusion

The distinctive characteristics of maize heavily influence breeding efforts and also have important implications for the dissemination of improved germplasm.

Critical Importance of Seed

With maize more than with any other crop, the dissemination of improved germplasm is critically dependent on the timely availability and affordability of high quality seed. Because the genetic composition of maize plants grown from farm-saved seed can change considerably from generation to generation, farmers must purchase fresh seed for each cropping cycle if they wish to maintain a high level of genetic purity.

Need for an Effective Seed Industry

Since it is too costly and technically difficult for farmers to produce genetically pure maize seed, the fact that fresh seed must be acquired for each cropping cycle means that modern varieties can disseminate only with the support of a viable seed industry. This can present a bottleneck, particularly in developing countries, because many subsistence-oriented farmers have been neglected by the seed industry, which tends to focus on more lucrative markets. Thus all farmers do not have reliable access to sufficient quantities of high quality seed.

Investment in Maize Breeding Research

International Agricultural Research Centers

Maize genetic improvement is carried out at two of the 16 international agricultural research centers (IARCs) that are members of the Consultative Group for International Agricultural Research. CIMMYT, headquartered in Mexico, holds a global mandate for maize improvement research and targets lowland tropical, subtropical, midaltitude, and tropical highland environments throughout the developing world. Nigeria-based IITA holds a regional mandate for maize improvement research and targets mainly humid tropical zones of western and central Africa.

Judged strictly in terms of numbers of researchers, the IARCs are minor actors in the global maize breeding industry. The CIMMYT Maize Program currently includes about 35 scientist “full time equivalents” (FTEs), of which approximately 30 are engaged in breeding or breeding support (including genetic resources conservation and management). The IITA Crop Improvement and Plant Health Management Divisions currently include about 12 maize scientist FTEs, of which approximately eight are engaged in breeding or breeding support. Numbering less than 50 scientist FTEs between them, the CIMMYT and IITA maize breeding programs are considerably smaller than many national breeding programs.

Public National Breeding Programs

Public national breeding programs are major players in the global maize breeding industry, supporting nearly 1,000 senior breeders worldwide (Table 2). These breeders are fairly evenly distributed across all developing regions, with the exception of China, which claims a disproportionately large share.[3] The organization of public breeding programs, however, varies considerably by region. Public breeding activities in Latin America and Asia are generally more decentralized, with larger numbers of relatively small breeding programs, whereas in eastern and southern Africa they are generally more centralized, with fewer but larger breeding programs.

Regional differences also are evident in the intensity of public investment in maize research. Controlling for the size of the maize sector, the number of publicly supported maize breeders is much higher in Asia than in other regions, presumably reflecting the relatively low cost of

[3] Since the China data in Table 2 refer only to the five southern provinces of China in which maize is grown in nontemperate production zones, they do not include an additional 1,500 Chinese breeders working in central and northern China. When these additional breeders are included, two out of every three maize breeders in the developing world are Chinese!

Table 2. Public sector maize research investment indicators, developing countries, late 1990s

	Number of countries surveyed	Public maize breeding programs	Maize scientists (FTEs)	Maize scientists per program	Maize scientists per million ha maize area	Maize scientists per million t maize production
Latin America	18	49	290	5.9	10.2	4.2
Eastern and Southern Africa	12	4	109	27.3	7.6	4.1
East, South, and Southeast Asia[a]	7	116	505	4.4	26.3	11.0
All regions	37	169	904	5.3	14.6	6.4

Source: CIMMY maize research impacts survey.
FTEs = full-time equivalents.
[a] Excludes northern China.

human capital in Asia. Interestingly, both of the research intensity indicators (breeders/million hectares planted to maize, breeders/million tons of maize production) have decreased since the first CIMMYT global impacts study was conducted, indicating that public investment in maize breeding declined during the 1990s.

