

competent) in-house breeding programs. Perfectly capable of developing their own germplasm sources, these companies have usually not had to rely on CIMMYT for breeding materials. Perhaps more importantly, the germplasm available from CIMMYT has not always been well suited for African production environments. Most of the maize produced in Eastern and Southern Africa is grown in subtropical and mid-altitude transition zones, which for many years received relatively little attention from the CIMMYT Maize Program. When it became apparent that germplasm developed in Mexico could not be introduced successfully into Africa without undergoing additional adaptation breeding, CIMMYT established a major breeding station near Harare, Zimbabwe. Fifteen years later, this investment is paying off. The Harare program has released a number of high-yielding, drought-tolerant inbred lines showing excellent levels of resistance to major diseases and pests. These lines are being used by private seed companies and are starting to show up in commercial releases. Seed industry contacts say that many experimental hybrids currently in the pipeline were developed using CIMMYT source materials, suggesting that use of CIMMYT lines is increasing.

In Asia, the relatively modest use of CIMMYT germplasm by private breeding programs can be explained mainly in terms of institutional constraints. Forced to cover a vast area with limited human and financial resources, the CIMMYT Maize Program for a long time was not able to interact as closely with the private sector in Asia as it was in other regions. The situation has improved in recent years following concerted efforts to strengthen links with private companies, and private-sector breeders now actively participate with public-sector scientists in CIMMYT-sponsored collaborative networks.

ADOPTION OF MODERN VARIETIES (MVs)

Information presented in the preceding sections of this report about improved varieties developed by public and private maize breeding programs in developing countries attests to the productivity of these programs and makes clear that breeders in both sectors have made extensive use of germplasm obtained from CIMMYT. What the data about varietal releases do not tell us, however, is the extent to which farmers have made use of these varieties. This section of the report presents information about the adoption of maize MVs in developing countries.

Before we turn to the evidence on adoption, a caveat is necessary. Estimating the area planted to improved germplasm is complicated by at least three factors. First, the physical environments and cropping systems in which maize is grown are extremely diverse, so the uptake of MVs often varies considerably even within the same country. Second, in many developing countries maize is grown by subsistence-oriented farmers who do not regularly purchase commercial seed; since these farmers often plant farm-saved seed, it can be extremely difficult to identify improved germplasm in the field, because the genetic makeup of successive crops can quickly change in the presence of seed recycling (for a review of evidence, see Morris, Risopoulos, and Beck 1999). Third, most commercial maize seed is now produced in the private sector; since many private companies consider seed sales information to be confidential, it is often difficult to get seed sales data for use in gauging varietal adoption trends.

Because of the difficulties inherent in estimating the adoption of improved germplasm, we present two types of data relating to the uptake and use of improved OPVs and hybrids. First we present

data about commercial seed sales. Although seed sales data do not always provide a reliable indicator of the area planted to improved cultivars, they provide important insights about the strength of the demand for improved varieties.⁸ After reviewing the evidence on commercial seed sales, we turn to direct estimates of the area planted to improved OPVs and hybrids.

Sales of Commercial Maize Seed

Table 12 shows sales of commercial maize seed for 1996/97 reported by the public seed agencies and private companies that participated in the CIMMYT survey. Since the survey targeted mainly larger companies with breeding programs, the figures reported in Table 12 do not include sales by many small local seed companies. Actual seed sales therefore were higher, with the margin of error varying by region. In Latin America, the survey coverage was quite extensive, so the figures reported in Table 12 are believed to be accurate to within 10%. In Asia, where it was not possible to achieve the same degree of coverage in the survey,

the figures reported in Table 12 could under-report actual seed sales by as much as 20%. In Eastern and Southern Africa, where small local seed companies are relatively uncommon, the figures reported in Table 12 are probably accurate to within 15%.

The seed sales data presented in Table 12 are noteworthy in three respects. First, maize seed is big business in the developing world. In 1996/97, maize seed sales by companies that participated in the CIMMYT survey exceeded half a million tons. This number would increase significantly with the addition of seed sales by companies that did not participate in the CIMMYT survey, especially companies operating in northern China. Second, outside China, the global maize seed industry has effectively been privatized. Excluding China, where control of the maize seed industry remains in the hands of provincial and municipal governments, private seed companies outsell public seed agencies by more than ten to one. Third, the global market for maize seed is dominated by hybrids. Sales of OPV seed account for only 6% of the total market, a number that would decrease even further if seed sales in northern China were included.

Table 12. Commercial maize seed sales, by type of seed and seed organization, 1996/97 (tons).

	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
Eastern and Southern Africa ^a	5,600	14,100	19,700	4,100	67,700	71,800	9,700	81,800	91,500
East, South, and Southeast Asia ^b	1,700	94,400	96,100	3,200	67,800	71,000	4,900	162,200	167,100
All regions	12,000	113,000	125,000	21,700	416,200	437,900	33,700	529,200	562,900

^a Estimated for some countries.

^b Southern China only.

Source: CIMMYT maize impacts survey.

⁸ Commercial seed sales data can be combined with information about average planting rates to derive estimates of the area potentially planted to modern varieties, but the results must be interpreted with caution. For a number of reasons, the procedure may generate misleading results. For example, use of commercial seed sales data will produce an underestimate of the area potentially planted to modern varieties when use of farm-saved seed is extensive. Alternatively, use of commercial seed sales data will produce an overestimate of the area potentially planted to modern varieties if a portion of the commercial seed that is reported as sold never gets planted, or if large areas must be replanted to overcome the effects of low germination, poor stand establishment, early season crop failure, etc.

Additional descriptive statistics relating to maize seed sold in 1996/97 are presented in Table 13a (global summary) and Tables 13b-d (regional sub-totals).⁹

In terms of ecological adaptation, maturity range, grain color, and grain texture, seed sales data offer few surprises. Regional differences in characteristics of maize seed sold in 1996/97 are consistent with regional differences in production environments, cropping systems, and consumption requirements, indicating that seed

producers are adept at identifying local germplasm needs and tailoring seed supply to meet those needs.

More interesting are the insights provided by the seed sales data into the relative popularity of public and private varieties. 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

Table 13a. Characteristics of commercial maize seed sold by public and private seed companies, developing countries, late 1990s.

