E C O N O M I C S

Working Paper 95-01

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

CIMMYT receives core support through the CGIAR from a number of sources, including the international aid agencies of Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, India, Germany, Italy, Japan, Mexico, the Netherlands, Norway, the Philippines, Spain, Switzerland, the United Kingdom, and the USA, and from the European Community, Ford Foundation, Inter-American Development Bank, OPEC Fund for International Development, UNDP, and World Bank. CIMMYT also receives non-CGIAR extra-core support from the International Development Research Centre (IDRC) of Canada, the Rockefeller Foundation, and many of the core donors listed above.

Printed in Mexico.

Correct citation: López-Pereira, M.A., and M.P. Filippello. 1995. *Emerging Roles of the Public and Private Sectors of Maize Seed Industries in the Developing World.* CIMMYT Economics Program Working Paper 95-01. Mexico, D.F.: CIMMYT.

ISSN: 0258-8587
AGROVOC descriptors: Zea mays, seed industry, seed production, public enterprises, private firms, sales, economic analysis, developing countries
AGRIS category codes: E21 , F03
Dewey decimal classification: 338.17315

Contents

Abstract

Interactions between public and private sector organizations in the world maize seed industry are analyzed, with emphasis on the developing world. Information is presented on the share of total maize seed sales in 1992 by different kinds of seed enterprise and by different types of seed (hybrids, open pollinated varieties) and its origin (public or private sector breeding programs). In most developing countries, private organizations remain the major producers and distributors of maize seed; maize seed production and distribution by the public sector has tended to diminish. Public breeding systems, however, are still important in maize seed industries; more than half of the seed sold in developing countries in 1992 was of public origin. Although schemes for direct production and distribution of maize seed by the public sector are largely a thing of the past, public breeding systems will remain important for fostering the development of domestic private seed enterprises and small-scale seed producers, and conducting research directed at small-scale farmers.

Acknowledgments

The authors are indebted to earlier work by Jim Longmire, whose 1986 study of commercial maize seed production in developing countries (CIMMYT 1987) was the point of departure for the present study. The authors also wish to thank many colleagues who provided the information used in this strudy: A.O. Akintunde, Recai Akman, Mohammad Aslam, Gonzalo Avila, Nenita Baldo, David Beck, Khadija Benahnia, Murat Bengi, Benti Tolessa, Angelo Bianchi, Calisto Bias, George Bigirwa, Cesar Antonio Boza Miranda, Luis Brizuela, Iveta Capková-Rothová, Orlando Carrillo, Mario Caviedes, Chen Zehui, Chen Zong-Long, Ntji Coulibaly, Toma Dankov, William Dar, Fernando J. de Almeida, M. Derieux, Martin D. Escobar, Alejandro Espinosa, Guillermo Eyherabide, Alberto Fassio, Yallou Chabi Gouro, Fidencio Antonio Guerra, Gengchen Han, Jorge Huezo, Hema Idrissa, A.A. Ismail, Celtus Janni, Kevin Kimle, Attiey Koffi, Luis Macagno, Cecilio Marcos Torres, Esseh-Yovo Mawule, S.B. McCarter, Helmut Messner, Y. Montalant, Lieketso Moremoholo, Jesús Moreno, L. Mose, Alfred Moshi, K. Mtinde, Catherine Mungoma, Alejandro Navas, Luis A. Narro León, Abdou Ndiaye, Emmanuel Ndoruhirwe, Rafael Obando, Guillermo Ortiz Ferrara, Manuel Oyervides, Orlando Paratori, Mahesh Man Palikhe, F.M. Quinn, Emmanuel Rufyikiri, Joseph Rusike, Félix San Vicente, Rodrigo Sbarbaro, J.A. Schillinger, Narongsak Senanarong, Dine Seyfoulaye, John Sfakianakis, N.N. Singh, Subandi, Tomás Szundy, Charles Thé, Nicola Tomov, Ching T. Tseng, M. Tsiu, Roger Urbina, Tran Hong Uy, P.P. Van der Walt, Deon Van Rooyen, W.H. Verburgt, Rubén Verges, José Alberto Yau Quintero, Roberto Zavaca, Zhang Shi-Huang, and staff of the Kenya Agricultural Research Institute.