Private Seed Companies

The private sector has become a major player in the maize breeding industries of most developing countries, employing more than 400 senior breeders worldwide (Table 3). Nearly 60% of them are employed by multinational companies, a marked increase from earlier years when most maize breeding work was still being carried out by national companies. In contrast with the public sector, however, private sector breeding capacity is not distributed evenly throughout the developing world. Latin America and Asia (with the exception of China) support a large number of private seed companies, reflecting the presence in those regions of important commercial maize sectors and also a friendlier business climate. Private seed companies are much less common in eastern and southern Africa, reflecting the relative scarcity in these regions of commercial maize sectors, as well as generally more challenging business environments.

Regional differences in numbers of private seed companies and numbers of private sector maize breeders are reflected in similar differences in the intensity of private sector investment in maize research. Controlling for the size of the maize sector, the number of private maize breeders is more than twice as high in Latin America and Asia than in eastern and southern Africa. Both of the research intensity indicators (breeders/million hectares planted to maize, breeders/million tons of maize production) have risen significantly since the first CIMMYT survey was conducted, indicating that private investment in maize breeding increased during the 1990s.

Products of Maize Breeding Research

The principal output of maize breeding programs is improved germplasm, so varietal releases represent one obvious productivity measure. CIMMYT maintains two varietal release databases—one for varieties developed by public breeding programs and one for varieties developed by private seed companies. The temporal coverage of these two databases is slightly different. The public sector varietal release database contains information about approximately 1,250 varieties and hybrids released since the mid-1950s by public breeding programs in the 37 developing countries that participated in the CIMMYT survey.[4] The private sector varietal release database contains information about approximately 1,025

[4] Here the discussion relates only to varieties released since 1966, the year in which CIMMYT was officially established.

Table 3. Private sector maize research investment indicators, developing countries, late 1990s

	Number of countries surveyed	Private seed companies with breeding programs		Private sector maize researchers		Maize scientists per million ha maize area	Maize scientists per million t maize production
		National	Multinational	National	Multinational		
Latin America	18	65	27	101	109	7.4	3.1
Eastern and Southern Africa	12	10	2	10	35	3.1	1.7
East, South, and Southeast Asia[a]	7	24	22	64	96	8.3	3.5
All regions	37	99	51	174	240	6.7	3.0

Source: CIMMY maize research impacts survey.
[a] Excludes northern China.

varieties that were sold by private seed companies during the late 1990s in the same 37 countries. Unlike the case of the public sector, with the private sector it was not possible to compile a complete list of all varieties developed since 1966, the year CIMMYT was established. Private seed companies therefore were asked to provide information only about varieties they were currently selling. In most instances, these consisted of relatively recent hybrids developed during the 1990s.

Public Sector Releases

Public maize breeding programs have been very productive, developing and releasing a steady stream of modern varieties (Figure 1). On aggregate, the rate at which varieties are released has grown steadily through time and shows no sign of slowing. Assuming that varietal testing and release procedures have not changed, this suggests that public maize breeding programs have not suffered any significant decline in productivity.

Since 1966, public maize breeding programs in developing countries have developed and released nearly twice as many OPVs as hybrids, reflecting the traditional emphasis in the public sector on breeding open pollinated materials. However, the ratio of OPVs to hybrids has changed through time in response to changes in the prevailing philosophy about the suitability of hybrid technologies for small-scale farmers. The proportion of hybrids among public sector releases increased sharply during the 1990s, and during the most recent period (1996–98), hybrids actually outnumbered OPVs by a slight margin.

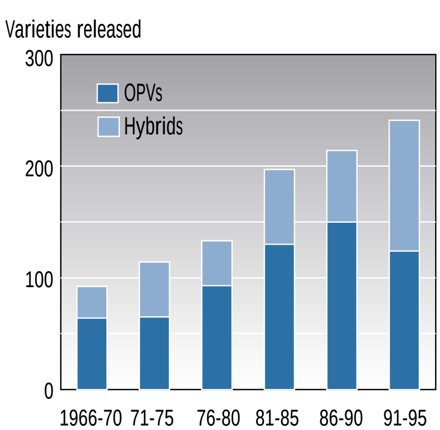

Figure 1. Public sector maize varietal releases, 1966–95.
Source: CIMMYT global maize impacts survey.