	Seed sold by:			
	Public agencies	Private companies		All organizations
		Domestic	MNCs	
Estimated total seed sales (t)	127,000	129,000 ^b	301,700 ^b	557,700
<i>Origin of variety</i>				
Public sector (%)	0.89	0.27	0.01	0.25
Private sector (%)	0.11	0.73	0.99	0.75
<i>Type of material</i>				
OPVs (%)	0.17	0.14	0.00	0.07
Hybrids (%)	0.83	0.86	1.00	0.93
<i>Ecological adaptation</i>				
Lowland tropical (%)	0.22	0.66	0.63	0.55
Subtropical / Mid-altitude (%)	0.26	0.15	0.11	0.15
Highland (%)	0.06	0.00	0.00	0.02
Temperate (%)	0.45	0.19	0.25	0.28
<i>Maturity range</i>				
Extra early / Early (%)	0.25	0.30	0.23	0.25
Intermediate (%)	0.35	0.32	0.31	0.32
Late / Extra late (%)	0.40	0.39	0.47	0.44
<i>Grain color</i>				
White grain (%)	0.34	0.19	0.15	0.20
Yellow / Other color grain (%)	0.66	0.81	0.85	0.80
<i>Grain texture</i>				
Flint / Semi-flint (%)	0.33	0.47	0.60	0.51
Dent / Semi-dent (%)	0.67	0.53	0.41	0.49
Other (%)	0.00	0.00	0.00	0.00
<i>Containing CIMMYT germplasm</i>				
All materials (%)	0.19	0.61	0.70	0.58
Non-temperate materials (%)	0.36	0.81	0.83	0.75

^a Percentages refer to commercial seed for which information is available.

^b Sales by domestic companies estimated to comprise 30% of total private sector seed sales.

Source: CIMMYT maize impacts database.

⁹ As with the statistics reported earlier for varietal releases, the statistics relating to commercial seed were calculated based on commercial seed for which descriptive information was available. Assuming that seed for which information was not available was similar to seed for which information was available, the statistics reported in Tables 13a-d are representative of all commercial maize seed sold in 1996/97.

very popular in Eastern and Southern Africa (accounting for 75% of all seed sales within the region), 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.

Last but not least, the seed sales data presented in Tables 13a-d provide additional evidence that germplasm obtained from CIMMYT is being used extensively. Of all commercial maize seed sold during 1996/97 in the survey countries and for which variety-specific information is available, 58% was seed of varieties that had been developed using germplasm obtained from CIMMYT.¹⁰ Focusing more directly on environments targeted by CIMMYT maize breeders, of all commercial maize seed sold during 1996/97 in countries with predominantly non-temperate production

Table 13b. Characteristics of commercial maize seed sold by public and private seed companies in 1996/97, Latin America.^a

	Seed sold by:			
	Public agencies	Private companies		All organizations
		Domestic	MNCs	
Estimated total seed sales (t)	9,200	82,600 ^b	212,400 ^b	304,200
<i>Origin of variety</i>				
Public sector (%)	1.00	0.34	0.00	0.11
Private sector (%)	0.00	0.66	1.00	0.89
<i>Type of material</i>				
OPVs (%)	0.47	0.18	0.00	0.06
Hybrids (%)	0.53	0.83	1.00	0.94
<i>Ecological adaptation</i>				
Lowland tropical (%)	0.74	0.66	0.60	0.62
Subtropical / Mid-altitude (%)	0.23	0.14	0.10	0.11
Highland (%)	0.03	0.00	0.00	0.00
Temperate (%)	0.00	0.20	0.31	0.27
<i>Maturity range</i>				
Extra early / Early (%)	0.06	0.15	0.14	0.14
Intermediate (%)	0.50	0.38	0.32	0.34
Late / Extra late (%)	0.44	0.48	0.54	0.52
<i>Grain color</i>				
White grain (%)	0.60	0.23	0.13	0.17
Yellow / Other color grain (%)	0.40	0.77	0.87	0.83
<i>Grain texture</i>				
Flint / Semi-flint (%)	0.46	0.50	0.58	0.56
Dent / Semi-dent (%)	0.52	0.50	0.42	0.44
Other (%)	0.02	0.00	0.00	0.00
<i>Containing CIMMYT germplasm</i>				
All materials (%)	0.57	0.66	0.80	0.76
Non-temperate materials (%)	0.57	0.82	0.99	0.93

^a Percentages refer to commercial seed for which information is available.

^b Sales by domestic companies estimated to comprise 28% of total private sector seed sales.

Source: CIMMYT maize impacts database.

¹⁰ Figures referring to the CIMMYT germplasm content of commercial seed sold in 1996/97 must be interpreted with caution, because data were not available for several important maize-producing countries in which CIMMYT germplasm has not been used extensively. Including seed sales data from these countries would reduce the proportion of all commercial seed classified as "CIMMYT-derived."

environments and for which variety-specific information is available, 75% was seed of varieties developed using CIMMYT germplasm.

Use of CIMMYT-derived varieties varied widely by region, however. In Latin America, 76% of all commercial maize seed sold in 1996/97 was seed of varieties developed using CIMMYT germplasm (93% of all seed sold in non-temperate regions). By contrast, in Eastern and Southern Africa, only 13% of all commercial maize seed sold in 1996/97 was seed of varieties developed using CIMMYT germplasm (14% of all seed sold in non-temperate regions). In East, South, and Southeast Asia, 21% of all commercial maize seed sold in 1996/97 was seed of varieties developed using CIMMYT

germplasm (36% of all seed sold in non-temperate regions).

The seed sales data presented in Tables 12 and 13 are revealing, but because they relate to a single year, the picture they provide is static. In order to get a better sense of how the maize seed industry has changed through time, it is useful to examine longer term trends in seed sales data. Figure 4 shows the evolution of total commercial maize seed sales from 1990-97. Summing across all three developing regions, the data show a slight upward trend. The aggregate global data mask significant differences at the regional level, however. In Latin America and Asia, total commercial seed sales increased steadily throughout the 1990s, while in Africa they decreased (Figures 5a-c).

Table 13c. Characteristics of commercial maize seed sold by public and private seed companies in 1996/97, Eastern and Southern Africa.^a

	Seed sold by:			
	Public agencies	Private companies		All organizations
		Domestic	MNCs	
Estimated total seed sales (t)	21,700	21,500 ^b	43,100 ^b	86,300
<i>Origin of variety</i>				
Public sector (%)	0.98	0.00	0.22	0.75
Private sector (%)	0.03	1.00	0.78	0.25
<i>Type of material</i>				
OPVs (%)	0.21	0.00	0.00	0.15
Hybrids (%)	0.79	1.00	1.00	0.85
<i>Ecological adaptation</i>				
Lowland tropical (%)	0.00	0.00	0.22	0.07
Subtropical / Mid-altitude (%)	0.72	1.00	0.69	0.71
Highland (%)	0.22	0.00	0.09	0.18
Temperate (%)	0.06	0.00	0.00	0.04
<i>Maturity range</i>				
Extra early / Early (%)	0.09	0.33	0.12	0.10
Intermediate (%)	0.08	0.33	0.28	0.14
Late / Extra late (%)	0.83	0.33	0.60	0.76
<i>Grain color</i>				
White grain (%)	0.96	1.00	0.97	0.96
Yellow / Other color grain (%)	0.04	0.00	0.04	0.04
<i>Grain texture</i>				
Flint / Semi-flint (%)	0.26	0.00	0.25	0.26
Dent / Semi-dent (%)	0.74	1.00	0.75	0.74
Other (%)	0.00	0.00	0.00	0.00
<i>Containing CIMMYT germplasm</i>				
All materials (%)	0.07	n.a.	0.31	0.13
Non-temperate materials (%)	0.07	n.a.	0.31	0.14

^a Percentages refer to commercial seed for which information is available.