Many CIMMYT staff also assisted with data collection and/or manuscript review: Jorge Bolaños, Derek Byerlee, Hugo Córdova, Carlos de León, Alpha O. Diallo, Catherine Giauffret, Larry Harrington, Rashid Hassan, Paul Heisey, Delbert Hess, David Jewell, Michael Morris, Wilfred Mwangi, Shivaji Pandey, Kevin Pixley, Joel Ransom, Roger Rowe, Gustavo Sain, Melinda Smale, Sam Vasal, Richard Wedderburn, and Donald Winkelmann. Elizabeth Cromwell, Donald Duvick, Rubén Echeverría, Jim Longmire, Ricardo Magnavaca, Ripusudan Paliwal, Carl Pray, Joseph Rusike, N.N. Singh, and Robert Tripp also provided helpful comments on drafts of this study. Their efforts are much appreciated.

Tables

Figures

Emerging Roles of the Public and Private Sectors of Maize Seed Industries in the Developing World

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Introduction

Nearly a decade ago, the *1986 CIMMYT World Maize Facts and Trends* (CIMMYT 1987) examined the economics of commercial maize seed production in developing countries, focusing on the relatively low use of improved maize seed in low income countries and the requirements for establishing viable seed industries. At that time, agricultural researchers and policy makers were deeply concerned over the extent to which maize seed enterprises would be able to address the needs of the world's farmers, especially poor farmers in developing countries. If anything, this concern is stronger today, sharpened by recent developments in the legal and technical environment surrounding maize breeding and seed production.

The years since 1986 have witnessed unprecedented activity in maize seed enterprises. More varied institutional arrangements for producing and distributing maize seed, ranging from local cooperatives and non-governmental organizations (NGOs) to national and multinational private companies, coexist with state seed enterprises. Growing skepticism about the role of the public sector in agricultural development in general, and the seed industry in particular, has made national governments and donor agencies less disposed to support state seed enterprises. Many of these enterprises have been closed or severely reduced. Although an increasing amount of faith has been placed in the private sector's ability to provide maize seed to farmers, the private sector's expanding presence in the maize seed industry has raised many serious questions. One of the most important concerns is that the private sector will devote little or no effort to developing maize hybrids for small-scale farmers in marginal areas. The growing capacity of molecular biology to provide novel germplasm (plant breeding material) in less time than conventional breeding techniques, and continuing debate about intellectual property rights and their applicability to plant materials, have also raised questions about the private sector's limitations and responsibilities in meeting the seed requirements of poor farmers. Partly in response to these concerns, local seed production initiatives among farmer groups and cooperatives have burgeoned.

This is the context in which we evaluate the industry's progress to date, paying special attention to the implications for the public sector's role in the maize seed industries of the developing world. To obtain a more accurate idea of the changes that have taken place in the maize seed industry in recent years, and to develop a baseline for future studies, information was assembled from a number of sources (Appendix A), including an extensive survey of maize seed industries throughout the world (Appendix B). This paper begins with an overview of how maize seed industries function and provides data on public and private sector investment in maize breeding and seed production in developing and industrialized countries. Recent trends in farmers' use of improved maize seed, the value of seed used by farmers, and commercial maize seed sales are reviewed. Next, the paper examines the economics of maize seed production and adoption, with emphasis on the factors affecting seed production costs on the one hand, and the decision to adopt improved seed on the other. The paper concludes with a look at the future environment of the world maize seed industry.

How the World Maize Seed Industry is Organized

Providing seed of almost any grain crop, including maize, for sale to farmers is the culmination of a lengthy process in which public and private sector organizations participate. This process can be divided into three broad sets of activities : 1) research and development (R&D), or breeding, 2) seed production and conditioning, and 3) seed marketing and distribution. Because these phases of the seed production process are highly interdependent, the effectiveness of the activities performed in one phase depends very much on the effectiveness with which activities are performed in the other phases.

