popular CIMMYT source material, followed by Population 22 (Mezcla Tropical Blanco) and Population 32 (ETO Blanco). All three of these populations are adapted to lowland topical environments.

Manner of Use of CIMMYT Germplasm

Public and private breeding programs in eastern and southern Africa have tended to use CIMMYT germplasm in different ways (Table 21). Public breeding programs have made extensive use of CIMMYT populations, pools and experimental varieties; most of the time, the CIMMYT source materials have been used directly, with little or no additional selection. In contrast, private seed companies have used mainly CIMMYT inbred lines; in most cases, the CIMMYT lines were subjected to further selection before being used.

Aggregating across public and private breeding programs, among all varieties that were developed using CIMMYT germplasm, in 43% of cases CIMMYT source materials were incorporated with little or no additional improvement at the hands of local breeders. Conversely, in 57% of cases CIMMYT source materials were further improved before being used. This suggests that although many national breeding programs have developed the capacity to do their own improvement work, a considerable number of breeding programs—especially public breeding programs—continue to make direct use of CIMMYT germplasm.

Table 21. Manner of use of CIMMYT source materials by public and private breeding programs, eastern and southern Africa, 1966-98 (% of varietal releases)[a]

Level of improvement	Public releases	Private releases	All releases
No additional improvement of material	25.8	0.0	17.0
No improvement of hybrids/inbred lines	0.0	0.0	0.0
Some improvement of material	32.3	12.5	25.5
Some improvement of hybrids/inbred lines	0.0	0.0	0.0
Substantial improvement of material	41.9	25.0	36.2
Substantial improvement of hybrids/inbred lines	0.0	62.5	21.3

Source: CIMMYT Maize Research Impacts Survey, 1998/99.

[a] Percentage of varietal releases whose manner of use CIMMYT source materials is known.

Farm Level Impacts of Maize Breeding Research

Previous sections of this report have presented information about the numbers and types of maize varieties that have been produced by public and private breeding programs in eastern and southern Africa, as well as information about the CIMMYT germplasm content of these varieties. Information about varietal releases provides an important measure of the productivity of breeding programs, but it does not provide a complete measure of the impacts of breeding programs on maize production. Improved varieties are able to increase maize production and to improve farmers' incomes and welfare only when they are planted in farmers' fields. In assessing the impacts of public and private maize breeding efforts, it is therefore important to estimate the extent to which modern varieties have been adopted by farmers and to estimate the resulting productivity gains.

The most reliable way to measure the adoption of modern varieties is through farm-level surveys. Unfortunately, relatively few of the countries covered by this report have carried out comprehensive national surveys in recent years to document farmers' use of improved maize varieties. Only in Kenya (Hassan et al. 1998), Tanzania (Moshi et al. 1997), and Malawi (Smale and Heisey 1997) have national surveys been carried out.

In the absence of survey data, it is necessary to rely on alternative sources of information to estimate varietal adoption rates. For this report, two methods were used to estimate farmers' use of improved

maize germplasm. Through the questionnaire, individuals with knowledge of the maize sector (e.g., scientists working in public research organizations, representatives of private seed companies) were asked to estimate (a) the total area planted to maize in 1996, and (b) the proportions within that total area planted to local varieties, improved OPVs, and hybrids. In addition, data were collected on commercial seed sales by public seed agencies and private companies in 1996. Based on the seed sales data, and using knowledge of average planting rates in each country, it was possible to estimate the area theoretically planted to commercial seed. These area estimates were then compared with direct area estimates to provide a consistency check.

Direct NARS Estimates of Area Under Improved Maize

Table 22 shows the estimates made by the survey respondents of the total area planted to maize in each country in 1996, along with the 1996 maize area reported by the Food and Agriculture Organization of the United Nations (FAO). With the exception of Angola[6] and Lesotho, where the FAO figures were about 22% lower than the survey respondents' estimates, in all countries the estimates made by the survey respondents closely matched the FAO data (difference of less than 10%). Aggregating to the regional level, the divergence between two estimates was negligible (1.2% difference in eastern Africa and 2.4% difference in southern Africa).