^b Sales by domestic companies estimated to comprise 33% of total private sector seed sales.

Source: CIMMYT maize impacts database.

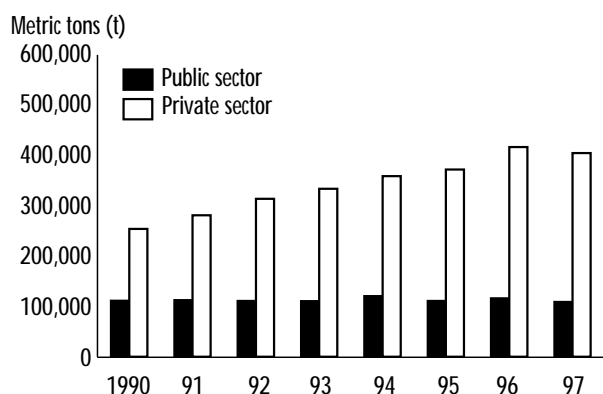


Figure 4. Total maize seed sales, all developing countries, 1990-97.

Source: CIMMYT survey.

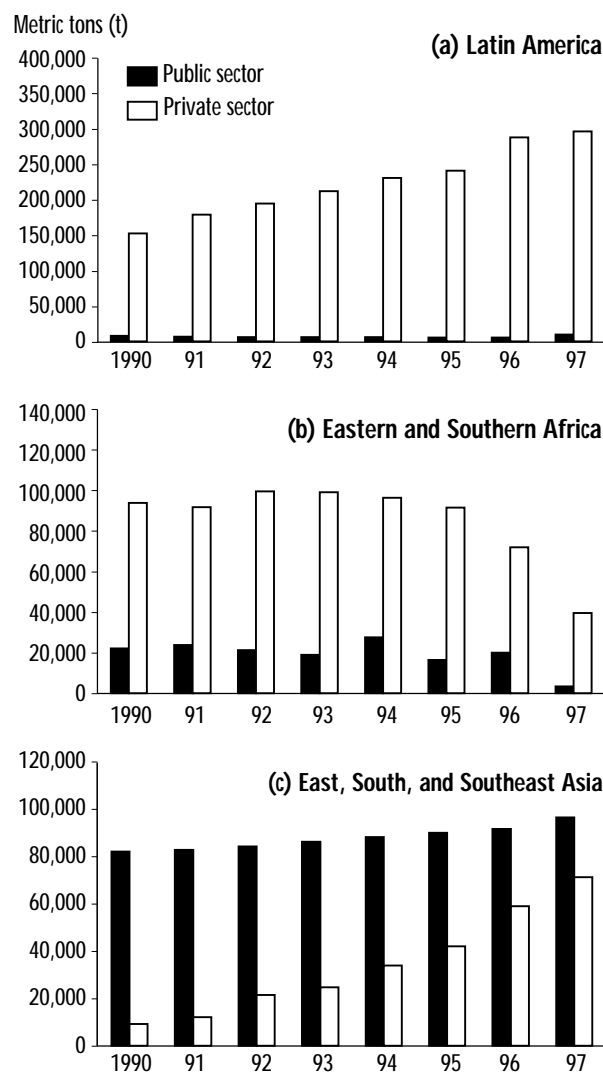


Figure 5. Total maize seed sales, by region, 1990-97.

Source: CIMMYT survey.

To what degree have public seed agencies contributed to these trends? Figure 6 shows the evolution of seed sales by public seed agencies from 1990-97. Summing across all three developing regions, public-sector seed sales remained relatively unchanged during this period. Overall, growth in public-sector seed sales was driven by developments in Asia, particularly in China, where demand for improved seed strengthened as farmers expanded plantings to meet the exploding demand for animal feed (Figure 7c). Public-sector seed sales were more erratic in Latin America and Eastern and Southern Africa (Figures 7a, 7b), partly as the result of highly variable weather that affected both regions.

Meanwhile, what was happening in the private sector? Figure 8 shows the evolution of seed sales by private seed companies from 1990-97. Since private-sector seed sales dominate total seed sales, it is not surprising that trends in private-sector seed sales closely resemble trends in total seed sales. Summing across all three developing regions, the data show a slight upward trend. Again, there was considerable variability between regions; in Latin America and Asia, private-sector seed sales increased steadily throughout the 1990s, while in Eastern and Southern Africa they decreased (Figures 9a-c).

Adoption of MVs

How extensive is the area planted in the developing world to improved maize cultivars? Survey respondents were asked to estimate the percentage of total national maize area under each of 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

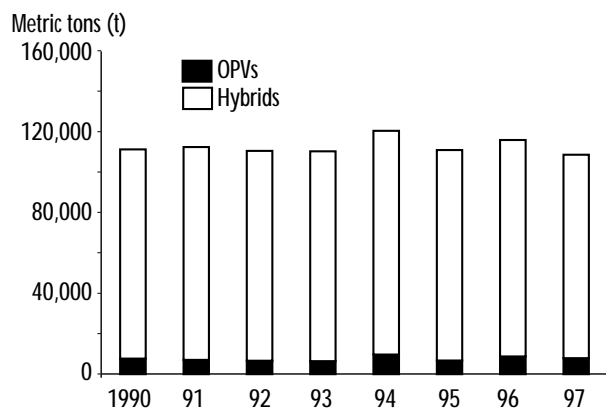


Figure 6. Public-sector maize seed sales, all developing countries, 1990-97.
Source: CIMMYT survey.

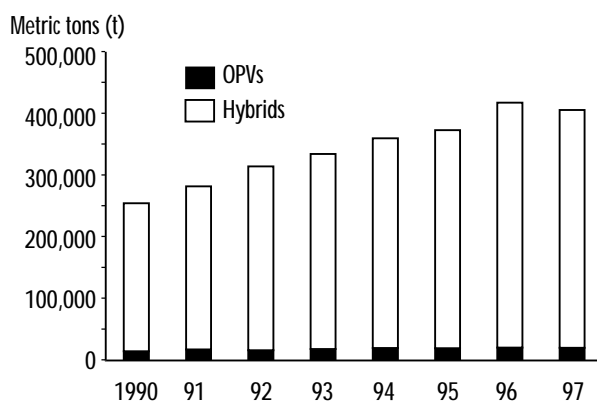


Figure 8. Private-sector maize seed sales, all developing countries, 1990-97.
Source: CIMMYT survey.