The Objective and Functions of the Commercial Maize Seed Industry

In principle, the maize seed industry has one basic objective: to provide high quality seed to maize farmers in such a way that it is economically attractive. The process by which the industry attempts to achieve this goal is described in Figure 1, which shows where the different public and private sector organizations obtain germplasm and how they transfer it among themselves and to their clients. Local maize varieties and land races form a large

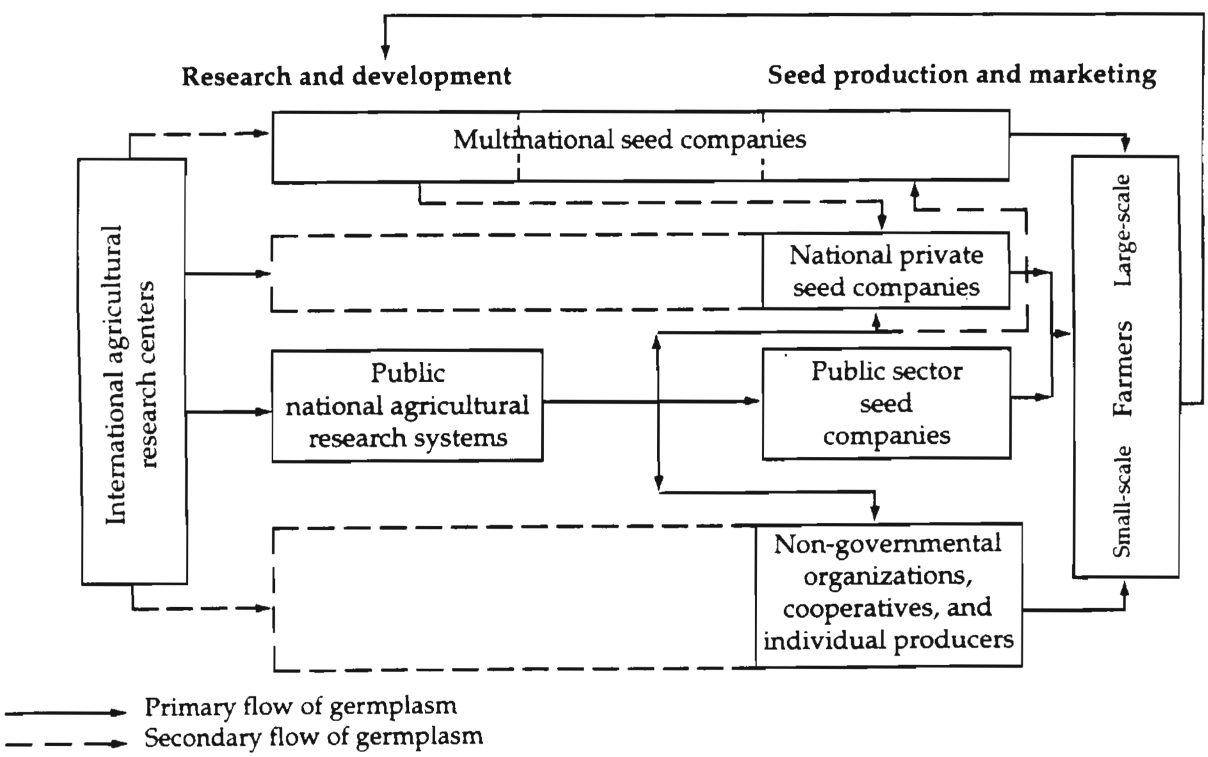

Figure 1. Public-private sector interactions in the maize seed industry.
Source: Adapted from Byerlee, Morris, and López-Pereira (1993).

part of the genetic reservoir that public and private breeding organizations draw upon in developing new improved open pollinated varieties (OPVs) and hybrids. These new materials are tested and subjected to a varietal certification and release process. After a variety is approved for release, seed can be produced and conditioned for distribution to farmers. Seed industries thus perform three general functions: breeding, testing, and releasing improved varieties and hybrids; producing and conditioning seed; and marketing and distributing seed.