To what extent have public maize breeding programs in developing countries made use of CIMMYT germplasm? This question is not easy to answer because it is difficult to track the use of CIMMYT germplasm for at least three reasons:

1) Defining "CIMMYT germplasm" is often problematic. Modern maize breeding is truly international, and today most breeders routinely work with source materials obtained from all over the world. Screening and evaluation require a great deal of teamwork because materials must be evaluated in multiple locations. In this context, it is not always clear how credit for the breeding effort should be attributed, so the definition of "CIMMYT germplasm" becomes very blurry.

2) Breeders who use CIMMYT source materials themselves may not know exactly how much CIMMYT germplasm is actually present in a finished cultivar. Modern maize improvement methods typically involve repeated cycles of selfing, crossing, and backcrossing. Selection strategies vary widely and frequently change. Because of the complex and frequently ad hoc nature of the breeding process, the precise genetic composition of finished varieties cannot be known with certainty. Even if the source materials can be identified, their relative contribution may be unknown.

3) Even when breeders know how much CIMMYT germplasm is present in a finished variety, they may not be willing to reveal this information. Most commercial maize varieties now have closed pedigrees, meaning that information about their genetic background is not publicly available. Breeding programs, especially commercial programs that respond to economic incentives, have an interest in keeping pedigrees closed, because once the genetic background of a variety becomes public knowledge, other breeders will be able to copy the variety. In the past, public breeding programs were rarely concerned with earning profits from sales of their germplasm products, so they were usually willing to provide pedigree information. More recently, the situation has changed. With the strengthening of IPR, many public breeding programs have adopted closed-pedigree policies.

Despite these complicating factors, a robust effort was made to document the use of CIMMYT germplasm. Survey respondents were asked whether the varieties developed by their respective breeding programs had used CIMMYT source materials, defined as materials that had been improved by the CIMMYT Maize Program. Materials that may have been obtained from the CIMMYT gene bank but that had not been selected by CIMMYT breeders were thus excluded.

Use of CIMMYT germplasm by public breeding programs has been extensive (Figure 2). Of all publicly bred maize varieties released from 1966 to 1998, more than one-half (53%) contained CIMMYT germplasm. Excluding varieties adapted for temperate environments (which are not targeted by CIMMYT maize breeders), the proportion containing CIMMYT germplasm was even higher (58%). The use of CIMMYT germplasm by public breeding programs has increased through time. During the most recent period, 65% of all public sector varietal releases contained CIMMYT germplasm (72% when temperate materials are excluded). Belying predictions that CIMMYT's role would decline as national programs gained in strength, the CIMMYT Maize Program continues to represent an important source of breeding materials for public breeding programs.

Private Sector Releases

Since the private sector varietal releases database contains only information about varieties sold during the late 1990s, it cannot be used to draw conclusions about the past productivity of private breeding programs. But while the historical coverage may be incomplete, the regional variability in the data is striking. During the late 1990s, many more proprietary varieties were sold in Latin America and Asia compared to eastern and southern Africa. This suggests that eastern and southern Africa has attracted less attention from the private sector than the two other regions. As expected, private breeding programs have focused almost exclusively on developing hybrids, which accounted for fully 98% of all proprietary materials sold during the late 1990s.

Use of CIMMYT germplasm by private breeding programs has been substantial. Of all private sector maize varieties sold during the late 1990s, 58% contained CIMMYT germplasm. The proportion varied greatly by region, however. In Latin America, nearly three-quarters (73%) of all private sector varieties contained CIMMYT germplasm; excluding varieties adapted for temperate production environments, the proportion containing CIMMYT germplasm was an astonishing 89%. In other regions, use of CIMMYT germplasm by private companies was much more modest. In eastern and southern Africa, 21% of the varieties developed by private breeding programs contained CIMMYT germplasm; in Asia the figure was 19%.