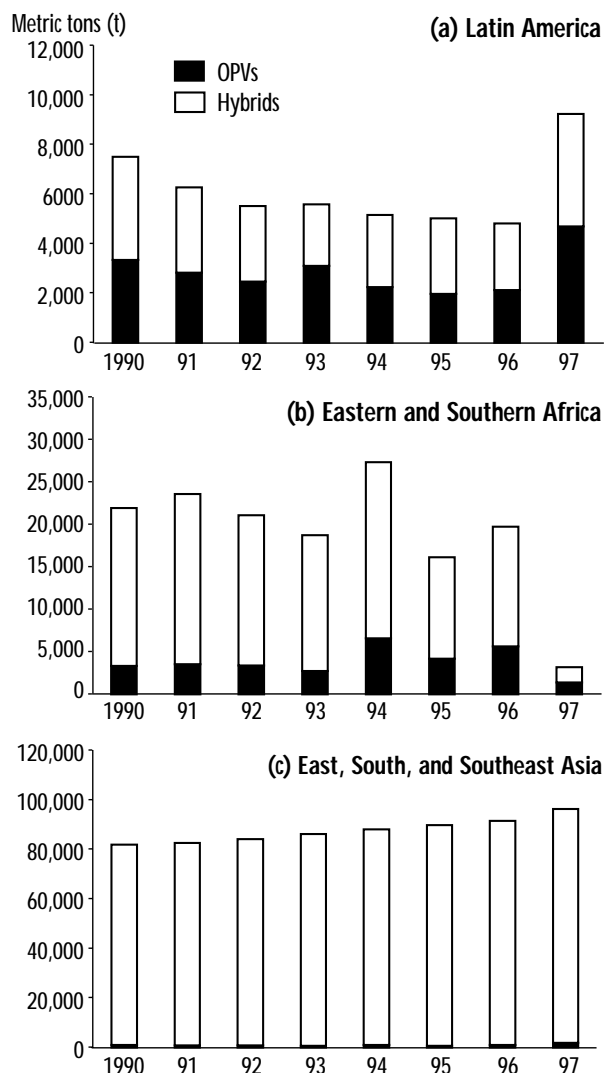


Figure 7. Public-sector maize seed sales, by region, 1990-97.
Source: CIMMYT survey.

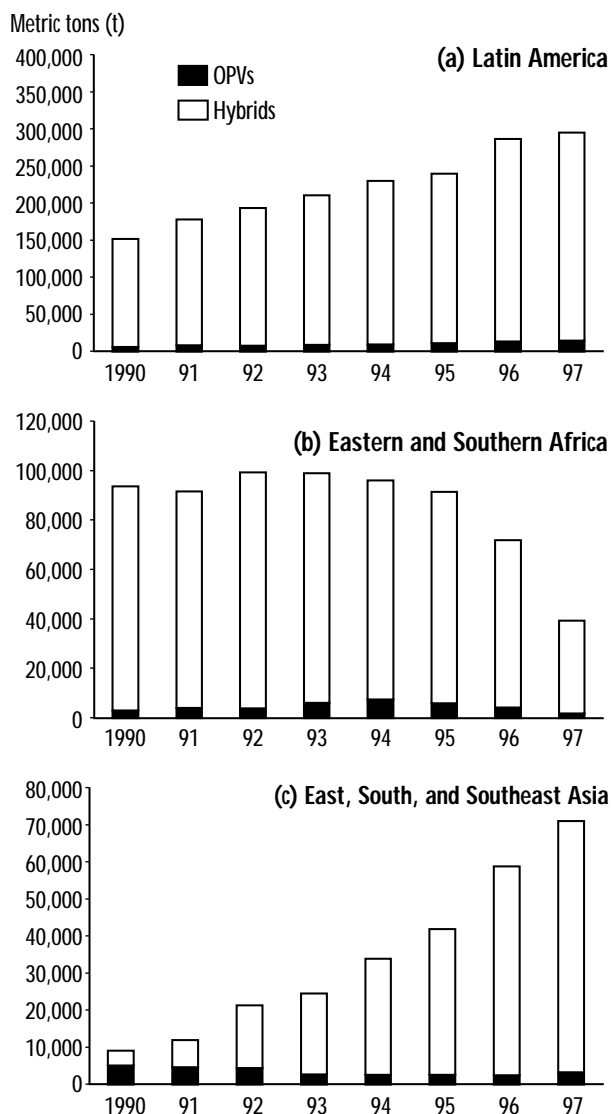


Figure 9. Private-sector maize seed sales, by region, 1990-97.
Source: CIMMYT survey.

(3) hybrids grown from newly-purchased commercial seed. Ideally these estimates would have been based on farm-level data, but varietal adoption surveys are rarely carried out at the national level because of their high cost. Therefore in most cases the respondents had to make subjective estimates based on whatever adoption data were available. These subjective estimates were later double-checked against commercial seed sales data for consistency.

Tables 14a-d present estimates of the area planted to each of the three germplasm categories during the late 1990s.¹¹ To provide a more complete picture of global adoption patterns, the tables reflect not only MV adoption data collected through the CIMMYT survey, but also MV adoption rates reported by IITA for 11 countries in West and Central Africa. In addition, adoption data were subjectively estimated for four non-surveyed countries: Côte d'Ivoire, northern China, Egypt, and Pakistan.

Table 13d. Characteristics of commercial maize seed sold by public and private seed companies in 1996/97, East, South, and Southeast Asia.^a

	Seed sold by:			All organizations
	Public agencies	Private companies Domestic	MNCs	
Estimated total seed sales (t)	96,200	24,900 ^b	46,200 ^b	167,200
<i>Origin of variety</i>				
Public sector (%)	0.86	0.00	0.00	0.44
Private sector (%)	0.14	1.00	1.00	0.56
<i>Type of material</i>				
OPVs (%)	0.12	0.00	0.02	0.07
Hybrids (%)	0.88	1.00	0.98	0.93
<i>Ecological adaptation</i>				
Lowland tropical (%)	0.23	0.83	0.93	0.50
Subtropical / Mid-altitude (%)	0.13	0.17	0.07	0.11
Highland (%)	0.02	0.00	0.00	0.01
Temperate (%)	0.62	0.00	0.00	0.39
<i>Maturity range</i>				
Extra early / Early (%)	0.31	0.89	0.70	0.53
Intermediate (%)	0.41	0.10	0.23	0.30
Late / Extra late (%)	0.28	0.02	0.07	0.17
<i>Grain color</i>				
White grain (%)	0.12	0.01	0.11	0.10
Yellow / Other color grain (%)	0.88	0.99	0.89	0.90
<i>Grain texture</i>				
Flint / Semi-flint (%)	0.33	0.37	0.74	0.48
Dent / Semi-dent (%)	0.67	0.63	0.26	0.52
Other (%)	0.00	0.00	0.00	0.00
<i>Containing CIMMYT germplasm</i>				
All materials (%)	0.19	0.27	0.23	0.21
Non-temperate materials (%)	0.52	0.30	0.26	0.36

^a Percentages refer to commercial seed for which information is available.