Table 23 shows the estimates of the percentage area in each country planted to improved OPVs and hybrids. According to the national program respondents, in 1996, more than one-half of the maize area in eastern and southern Africa was planted to modern varieties. Adoption rates varied, between individual countries, however. Adoption of modern varieties was highest in South Africa (98%), Zimbabwe (95%), Swaziland (75%), Lesotho (75%), and Kenya (72%). Adoption was lowest in Ethiopia (6%), Mozambique (8%), Tanzania (10%), and Malawi (11%). The pronounced inter-country variability in adoption rates presumably reflects differences between countries in terms of institutional and policy factors, including seed delivery infrastructure, economic incentives to adopt modern varieties, and the strength of the local extension service. These factors may be more important than agroclimatic suitability for the successful diffusion of modern varieties.

Table 22. Area planted to maize in eastern and southern Africa, 1996 (comparison of survey respondents' direct estimates with FAO data)

Country-region	FAO estimate (000 / ha)	Estimate of scientists in national research programs (000 / ha)	Difference between two estimates (%)
Ethiopia	1,881	1,776	-5.6
Kenya	1,300	1,383	6.4
Uganda	584	560	-4.1
Eastern Africa	3,765	3,719	-1.2
Angola	570	700	22.8
Lesotho	151	184	21.8
Malawi	1,243	1,300	4.6
Mozambique	1,008	1,113	10.4
South Africa	3,761	3,761	0.0
Swaziland	61	65	0.7
Tanzania	1,646	1,800	9.4
Zambia	676	649	-4.0
Zimbabwe	1,535	1,330	-13.4
Southern Africa	10,651	10,902	2.4
Southern Africa, excluding South Africa	6,890	7,141	3.6
Eastern and southern Africa	14,416	14,621	1.4
Eastern and southern Africa, excluding South Africa	10,655	10,860	1.9

Source: CIMMYT Maize Research Impacts Survey, 1998/99.

[6] When shown the difference between their estimate and the FAO figure, the Angolan respondents confirmed their estimate and challenged the accuracy of the FAO figure.

The varietal adoption estimates reveal interesting patterns in the types of modern varieties being grown in eastern and southern Africa. Generally speaking, use of hybrids was much more extensive than use of improved OPVs. According to the national program respondents, in 1996, hybrids occupied approximately 46% of the maize area planted, compared to only 7% occupied by OPVs. The greater use of hybrids reflects the increasing dominance of the private seed industry.

Estimates of Area Under Improved Maize Based on Seed Sales

Seed sales data for 1996 collected from public and private companies were used to derive an alternative set of estimates of the area planted to commercial maize seed in eastern and southern Africa. This was done by dividing total commercial seed sales in each country by the average planting rate for that country. In eastern and southern Africa, recommended planting rates for maize generally range from 20-25 kg/ha, although they are lower in some countries, including South Africa (10kg/ha), Lesotho (10 kg/ha), Uganda (16 kg/ha), and Swaziland (16 kg/ha). Many of the survey respondents indicated that farmers often plant at rates lower than the recommended rate, however, so the recommended planting rates were adjusted downward. Accordingly, an average planting rate of 17.5 kg/ha was used for all countries except South Africa and Lesotho, where an average rate of 12.5 kg/ha was used. These planting rates implicitly accommodate a certain amount of wastage, since the seed sales data were not adjusted to allow for the fact that in most years a certain amount of seed remains unplanted, some farmers replant the same field several times in order to establish a satisfactory stand, some of the area planted to commercial seed is never harvested, etc.

Table 23. Percentage of total national maize area planted to improved OPVs and hybrids, eastern and southern Africa, 1996 (comparison of survey respondents' direct estimates and calculations based on commercial seed sales)