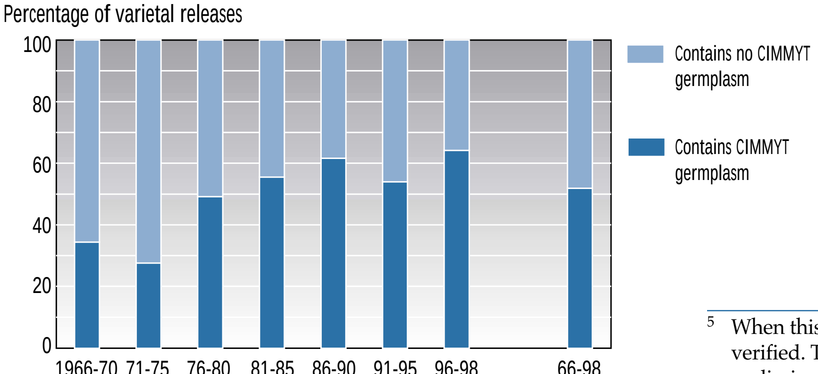

Figure 2. Use of CIMMYT germplasm by public breeding programs.
Source: CIMMYT global maize impacts survey.

Use of Modern Varieties by Farmers

The varietal release data attest to the productivity of maize breeding programs in developing countries and show that breeders, both in the public and private sectors, have made extensive use of CIMMYT germplasm. What the varietal release data do not reveal, however, is the extent to which farmers have taken up modern varieties. For that it is necessary to examine varietal adoption patterns. Because of the difficulties inherent in estimating the adoption of improved germplasm, we present two types of data that relate to the uptake of modern varieties[5]. First, we present information about commercial seed sales. Although seed sales do not provide a direct measure of the area planted to modern varieties, seed sales data nevertheless provide important information about the strength of the demand for modern varieties. Following that we turn to direct estimates of the area planted to improved OPVs and hybrids.

Sales of Commercial Maize Seed

Table 4 shows sales of commercial maize seed for 1996/97 reported by the public seed agencies and private companies that participated in the CIMMYT survey.[6] The seed sales data are noteworthy in four respects:

1) Maize seed is big business in the developing world; sales for the industry as a whole exceeded half a million tons in 1996/97.

[5] When this publication went to press, MV adoption data were still being verified. The results presented here should therefore be considered preliminary.

[6] Consistent with the rest of this report, the data for China include only the five southern provinces in which maize is grown in nontemperate production environments.

Table 4. Commercial maize seed sales, by type of seed and seed organization, 1996/97[a]

	Public sector			Private sector			Total		
	OPVs	Hybrids	Total	OPVs	Hybrids	Total	OPVs	Hybrids	Total
Latin America	4,700	4,500	9,200	14,400	280,700	295,100	19,100	285,200	304,300
East and Southern Africa	1,300	1,800	3,200	1,800	37,400	39,200	3,100	39,200	42,300
East, South, and Southeast Asia[b]	1,700	94,000	96,200	3,200	67,800	71,000	4,900	162,300	167,200
All regions	7,700	100,300	108,500	19,300	385,900	405,300	27,100	486,700	513,800

Source: CIMMYT maize impacts survey.
[a] Column totals may not sum exactly due to rounding error.
[b] Excludes northern China.

2) The size of the commercial maize seed industry varies tremendously between regions. Latin America represents by far the largest regional market, followed by East, South, and Southeast Asia, with East and Southern Africa trailing far behind.

3) With the significant exception of China, the maize seed industry has effectively been privatized; at the global level, private seed companies outsell public seed agencies by more than two to one (this ratio increases to nearly ten to one when China is excluded).

4) The market for maize seed is dominated by hybrids; in all three regions, sales of OPV seed account for less than 10% of the total market share.

Of all maize seed sold in 1996/97, one-quarter (25%) was seed of varieties developed and released by public breeding programs, and three-quarters (75%) was seed of varieties developed and released by private breeding programs. Publicly-bred varieties were popular in East and Southern Africa (accounting for 75% of all seed sales within these regions), whereas privately-bred varieties were highly favored in Latin America (accounting for 89% of all seed sales within the region). Use of public and private sector varieties was more evenly balanced in Asia, although variability within the region was great; most of the seed sold in China (also parts of India) was seed of public varieties, while most of the seed sold in other countries was seed of private varieties.