Who Produces Commercial Maize Seed?
Each function of the seed industry can be performed by different organizations. Which organizations are involved and the functions they perform depend mainly on the degree of development of the industry. If the seed industry is not developed, farmers will produce most maize seed themselves for their own use. On the other hand, the numbers and types of organizations prevalent in highly developed seed industries are much greater. The various groups interacting in the maize seed industry are described in detail below. Although the discussion focuses mostly on organizations involved in commercial maize seed production (and even individual seed producers, as long as they produce seed for sale to other farmers), the reader should bear in mind that large numbers of farmers — mainly in the developing world — produce their own maize seed and thus are an important part of the seed industry. In many developing countries, this is the most important type of maize seed production and exchange.

Public breeding programs and seed companies — This group of seed enterprises is composed mainly of one or more breeding institutes and/or one or more parastatal seed companies that produce and distribute seed under the aegis of the public national agriculture research system (NARS) in a given country. The public breeding institutes often combine improved germplasm from many sources, including germplasm from the international breeding institutes and farmers' local materials, and select varieties and hybrids for local release after extensive evaluation. They may also offer germplasm to private seed organizations for a fee and/or produce and distribute commercial maize seed directly through their own public seed enterprises. Public sector seed companies normally produce and distribute seed of materials developed by public breeding organizations. In many countries breeding and seed production/distribution are handled by separate entities within the public NARSs.

Public breeding institutes and seed companies once dominated the maize seed industries of many developing countries, but public sector seed companies have largely exited the industry, and the public NARSs concentrate their efforts on maize R&D. Today, many public breeding programs make their germplasm available to private seed organizations, either for further breeding or for direct seed production and distribution. Public breeding programs may or may not charge private seed companies for this service. They may also make improved germplasm available to other public programs, especially in neighboring countries. Public sector organizations also appear to have become less important in the seed certification process, increasingly restricting themselves to testing their own materials and those of the private sector.

International agricultural research centers — International research centers such as CIMMYT and the International Institute of Tropical Agriculture (IITA) are also public research organizations. They conduct breeding research but do not engage in seed production and distribution. The non-commercial germplasm products that these organizations develop, such as improved populations and pools, OPVs, and inbred lines, are made available to public and private research organizations throughout the world, usually free of charge. See Appendix C for information on CIMMYT's maize breeding activities.

Multinational seed companies — Multinational seed companies operate in more than one country. Their headquarters are normally located in industrialized countries, and their breeding and/or seed production and distribution operations in developing countries are either wholly owned subsidiaries or joint ventures with national companies. The extent of their operations in developing countries ranges from simply importing maize seed (as in most of Central America and some Asian countries) to sophisticated breeding programs and facilities for marketing locally produced seed (as in Mexico, Brazil, Argentina, India, and Thailand). These companies are less common in Africa than in other regions, and some companies are reconsidering their investments in Africa after several attempts to establish operations.[1] Multinational seed companies normally have sophisticated breeding programs for developing their own proprietary hybrids. Commercial seed of these hybrids is usually produced by the multinational or by other private companies under contract, subject to royalty agreements.

Private national seed companies — Private national seed companies are companies with majority ownership by local individuals or organizations. Such companies have long been active in the seed industries of developing countries, but until recently their share of the seed market was relatively minor, owing to the public sector's extensive control of the industry (combined, in some cases, with the presence of multinational seed companies). Following the liberalization of the seed industry in many countries, private national companies have become much more important in the developing world's maize seed industries; in fact, they are the main beneficiaries of the restructuring of maize seed industries in developing countries. The availability of germplasm from the public breeding system for direct seed production and distribution has allowed these companies to enter the industry with low capital investments.