	OPVs		Hybrids		All MVs		
Country / region	National program estimates	Seed sales	National program estimates	Seed sales	National program estimates	Seed sales	Percentage deviation from national program estimates
Ethiopia	1.89	2.99	3.94	5.47	5.83	8.46	45.1
Kenya	7.49	9.42	64.96	61.69	72.45	71.11	-1.8
Uganda	50.00	4.42	4.68	4.46	54.68	8.88	-83.8
Eastern Africa	11.62	5.60	28.09	26.24	39.71	31.83	-19.8
Angola	25.00	11.30	0.05	-	25.50	11.80	-53.7
Lesotho	10.87	13.05	63.94	57.72	74.81	70.76	-5.4
Malawi	4.38	1.05	7.00	12.75	11.38	13.80	21.3
Mozambique	7.96	9.10	0.05	0.04	8.01	9.14	14.1
South Africa	3.06	3.66	94.5	92.23	97.56	95.90	-1.7
Swaziland	2.23	0.00	73.22	78.37	75.45	78.37	3.9
Tanzania	4.00	1.92	6.00	2.33	10.00	4.25	-57.5
Zambia	0.62	0.72	18.63	22.17	19.25	22.89	18.9
Zimbabwe	4.51	0.00	90.98	81.63	95.49	81.63	-14.5
Southern Africa	5.24	3.77	51.73	43.51	56.97	47.28	-17.0
Southern Africa, excluding South Africa	6.49	3.82	27.37	21.76	33.86	25.57	-24.5
Eastern and southern Africa	6.88	4.24	45.67	39.02	52.55	43.27	-17.7
Eastern and southern Africa, excluding South Africa	8.29	4.41	27.62	23.26	35.91	27.68	-22.9

Source: CIMMYT Maize Research Impacts Survey, 1998/99.

Generally speaking, the seed sales-based estimates of the area planted to improved germplasm were consistent with the direct estimates made by the survey respondents (Table 23). In many countries, the estimates based on seed sales data were lower than the direct estimates, but this is expected, since the seed sales-based estimates include only area planted to newly purchased seed, whereas the direct estimates additionally include area planted to recycled seed. Countries in which the direct estimates significantly exceeded the seed-sales based estimates tended to be those in which a large amount of seed recycling is known to occur (e.g., Angola, Tanzania, Uganda).

Role of the Private Sector and Importance of Hybrids

Table 24 and Figures 5a and 5b show recent trends in commercial maize seed sales in eastern and southern Africa.[7] After increasing sharply during the early 1990s, maize seed sales leveled off around 120,000 tons for several years before dropping by more than 25% between 1994 and 1996. The decline in commercial maize seed sales during the mid-1990s can be attributed to several factors. In a number of countries (e.g., Kenya, Malawi, Zimbabwe), economic reforms resulted in the removal of input subsidies and elimination of exchange rate distortions, which had the effect of significantly increasing the price of maize seed. Unfavorable weather conditions also played a role, as a prolonged drought caused the area planted to maize to drop significantly in several major maize producing countries (e.g., South Africa).

The commercial seed sales data confirm that the maize seed market in eastern and southern Africa is now almost entirely privatized. By 1996, the most recent year for which data are available, private seed companies controlled more than 90% of the total market (Table 24). The domination of the private sector was pronounced not only in southern Africa, where private seed companies are relatively numerous, but also in eastern Africa, where private seed companies are still relatively scarce.

[7] Since it was not possible to obtain complete historical seed sales data for Angola, Angola was excluded from the analysis of trends in seed sales.

Table 24. Evolution of commercial maize seed sales by public and private seed organizations, eastern and southern Africa, 1990-96

Region / seed agency / seed type	1990	1991	1992	1993	1994	1995	1996
Eastern Africa							
Sales by public agencies (tons)	2,957	1,136	1,529	2,384	3,610	2,632	1,889
Hybrid seed sold (%)	11.0	10.0	11.0	11.0	11.0	24.2	50.8
Sales by private agencies (tons)	19,885	21,752	19,537	17,875	22,830	13,080	18,757
Hybrid seed sold (%)	88.7	88.4	86.8	87.9	88.1	86.9	85.7
Southern Africa, excluding Angola							
Sales by public agencies (tons)	2,003	1,962	1,504	838	836	711	2,079
Hybrid seed sold (%)	47.3	53.3	48.5	35.4	24.5	36.4	8.3
Sales by private agencies (tons)	43,544	91,470	99,310	98,872	96,084	90,192	68,921
Hybrid seed sold (%)	93.5	95.7	96.3	94.0	92.4	93.6	93.7
Eastern and southern Africa, excluding Angola							
Sales by public agencies (tons)	4,960	3,098	3,033	3,222	4,446	3,343	3,968
Hybrid seed sold (%)	25.7	37.4	29.6	17.4	13.6	26.8	28.5
Sales by private agencies (tons)	63,429	113,222	118,847	116,747	118,914	108,872	87,678
Hybrid seed sold (%)	92.0	94.1	94.7	93.1	91.6	92.7	92.0

Source: CIMMYT Maize Research Impacts Survey, 1998/99.