^b Sales by domestic companies estimated to comprise 35% of total private sector seed sales.

Source: CIMMYT maize impacts database.

¹¹ The country-level maize area planted data reported here were downloaded on 03/31/01 from the FAOSTAT Agricultural Production online database. The FAOSTAT database is periodically updated, so the maize area planted data reported here may differ slightly from those that were reported in the three regional maize impacts studies published previously. For this reason, estimates of the area planted to MVs reported here also may differ slightly from those reported in the regional impacts studies.

Overall, of the 94.2 million ha planted to maize in 51 developing countries, approximately 62.4% (representing about 58.8 million ha) were planted to improved cultivars. Excluding Argentina, northern China, and South Africa, where maize is grown mainly in temperate environments, of the 65.7 million ha planted to maize in non-temperate environments, approximately 47.2 % (representing 31 million ha) were planted to improved cultivars.

How do these findings compare to those of the CIMMYT global impacts study carried out in 1992? Since the geographical coverage of the earlier study was different, care should be taken in comparing the two sets of results. The 1992 survey covered mainly non-temperate countries; Argentina, northern China, and South Africa were not included. On the other hand, the earlier survey

included a number of countries in WANA that were not included in the more recent survey, but these countries account for a small proportion of global maize production and have relatively little influence on regional and global totals. The estimated current MV adoption level in the non-temperate countries of 47.2% is significantly higher than the MV adoption level estimated during the earlier CIMMYT impacts study, which found that in 1990 approximately 42.6% of the developing world's maize area was planted to improved cultivars (López-Pereira and Morris 1994).

Several conclusions can be drawn from the adoption data summarized in Tables 14a-d.

- Maize MVs have spread widely throughout the developing world.

Table 14a. Maize area planted to traditional and modern varieties, Latin America, 1996.

	1996 maize area planted (000 ha)	Planted to farm-saved seed ^a (%)	Planted to modern varieties:		
			OPVs ^b (%)	Hybrids (%)	Total (%)
Caribbean	379	66.2	20.0	13.8	33.8
Cuba	89	5.5	36.0	58.5	94.5
Dominican Republic	33	24.0	76.0	0.0	76.0
Haiti	257	92.8	7.3	0.0	7.3
Mexico and Central America	9,676	79.5	1.5	19.0	20.5
Costa Rica	16	58.0	1.1	40.9	42.0
El Salvador	278	51.9	0.5	47.6	48.2
Guatemala	575	82.8	1.7	15.5	17.2
Honduras	407	84.3	7.2	8.6	15.7
Mexico	8,051	79.7	1.1	19.2	20.3
Nicaragua	278	93.1	5.6	1.3	6.9
Panama	72	57.1	0.6	42.3	42.9
Andean Zone	2,203	58.4	8.7	32.9	41.6
Bolivia	287	47.9	27.1	25.1	52.1
Colombia	593	73.7	6.6	19.8	26.3
Ecuador	556	73.2	5.0	21.8	26.8
Peru	401	75.3	11.7	13.0	24.7
Venezuela	366	1.0	0.0	99.0	99.0
Southern Cone	14,862	38.5	6.3	55.2	61.5
Argentina	2,604	12.7	2.4	84.9	87.3
Brazil	11,934	43.4	7.3	49.3	56.6
Paraguay	325	64.5	1.7	33.9	35.5
Latin America	27,121	55.1	5.0	39.9	44.9
w/o Argentina	24,517	59.6	5.3	35.1	40.4

^a Includes landraces and very old OPVs and hybrids grown from advanced-generation recycled seed.

^b Includes area planted to recycled OPV seed.

Source: CIMMYT global maize impacts survey.

- The area planted to maize MVs continues to expand.
- Maize MVs have been adopted less extensively in non-temperate areas 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.
- Expressed as a percentage of the total area planted to maize, the area under MVs has increased markedly during the past decade.

Adoption of MVS Developed Using CIMMYT Germplasm

The MV adoption estimates presented in Tables 14a-d were combined with information about varietal releases and/or commercial seed sales data to derive estimates of the area planted to cultivars developed using CIMMYT germplasm. Depending on the availability of data, two different estimation methods were used.

Table 14b. Maize area planted to traditional and modern varieties, sub-Saharan Africa, 1997.

	1997 maize area planted (000 ha)	Planted to farm-saved seed ^a (%)	Planted to modern varieties:		
			OPVs ^b (%)	Hybrids (%)	Total (%)
Western and Central Africa^c	9,067	64.0	32.3	3.7	36.0
Benin	577	74.7			25.3
Burkina Faso	241	54.5			45.5
Cameroon	375	72.0			28.0
Chad	104	30.0			70.0
Congo, D.R.	1,427	68.7			31.3
Côte d'Ivoire ^d	700	68.0			32.0
Ghana	652	47.0			53.0
Guinea	84	77.4			22.6
Mali	202	77.1			22.9
Nigeria	4,200	60.0			40.0
Senegal	62	10.8			89.2
Togo	423	98.7			1.3
Eastern Africa	3,821	60.3	11.6	28.1	39.7
Ethiopia	1,718	94.2	1.9	3.9	5.8
Kenya	1,505	27.6	7.5	65.0	72.5
Uganda	598	45.3	50.0	4.7	54.7
Southern Africa	11,088	43.0	5.2	51.7	57.0
Angola	620	74.5	25.0	0.5	25.5
Lesotho	144	25.2	10.9	63.9	74.8
Malawi	1,234	88.6	4.4	7.0	11.4
Mozambique	1,154	92.0	8.0	0.1	8.0
South Africa	4,023	2.4	3.1	94.5	97.6
Swaziland	61	24.6	2.2	73.2	75.5
Tanzania	1,564	90.0	4.0	6.0	10.0
Zambia	649	80.8	0.6	18.6	19.3
Zimbabwe	1,640	4.5	4.5	91.0	95.5
Eastern and Southern Africa w/o South Africa	14,910	47.5	6.9	45.7	52.6
Sub-Saharan Africa w/o South Africa	19,934	64.1	8.3	27.6	35.9
Sub-Saharan Africa	23,957	53.7	16.5	29.8	46.3
w/o South Africa	19,934	64.1	19.2	16.8	36.0

^a Includes landraces and very old OPVs and hybrids grown from advanced-generation recycled seed.