In general, most private national seed enterprises in developing countries restrict themselves to producing and distributing seed of maize materials developed by public sector breeding programs. However, some private national companies have started modest breeding programs using germplasm from the public research system and from international agricultural research centers, such as CIMMYT and IITA, and a few private national seed companies produce and distribute their own materials. Private national companies and small-scale seed organizations (see below) are expected to heighten competition in maize seed industries over the next 10-20 years and to improve the effectiveness with which seed of public origin is delivered to farmers. These organizations often have the advantage of being able to operate effectively in markets that are too small to interest the multinational companies.

Other types of seed producers — Several kinds of organizations produce and sell maize seed but do not belong to any of the categories described above; these include seed producers' cooperatives, NGOs,[2] and individual farmer/seed producers who produce maize seed for sale to other farmers. These enterprises often perform the important function of distributing maize seed to small-scale farmers in marginal and isolated regions, or to a specific group of farmers, such as members of cooperatives. By focusing on these clients, they complement the activities of more formal seed enterprises, which concentrate on serving medium- and large-scale farmers. Recently NGOs have been instrumental in making seed available to farmers in countries such as Mozambique where, because of unusual circumstances (e.g., war, natural disasters), the more formal seed system is not effective. With a few notable exceptions, these "less formal" seed producers have no breeding programs.[3] Instead they rely almost exclusively on the public sector for the seed they produce and/or distribute, thus aiding in the diffusion of public maize germplasm, especially to small-scale farmers.

Industry Structure and Level of Investment in Research

The worldwide survey of maize seed industries conducted by CIMMYT elicited considerable information on the structure of maize seed industries and levels of research investment. The 51 developing countries for which data were collected support 245 public research stations with maize breeding responsibilities. About half of these stations are located in Asia (Table 1). In 1992, 1,377 maize breeders worked in the developing world,

Table 1. Number of public maize research stations and public and private sector maize breeders in the world, 1992

Region	Number of public research stations	Number of maize breeders		
		Public sector	Private sector	Total
Sub-Saharan Africa	42	95	23	118
West Asia and North Africa	24	93	27	120
Asia, less China	51	220	107	327
China	55	440	0	440
Latin America	73	224	148	372
Developing countries	245	1,072	305	1,377
Developing countries, less China	190	632	305	937
Industrialized countries	82	214	800	1,014
World	**327**	**1,286**	**1,105**	**2,391**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: Includes data from 51 developing and 11 industrialized countries.

1 See Pioneer (1994) for an account of a major multinational seed company's retrenching in Africa.

2 Non-govermental organizations are considered "non-public" institutions rather than "private" ones. Although they generally do not depend *directly* on public funds to operate, NGOs are distinct from private companies in that they normally do not seek to make a profit. For simplicity's sake we refer to them together with private institutions such as seed cooperatives, but the reader should be aware that NGOs are in a class by themselves.

3 Exceptions include several cooperatives in Brazil, which serve large-scale farmers, and the Seed Co-op of Zimbabwe, which has a breeding program and serves large-, medium- and small-scale maize farmers.

1,072 of them in the public sector (including public seed companies) and 305 in the private sector. The greatest number of private sector maize breeders is found in Latin America, which has about half of all private sector maize breeders in the developing world; sub-Saharan Africa has the fewest. The public-private sector proportions of maize breeders are quite different in industrialized countries, where about 80% of all breeders work in the private sector (800 out of 1,014), although the number of public sector maize breeders is substantial (214).

The composition and number of seed companies vary considerably across regions (Table 2). There are still fairly large numbers of public seed companies in the developing world, although their participation in the seed market is small. Thus many public seed enterprises in developing countries may be idle or underutilized, indicating that the process of public sector divestiture from the seed business has not yet been completed in many countries (see below). In some Asian countries, the number of public seed companies is large because it is common to have one public sector seed company per province or region. National and multinational seed companies have a stronger presence in Asia and Latin America, where private seed sectors are better developed. The number of "other" seed organizations (NGOs, seed cooperatives, and individual seed producers) is striking, matching or surpassing the total of the other three categories; they constitute two-thirds of all seed organizations in the developing world.[4] In industrialized countries, private national seed companies predominate.