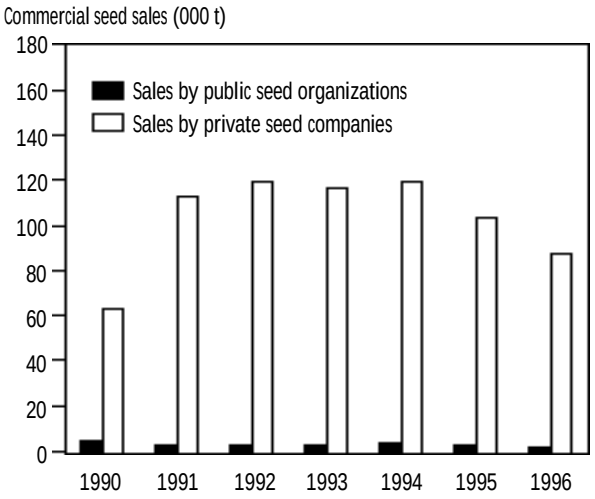

Figure 5a. Commercial maize seed sales, by sector, eastern and southern Africa, 1990-96
Source: CIMMYT Maize Research Impacts Survey, 1998/99.

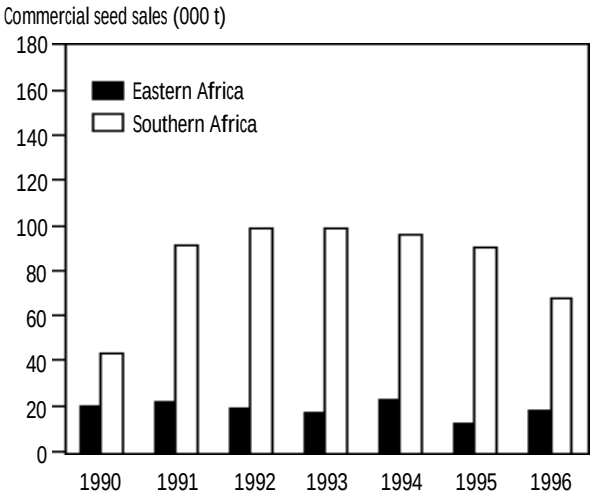

Figure 5b. Commercial maize seed sales, by region, eastern and southern Africa, 1990-96
Source: CIMMYT Maize Research Impacts Survey, 1998/99.

In terms of market size, southern Africa is a much more important market for private seed companies than eastern Africa; the volume of private-sector seed sales in southern Africa is more than three times larger than the volume of seed sales in eastern Africa (Table 24). For public seed companies, the reverse is true; public seed companies continue to sell more maize seed in eastern Africa than they do in southern Africa (Table 24).

Aggregating across the two regions, sales of hybrid seed have grown as a proportion of total seed sales. By 1996, hybrid seed accounted for more than 92% of total seed sales (Table 24 and Figure 6). The only significant exception to the trend toward greater emphasis on hybrids has occurred in southern Africa, where public-sector seed sales have become increasingly dominated by OPVs. This finding can be attributed to the fact that with Angola excluded from the analysis, the only public seed company still operating in southern Africa is in Tanzania, where public seed agencies have made a conscious decision to concentrate on OPVs. Given the current environment, most smallholders in Tanzania cannot afford to purchase hybrid seed and other inputs such as chemical fertilizer.

The rise of the private maize seed industry and the related increase in the production of hybrid seed raises difficult questions for policy makers. In particular, it is justifiable to ask whether current trends will lead eventually to further marginalization of small-scale, subsistence-oriented farmers, many of whom are likely to find it difficult