The seed sales data provide direct evidence that CIMMYT germplasm is being used extensively. Of all the commercial maize seed sold during 1996/97 in developing countries and whose parentage could be determined, 57% was seed of varieties developed using CIMMYT germplasm. Focusing more directly on environments targeted by the CIMMYT Maize Program, of all commercial maize seed sold during 1996/97 in nontemperate areas (i.e., excluding Argentina and South Africa) and whose parentage could be determined, 63% was seed of varieties developed using CIMMYT germplasm.

In order to get a better sense of how the maize seed industry is changing through time, it is useful to examine longer-term trends in seed sales data. Figure 3 shows the evolution of total commercial maize seed sales during 1990–97. Summing across all three developing regions, the data show a slight upward trend. Although public seed agencies contributed slightly to this trend, the growth in commercial seed sales was driven mainly by increases in private-sector seed sales.

Adoption of Modern Varieties

How extensive is the area planted to modern maize varieties in the developing world? Respondents to the recent survey were asked to provide estimates of the percentage area under three categories of materials: (1) cultivars grown from farm-saved seed (including landraces, farmers' traditional varieties, and older OPVs and hybrids grown from advanced-generation recycled seed); (2) newer OPVs grown from commercial seed or from recycled seed emanating from recently purchased commercial seed; and (3) hybrids grown from newly purchased commercial seed.

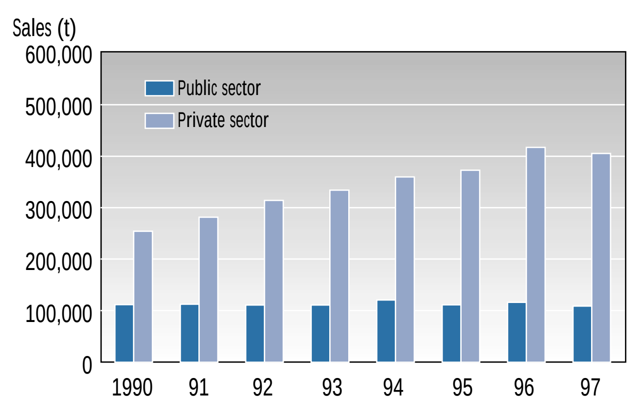

Figure 3. Total maize seed sales, all regions, 1990–97.

Table 5 presents estimates of the area under each of the three germplasm categories during the late 1990s. Overall, of the 70.0 million hectares planted to maize in the countries covered by the CIMMYT and IITA surveys approximately 36.0 million hectares (51.5%) were planted to modern varieties. Of the 63.3 million hectares planted to maize in nontemperate production environments (excluding Argentina and South Africa, where maize is grown mainly in temperate production environments), approximately 29.8 million hectares (47.0%) were planted to modern varieties.

How do these findings compare to those of the 1992 CIMMYT global impacts study? Since the geographical coverage of the earlier study was different, care should be taken in comparing the two sets of results. To make the results of the recent survey more directly comparable, it is necessary to drop countries from the current sample that were not included in the earlier survey (Argentina and South Africa).[7] Excluding these two countries, of the 55.0 million hectares planted to maize during the late 1990s, approximately 26.8 million hectares (48.7%) were planted to modern varieties. In percentage terms, this finding is slightly higher than the results of the earlier CIMMYT impacts study, which found that in 1990 approximately 43% of the developing world's maize area was planted to modern varieties (López-Pereira and Morris 1994).

Several conclusions can be drawn from the adoption data summarized in Table 5.

- Modern maize varieties have spread widely throughout the developing world.
- Adoption of modern maize varieties in nontemperate areas has been less extensive than in temperate areas.
- The area planted to hybrids is much larger than the area planted to OPVs.
- A significant proportion of the developing world's maize area continues to be planted to farm-saved seed.