^b Includes area planted to recycled OPV seed.

^c MV adoption data for Western and Central Africa provided by IITA.

^d Not included in IITA survey; data estimated indirectly.

Source: CIMMYT global maize impacts survey.

Table 14c. Maize area planted to traditional and modern varieties, East, South, and Southeast Asia, 1999.

	1999 maize area planted (000 ha)	Planted to farm-saved seed ^a (%)	Planted to modern varieties:		
			OPVs ^b (%)	Hybrids (%)	Total (%)
East Asia	25,939	1.0	5.2	93.8	99.0
Southern China	4,114	1.0	11.8	87.2	99.0
Northern China ^c	21,825	1.0	4.0	95.0	99.0
South Asia	8,207	50.0	24.6	25.4	50.0
India	6,511	49.0	22.0	29.0	51.0
Nepal	802	36.0	45.4	18.6	64.0
Pakistan ^d	894	70.0	25.0	5.0	30.0
Southeast Asia	8,144	37.8	24.8	37.4	62.2
Indonesia	3,456	30.0	41.0	29.0	70.0
Philippines	2,701	64.0	12.0	24.0	36.0
Thailand	1,300	0.3	13.9	85.8	99.7
Vietnam	687	44.5	14.7	40.8	55.5
East, South, and Southeast Asia w/o northern China	42,290	17.6	12.3	69.6	82.4
	20,465	35.3	22.1	42.6	64.7

^a Includes landraces and very old OPVs and hybrids grown from advanced-generation recycled seed.

^b Includes area planted to recycled OPV seed.

^c Not included in CIMMYT survey. MV adoption estimated based on information provided by sources in the Chinese national maize breeding program (Zhang, personal communication).

^d Not included in CIMMYT survey. MV adoption estimated based on information provided by sources in the Pakistan national maize breeding program (Aslam, personal communication).

Source: CIMMYT global maize impacts survey.

Table 14d. Maize area planted to traditional and modern varieties, developing countries, late 1990s.^a

	1990s maize area planted ^b (000 ha)	Planted to farm-saved seed ^c (%)	Planted to modern varieties:		
			OPVs ^d (%)	Hybrids (%)	Total (%)
Latin America w/o Argentina	27,121	55.1	5.0	39.9	44.9
	24,517	59.6	5.3	35.1	40.4
Western and Central Africa^e	9,047	64.0	32.3	3.7	36.0
Eastern and Southern Africa w/o South Africa	14,910	47.5	6.9	45.7	52.6
	10,886	64.1	8.3	27.6	35.9
Sub-Saharan Africa w/o South Africa	23,957	53.7	16.5	29.8	46.3
	19,934	64.1	19.2	16.8	36.0
East, South, and Southeast Asia w/o northern China	42,290	17.8	12.8	69.6	82.4
	20,465	35.3	22.1	42.6	64.7
All regions	94,182	37.6	11.5	51.0	62.4
All non-temperate regions^f	65,731	52.8	14.8	32.4	47.2

^a Includes data for 48 countries covered by the CIMMYT and IITA surveys, plus northern China, Côte d'Ivoire, Pakistan, and Egypt. Countries with 100,000 ha or more planted to maize that were not included: Turkey (545,000 ha), Korea DPR (496,000 ha), Morocco (341,000 ha), Myanmar (203,000 ha), Afghanistan (200,000), Somalia (200,000 ha), Madagascar (190,000 ha), Iran (133,000 ha), Burundi (115,000).

^b Years: Latin America = 1996; Eastern and Southern Africa = 1997; Western and Central Africa = 1998; East, South, and Southeast Asia = 1999.

^c Includes landraces and very old OPVs and hybrids grown from advanced-generation recycled seed.

^d Includes area planted to recycled OPV seed.

^e Estimated based on results of IITA impacts study, 1992 CIMMYT impacts study.

^f Excluding Argentina, South Africa, and northern China.

Source: CIMMYT global maize impacts survey.

SEED-BASED METHOD

For many countries, the survey of seed organizations generated data on a significant proportion of all commercial maize seed sold during the reference year (1996 for Latin America, 1997 for Africa and Asia). Most of the seed sales data were cultivar-specific, and since the CIMMYT germplasm content of most cultivars was known, it was often possible to calculate the proportion of commercial seed sold in each country that was seed of CIMMYT-derived cultivars. This proportion was then applied to the area planted to MVs to derive an estimate of the area planted to CIMMYT-derived MVs. In other words, if 40% of the commercial maize seed sold during the reference year was known to be seed of CIMMYT-derived cultivars, it was assumed that 40% of the area planted to MVs during the reference year was planted to CIMMYT-derived cultivars. This method is based on the assumption (reasonable when data are available about a significant proportion of total seed sales) that the seed for which no information is available is similar in its CIMMYT germplasm content to the seed for which information is available.

VARIETAL RELEASES-BASED METHOD

One disadvantage of the seed-based method is that it requires detailed knowledge of the germplasm content of a significant proportion of all seed planted by farmers. The method therefore can give misleading results if data on commercial seed sales are incomplete. This was a concern for the present study, because in some countries the survey generated limited information about commercial seed sales, at least for certain types of cultivars. In five African countries (Angola, Lesotho, South Africa, Swaziland, Tanzania), relatively little

information was generated about sales of OPV or hybrid seed. In six Asian countries (India, Indonesia, Nepal, the Philippines, Thailand, Vietnam), relatively little information was generated about sales of OPV seed.¹²

The seed-based method has a second potential drawback. Even when detailed information is available about the germplasm content of commercial seed, the method can give misleading results if a significant proportion of the area planted to maize MVs is planted to farm-saved seed. Farm-saved seed often includes advanced-generation seed of older varieties, especially OPVs, so estimating the area planted to CIMMYT-derived cultivars on the basis of commercial seed is risky, because the CIMMYT germplasm content of varieties currently being sold may differ from that of varieties sold in earlier years.