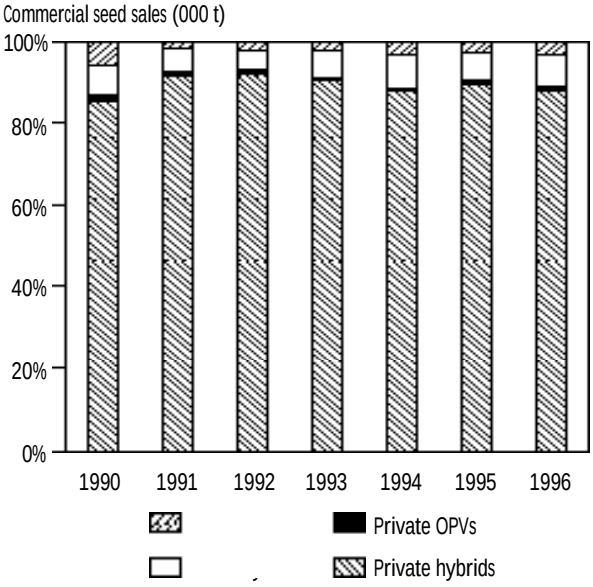

Figure 6. Compostion of commercial maize seed sales, eastern and southern Africa, 1990-96
Source: CIMMYT Maize Research Impacts Survey, 1998/99.

to buy fresh hybrid seed every year. To date, no definitive answer has emerged to this important question. Despite the widespread belief that hybrid technology is inappropriate for smallholders, evidence from a number of countries in the region suggests that hybrids can be adopted successfully by small-scale producers. In Kenya (Hassan et al. 1998b), Zimbabwe (Eicher and Kupfuma 1997, Eicher 1995), Lesotho, Swaziland and South Africa, smallholders have achieved rates of adoption of hybrid maize that are comparable to those achieved by large commercial farmers.

Estimates of Area Under CIMMYT Germplasm

How extensive is the area planted in eastern and southern Africa to maize varieties that were developed using CIMMYT germplasm? In the absence of detailed information about the area planted to individual varieties, the area planted to varieties containing CIMMYT germplasm had to be calculated indirectly based on (1) estimates of the area planted to all modern varieties, (2) quantitative data on the use of CIMMYT germplasm in all varietal releases, and (3) qualitative information provided by public- and private-sector breeders. For most countries, it was assumed that of the total area planted to modern varieties, the proportion planted to varieties containing CIMMYT germplasm was identical to the proportion of all varietal releases that have contained CIMMYT germplasm. Implicit in this approach is the assumption that on average, varieties developed using CIMMYT germplasm have been adopted at the same rate as varieties developed without the use of CIMMYT germplasm. For five countries in which only limited information was available about the CIMMYT germplasm content of varietal releases (Angola, Lesotho, South Africa, Swaziland, Uganda), the proportion of modern varieties containing CIMMYT germplasm was subjectively estimated based on information provided by breeders in the public and private sectors about the use of CIMMYT source materials in their breeding programs.

Based on these estimates, it is estimated that in 1996 over 1.6 million hectares in eastern and southern Africa were planted to varieties containing CIMMYT germplasm (Table 25). Of this amount, 0.32 million ha were located in eastern Africa (representing 8% of the total maize area in that region, and 21% of the area planted to modern varieties) and 1.31 million ha were located in southern Africa (representing 12% of the total maize area in that region, and 21% of the area planted to modern varieties). Excluding South Africa, where maize is grown mainly in temperate production environments that are not directly targeted by CIMMYT's breeding program, 16% of the total maize area in southern Africa was planted to CIMMYT derived varieties, representing 47% of the area planted to modern varieties.

Table 25. Area planted to maize varieties developed using CIMMYT germplasm, eastern and southern Africa, 1996

Country / region	Area planted to materials containing CIMMYT germplasm (000 / ha)	Percentage of total area under MVs
Ethiopia	36.4	36.4
Kenya	121.1	11.1
Uganda	163.5	50.0
Eastern Africa	*321.1*	*21.2*
Angola	52.7	33.3
Lesotho	5.4	5.0
Malawi	78.0	55.6
Mozambique	69.3	75.0
South Africa	196.3	5.0
Swaziland	2.3	5.0
Tanzania	52.1	33.3
Zambia	17.0	13.6
Zimbabwe	835.3	53.3
Southern Africa	*1,308.4*	*20.7*
Southern Africa, excluding South Africa	*1,112.1*	*46.5*
Eastern and southern Africa	*1,629.4*	*20.8*
Eastern and southern Africa, excluding South Africa	*1,433.2*	*36.7*

Source: CIMMYT Maize Research Impacts Survey, 1998/99.