Table 5. Maize area planted to improved OPVs and hybrids, developing countries, late 1990s[a]

	Total maize area[b] (million ha)	Area planted using farm-saved seed[c] (%)	Area planted using commercial seed: OPVs[d] (%)	Area planted using commercial seed: Hybrids (%)	Area planted using commercial seed: All MVs (%)
Latin America	27.1	55.1	5.0	39.9	44.9
excluding Argentina	*24.5*	*59.6*	*5.3*	*35.1*	*40.4*
Sub-Saharan Africa[e]	23.3	53.3	16.1	30.6	46.7
excluding South Africa	*19.2*	*63.9*	*18.9*	*17.2*	*36.1*
East, South, and Southeast Asia[f]	19.6	33.7	22.0	44.3	66.3
All regions	70.0	48.5	13.5	38.0	51.5
All nontemperate regions	63.3	52.9	14.6	32.5	47.1
Countries covered by 1992 impacts study, excluding Argentina, China, South Africa	55.0	51.3	11.8	36.9	48.7

Source: CIMMYT global maize impacts survey.

a Data refer to the following years: Latin America = 1996; Eastern and Southern Africa = 1997; East, South, and Southeast Asia = 1998.

b Includes only countries covered by the CIMMYT and IITA surveys.

c Includes landraces, farmers' traditional varieties, and older OPVs and hybrids grown from advanced-generation seed recycled more than three times.

d Includes area grown from commercial OPV seed that has been recycled up to a maximum of three times.

e Includes data for West and Central Africa.

f Excludes northern China.

Adoption of Modern Varieties Developed using CIMMYT Germplasm

Seed sales and varietal releases data can be combined with modern variety (MV) adoption data to derive estimates of the area planted to varieties developed using CIMMYT germplasm (Table 6). In 1996/97, of the 36.0 million hectares planted to modern varieties in the countries covered by the CIMMYT and IITA surveys about 18.0 million hectares (50.0%) were planted to varieties that had been developed using CIMMYT germplasm. Restricting the focus to nontemperate production environments targeted by the CIMMYT Maize Program, of the 29.8 million hectares planted to modern varieties in these environments, about 17.1 million hectares (57.5%) were planted to varieties that had been developed using CIMMYT germplasm.

Use of CIMMYT-derived varieties varied greatly by region. Nearly 10 million hectares were planted to CIMMYT-derived varieties in Latin America, compared to about 4.5 million hectares in Asia and about 3.7 million hectares in Sub-Saharan Africa.[8] These regional differences in the use of CIMMYT germplasm can be explained partly in terms of environmental factors. Since its inception, the CIMMYT Maize Program has invested more resources in breeding for lowland tropical environments than for other environments. Most of the maize grown in Latin America is grown in lowland tropical environments, so

7 The geographical coverage is still not identical, because the earlier survey included a number of countries in northern, western, and central Africa.

8 The figure for Sub-Saharan Africa includes an estimated 2.0 million ha in West and Central Africa.

Table 6. Maize area planted to MVs developed using CIMMYT germplasm, developing countries, late 1990s[a]

	Maize area[b] (million ha)	Maize area under MVs (%)	Maize area under MVs (000 ha)	Proportion with CIMMYT germplasm (%)	Maize area under MVs with CIMMYT germplasm (000 ha)
Latin America	27.1	44.9	12,171	80.1	9,842
excluding Argentina	*24.5*	*40.4*	*9,899*	*92.8*	*9,183*
Sub-Saharan Africa[c]	23.3	46.7	10,886	33.6	3,650
excluding South Africa	*19.2*	*36.1*	*6,941*	*49.8*	*3,454*
East, South, and Southeast Asia[d]	19.6	66.3	12,976	34.7	4,500
All regions	70.0	51.5	36,013	50.0	17,993
All nontemperate regions	63.3	47.1	29,816	57.5	17,138

Source: CIMMYT global maize impacts survey.

a Data refer to the following years: Latin America = 1996; Eastern and Southern Africa = 1997; East, South, and Southeast Asia = 1998.