In countries where commercial seed sales data were deemed incomplete, therefore, the area planted to CIMMYT-derived cultivars was estimated based on the CIMMYT content of varietal releases. This was done by calculating the proportion of all cultivars released between 1966 and 1999 that had been developed using CIMMYT germplasm; this proportion was then applied to the area planted to MVs during the reference year to derive an estimate of the area planted to CIMMYT-derived MVs. In other words, in countries where limited information was available about the germplasm content of commercial seed, if 70% of the MVs released between 1966 and 1997 had been developed using CIMMYT germplasm, then it was assumed that 70% of the area planted to MVs during the reference year was planted to CIMMYT-derived MVs. In African countries, where variety-specific seed sales data were sometimes unavailable for OPVs and hybrids, this method was applied to the entire area planted to

¹² The fact that the survey generated relatively little information about sales of OPV seed is not surprising, because relatively little OPV seed was sold by the organizations that participated in the survey. OPV seed is produced mainly by small local seed companies, community-based seed organizations, and NGOs, which were underrepresented in the survey.

MVs. In Asian countries, where variety-specific seed sales data were available only for hybrids, the varietal releases-based method was applied only to the area planted to improved OPVs.

Estimates of the area planted to CIMMYT-derived cultivars appear in Tables 15a-d. Overall, of the 94.2 million ha planted to maize in 51 developing countries, approximately 58.8 million ha were planted to MVs, of which 21.2 million ha were planted to CIMMYT-derived MVs. Excluding Argentina, northern China, and South Africa, of the 65.7 million ha planted to maize, approximately 31 million ha were planted to MVs, of which 18.2 million ha were planted to CIMMYT-derived MVs. In other words, over one-third

(36.1%) of the total area planted to modern maize varieties in the developing world and over one-half (58.7%) of the non-temperate area planted to modern maize varieties in the developing world was planted to varieties developed using germplasm obtained from CIMMYT.

The area planted to CIMMYT-derived MVs varied by region. In Latin America, 9.8 million ha were planted to CIMMYT-derived MVs (Table 15a). In Africa, 3.8 million ha were planted to CIMMYT-derived MVs (Table 15b). In East, South, and Southeast Asia, 7.2 million ha were planted to CIMMYT-derived MVs (Table 15c).

Table 15a. Maize area planted to CIMMYT-derived modern varieties, Latin America, 1996.^a

	1996 maize area planted (000 ha)	Proportion of maize area under MVs (%)	1996 maize area under MVs (000 ha)	Proportion of MVs with CIMMYT germplasm (%) ^b	Maize area under CIMMYT-derived MVs (000 ha)
Caribbean	379	33.8	128	36.9	47
Cuba	89	94.5	84	50.0	42
Dominican Republic	33	76.0	25	7.9	2
Haiti	257	7.3	19	16.9	3
Mexico and Central America	9,676	20.5	1,988	90.4	1,796
Costa Rica	16	42.0	7	100.0	7
El Salvador	278	48.2	134	93.4	125
Guatemala	575	17.2	99	98.5	97
Honduras	407	15.7	64	99.9	64
Mexico	8,051	20.3	1,634	88.9	1,453
Nicaragua	278	6.9	19	100.0	19
Panama	72	42.9	31	100.0	31
Andean Zone	2,203	41.6	916	97.2	891
Bolivia	287	52.1	149	96.9	145
Columbia	593	26.3	156	100.0	156
Ecuador	556	26.8	149	99.4	148
Peru	401	24.7	99	88.3	87
Venezuela	366	99.0	362	97.7	354
Southern Cone	14,862	61.5	9,140	77.8	7,109
Argentina	2,604	87.3	2,272	29.0	659
Brazil	11,934	56.6	6,752	93.9	6,340
Paraguay	325	35.5	115	94.9	109
Latin America w/o Argentina	27,121	44.9	12,171	80.9	9,842
	24,517	40.4	9,899	92.8	9,183

^a Data presented for 18 countries covered by the CIMMYT survey.

^b Based on proportion commercial seed sold in 1996 that contained CIMMYT germplasm.

Source: CIMMYT global maize impacts survey.

Factors Affecting MV Adoption

Why does the use of maize MVs differ between countries? What explains the fact that MV adoption rates are high in some countries and low in others? Can the factors associated with differences in MV adoption rates be identified?

EVIDENCE AT THE FARM LEVEL

Technology adoption decisions in developing countries have been extensively analyzed. (For surveys of the adoption literature, see Feder, Just, and Zilberman, 1985; Rauniyar and Goode 1992.) Complementing the large amount of theoretical work that focuses on technology adoption in

Table 15b. Maize area planted to CIMMYT-derived modern varieties, sub-Saharan Africa, 1997.^a

	1997 maize area planted (000 ha)	Proportion of maize area under MVs (%)	1997 maize area under MVs (000 ha)	Proportion of MVs with CIMMYT germplasm (%) ^b	Maize area under CIMMYT-derived MVs (000 ha)
Western and Central Africa	9,047	36.0	3,256	66.7	2,170
Benin	577	25.3	146	66.7	97
Burkina Faso	241	45.5	110	66.7	73
Cameroon	375	28.0	105	66.7	70
Chad	104	70.0	73	66.7	48
Congo, D.R.	1,427	31.3	447	66.7	298
Côte d'Ivoire ^c	700	32.0	224	66.7	149
Ghana	652	53.0	345	66.7	230
Guinea	84	22.6	19	66.7	13
Mali	202	22.9	46	66.7	31
Nigeria	4,200	40.0	1,680	66.7	1,120
Senegal	62	89.2	56	66.7	37
Togo	423	1.3	6	66.7	4
Eastern Africa	3,821	39.71	1,517	21.2	321
Ethiopia	1,718	5.8	100	36.4	36
Kenya	1,505	72.5	1,090	11.1	121
Uganda	598	54.7	327	50.0	164
Southern Africa	11,088	57.0	6,317	20.7	1,308
Angola	620	25.5	158	33.3	53
Lesotho	144	74.8	108	5.0	5
Malawi	1,234	11.4	140	55.6	78
Mozambique	1,154	8.0	92	75.0	69
South Africa	4,023	97.6	3,925	5.0	196
Swaziland	61	75.5	46	5.0	2
Tanzania	1,564	10.0	156	33.3	52
Zambia	649	19.3	125	13.6	17
Zimbabwe	1,640	95.5	1,566	53.3	835
Eastern and Southern Africa w/o South Africa	12,168	52.6	7,834	20.8	1,629
Sub-Saharan Africa w/o South Africa	10,886	35.9	3,910	36.7	1,433
Sub-Saharan Africa	23,957	46.3	11,090	34.3	3,800
w/o South Africa	19,934	36.0	7,165	50.3	3,603

^a Data presented for 23 countries covered by the CIMMYT and IITA surveys, plus Côte d'Ivoire.

^b Based on proportion of commercial seed sold in 1997 that contained CIMMYT germplasm. For Angola, Lesotho, Mozambique, South Africa, and Swaziland based on proportion of varietal releases from 1966-98 that contained CIMMYT germplasm.

^c Not included in IITA survey; data estimated indirectly.