b Includes only countries covered by the CIMMYT and IITA surveys.

c Includes data for West and Central Africa.

d Excludes northern China.

breeding programs in this region have been able to take advantage of some of CIMMYT's best materials. By contrast, much of the maize area in East and Southern Africa is located in subtropical and midaltitude environments, which until the mid-1980s received less emphasis from CIMMYT breeders. Similarly, before they can be grown successfully in Asia, materials developed in Mexico generally must undergo local adaptation. Breeding programs in Africa and Asia until recently thus had a more limited range of CIMMYT materials on which to draw. This situation has already started to change following moves by the CIMMYT Maize Program to strengthen its local breeding efforts in both regions.

Although this report includes information only on the use of CIMMYT germplasm by breeding programs in southern China, sources in the Chinese national maize breeding program recently reported that CIMMYT germplasm is also being used extensively in the breeding programs of northern China. These sources estimate that possibly as much as one-fourth of the total area planted to maize in China is planted to cultivars having CIMMYT parentage (i.e., as much as 6 million ha).

Future Directions for International Maize Breeding

These results confirm the findings of CIMMYT's original global impacts study conducted nearly 10 years ago: international maize breeding efforts have generated enormous benefits. Modern varieties currently cover nearly two-thirds of the area planted to maize in developing countries, bringing increased incomes to millions of maize producing households and lower food prices for even greater numbers of maize consumers. The widespread diffusion of modern maize varieties is especially impressive given the distinctive characteristics of maize, in particular, the open pollinating nature of the crop that requires farmers who grow modern varieties to replace their seed regularly. For this reason, modern maize varieties can disseminate only in the presence of an efficient seed industry.

The critical role of the maize seed industry has not gone unnoticed by policymakers. During the 1990s, liberalization measures introduced in many developing countries opened the door to increased participation by private companies, which responded by quickly capturing a large share of many national seed markets. The private sector now dominates commercial maize seed production throughout the developing world, with the notable exception of China, where private sector participation in seed production is still proscribed. Seed market liberalization has also had a pronounced effect on research. Recognizing that long-term survival in an increasingly competitive industry depends on the continued availability of superior products, private seed companies have significantly increased their investment in maize breeding research. The fruits of this increased investment are becoming evident in the steady stream of modern varieties emanating from private breeding programs, many of which have been developed using germplasm obtained from the public sector.

Increased privatization of national maize seed industries has brought generally positive results, but at the same time there are grounds for concern. The accelerating cost of genetic improvement research, coupled with the growing importance of IPR, is rapidly changing the rules of the plant breeding game. Fearful of conceding advantages to potential competitors, most of the large corporations that currently dominate the global maize seed industry are becoming less enthusiastic about sharing information, technology, and germplasm. As a result, maize breeding is rapidly being transformed from a collaborative activity undertaken for the common good into a competitive activity undertaken for individual profit. Since most public breeding programs depend heavily on the free exchange of germplasm and information, this trend raises questions about the future survival of the international breeding system.

Against a backdrop of declining public sector support for maize research, IARCs continue to play a vital facilitating role in support of international breeding efforts. The germplasm exchange network coordinated by CIMMYT has served as a particularly effective mechanism for promoting international flows of improved germplasm, as evidenced by the widespread use of CIMMYT materials in both public and private breeding programs. Yet despite the impressive progress achieved to date, considerable challenges remain to be overcome if modern varieties are to reach the poorest of the poor.

More than one-third of the developing world's maize area (nearly one-half of the maize area in nontemperate production environments) is still planted to farm-saved seed of uncertain genetic background and highly variable quality. In many instances, improved germplasm is available, but small-scale farmers located in isolated rural areas continue to use farm-saved seed because they are not attractive customers for profit-oriented commercial seed producers. As IARCs reposition themselves in the rapidly evolving global seed industry, they are being challenged to come up with creative approaches to reaching the millions of small-scale farmers who have not yet been integrated into the commercial farming sector.