Source: CIMMYT global maize impacts survey.

Table 15c. Maize area planted to CIMMYT-derived modern varieties, East, South, and Southeast Asia, 1999.^a

	1999 maize area planted (000 ha)	Proportion of maize area under MVs (%)	1999 maize area under MVs (000 ha)	Proportion of MVs with CIMMYT germplasm (%) ^b	Maize area under CIMMYT-derived MVs (000 ha)
East Asia	42,290	99.0	25,670	10.9	2,786
Southern China	4,114	99.0	4,073	15.4	625
Northern China ^c	20,465	99.0	21,607	10.0	2,161
South Asia	7,313	50.0	4,102	40.5	1,662
India	6,511	51.0	3,321	36.7	1,218
Nepal	802	64.0	514	60.3	310
Pakistan ^d	894	30.0	268	50.0	134
Southeast Asia	8,144	62.2	5,069	54.7	2,775
Indonesia	3,456	70.0	2,420	63.5	1,536
Philippines	2,701	36.0	972	40.0	389
Thailand	1,300	99.7	1,296	53.0	687
Vietnam	687	55.5	381	42.5	162
East, South, and Southeast Asia w/o northern China	42,290	82.4	34,851	20.7	7,222
w/o northern China	20,465	64.7	13,244	38.2	5,062

^a Data presented for seven countries covered by the CIMMYT survey, plus northern China and Pakistan.

^b For improved OPVs, based on proportion of varietal releases from 1966-98 that contained CIMMYT germplasm. For hybrids, based on proportion of commercial seed sold in 1998 that contained CIMMYT germplasm.

^c Not included in the CIMMYT survey; data estimated indirectly.

^d Not included in the CIMMYT survey; data estimated indirectly.

Source: CIMMYT global maize impacts survey.

Table 15d. Maize area planted to CIMMYT-derived modern varieties, developing countries, late 1990s.^a

	1990s maize area planted (000 ha) ^b	Proportion of maize area under MVs (%)	1999 maize area under MVs (000 ha)	Proportion of MVs with CIMMYT germplasm (%) ^c	Maize area under CIMMYT-derived MVs (000 ha)
Latin America	27,121	44.9	12,171	80.9	9,842
Sub-Saharan Africa	23,957	46.3	11,090	34.3	3,800
East, South, Southeast Asia	42,290	82.4	34,851	20.7	7,222
West Asia, North Africa^d	814	85.0	692	50.0	346
All environments^e	94,182	62.4	58,805	36.1	21,210
Non-temperate environments^f	65,731	47.2	31,001	58.7	18,195

^a Data presented for 51 countries representing 97% of total area planted to maize in developing countries.

^b Reference year varies by region. Latin America = 1996; Eastern and Southern Africa = 1997; Western and Central Africa = 1998; East, South, and Southeast Asia = 1999.

^c For details about estimation methods, see notes to Tables 15a, 15b, and 15c.

^d Includes Egypt.

^e Includes data for the 48 countries covered by the CIMMYT and IITA surveys, plus Côte d'Ivoire, northern China, Egypt, and Pakistan.

^f Excluding Argentina, South Africa, and northern China.

Source: CIMMYT global maize impacts survey.

general, numerous empirical case studies provide a wealth of information about the factors affecting farm-level decision to adopt hybrid maize (for example, see Gerhart 1975; Walker 1981; CIMMYT 1992; Byerlee, Morris, and López-Pereira 1993; Smale et al. 1991, 1995; Kumar 1994; Heisey et al., 1998). The common theme emerging from this literature is that farm-level decision to adopt hybrid maize is influenced by a complex and highly variable set of factors. Depending on the context, these can include demographic characteristics of the household (for example, size, age and gender composition, wealth, education level of the household head), the expected profitability and/or perceived risk of the technology, farmers' consumption preferences, and the availability and cost of inputs, especially seed.

EVIDENCE AT THE INDUSTRY LEVEL

While the farm-level decision to adopt hybrid maize has been the focus of considerable research, much less work has been done at the aggregate industry level to identify factors that influence the diffusion of hybrid technology. In his pioneering study of the spread of hybrid maize in the US, Griliches (1957) hypothesized that the uneven rate of diffusion could be linked to both demand and supply factors. Griliches determined that variability in the demand for hybrid maize is related to the additional profits that farmers expect to gain by switching from open-pollinating varieties to hybrids. He also found that variability in the supply of hybrid seed is related to the revenue that seed suppliers expect to earn by entering the market, which depends on factors such as the size of the market, marketing costs, product innovation costs, and expected rate of acceptance.

More recently, Heisey et al. (1998) used cross-sectional data to investigate how demand and supply factors influence the spread of hybrid

maize in 32 developing countries. Heisey et al. concluded that at the aggregate (country) level, diffusion of hybrid maize depends partly on the expected profitability of the technology, which is driven by germplasm performance and seed price. As well, they determined that the diffusion of hybrid maize is strongly influenced by industry-level profitability, which depends on characteristics of the seed market, the organization of the local seed industry, and the cost of research innovation, among other factors.

Using a similar approach, Kosarek, Garcia, and Morris (2001) examined the diffusion of hybrid maize in 23 developing countries in Latin America and the Caribbean region. Like the earlier authors, Kosarek et al. found that diffusion of hybrid maize is influenced not only by demand side factors that affect the profitability of the technology at the farm level (including the level of government policy support provided to maize producers), but also by supply side factors that shape the incentives for firms to invest in seed research and development, seed production, and seed distribution (including the prevailing level of intellectual property protection).

The empirical studies by Griliches, Heisey et al., and Kosarek et al. highlight an important but frequently overlooked point: even when farmers have become convinced that they can benefit from adopting hybrids, successful adoption cannot occur without adequate supplies of hybrid seed. In attempting to explain the diffusion of hybrid technology, therefore, it is important not only to analyze farmers' varietal adoption decisions, but also to examine the factors that shape incentives for firms to produce and sell improved seed. The question of supply-side incentives is especially relevant in developing countries, where private companies have often been reluctant to enter into the production and marketing of hybrid maize seed.

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

ECONOMIC BENEFITS ASSOCIATED WITH MV ADOPTION

As more and more demands are placed on the limited pool of funds available for agricultural research, research organizations face increasing

pressure to show that resources are being used efficiently. In today's highly competitive funding environment, scientists must not only demonstrate that their work is having an impact, but frequently they are also required to quantify the economic benefits that have been generated.

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

The economic benefits estimates presented below were not generated using a formal modeling approach. Instead, they were derived through "back-of-the-envelope" calculations involving a number of simplifying assumptions. Furthermore, they refer only to the benefits received by developing-country maize farmers in the form of increased grain production; no attempt was made to account for indirect benefits received by