Expressing the capital resource investment (research stations) and human resource investment (maize breeders) per million tons of maize production or per thousand tons of

Table 2. Structure of the world maize seed industry by type of company, 1992

Region	Number of countries in each region	Number of seed companies				
		Multinational[a]	Private national	Other nonpublic[b]	Public	Total
Sub-Saharan Africa	20	13	12	164	63	252
West Asia and North Africa	4	8	45	1	6	60
Asia, less China	9	20	208	597	41	866
China	1	0	0	0	24	24
Latin America	18	40	114	175	37	366
Developing countries	51	81	379	937	171	1,568
Developing countries, less China	50	81	379	937	147	1,544
Industrialized countries	11	76	362	94	34	566
World	**62**	**157**	**741**	**1,031**	**205**	**2,134**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: Includes data from 51 developing and 11 industrialized countries.
[a] Multinational companies operating in several countries are counted as individual companies in each country.
[b] Includes NGOs, seed producers' cooperatives, and individual seed producers.

[4] It should be noted that this group may include some seed organizations that only distribute maize seed, as opposed to producing and distributing it. This may be especially the case for NGOs.

seed sales provides an indication of the intensity with which these resources are utilized in a region, as well as of the efficiency with which they are used. There are about three public research stations for every million tons of maize produced in the developing world, and the intensity of public research stations is approximately equal in all regions, if China is excluded from the analysis (Figure 2). Also, in both developing and developed countries there is an average of one maize breeder per thousand tons of seed sales (Table 3). The relatively large number of maize breeders per thousand tons of seed production in Asia (4.1) appears to be related to the large numbers of research stations and seed enterprises in these countries, as well as the need to staff these stations and enterprises, even though total seed production may be low in some regions. Excluding China, there are about twice as many public and private breeders per thousand tons of seed production in developing countries as in the industrialized world. However, the difference is due almost entirely to the large number of public maize breeders in developing countries, since the number of private sector breeders is similar to that in industrialized countries. This apparent difference in efficiency may be exacerbated by the fact that normally public sector breeders in developing countries have fewer resources to do their work compared to their counterparts in industrialized countries.

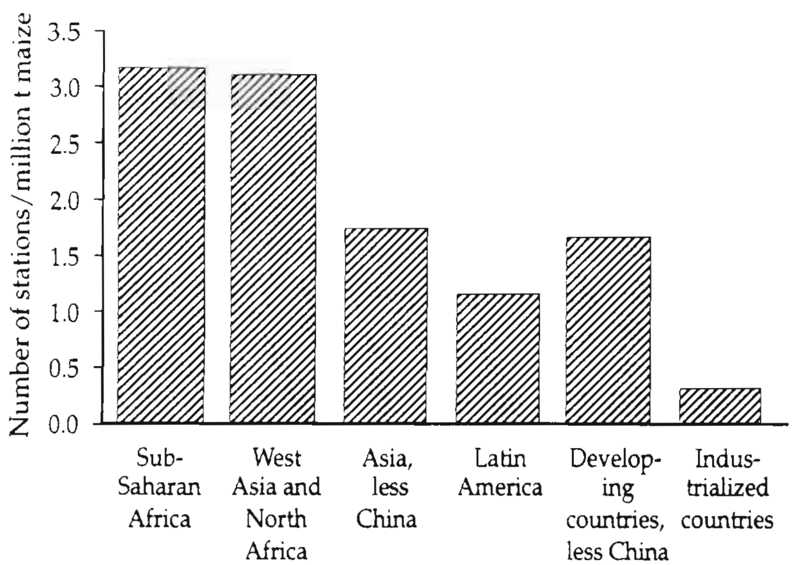

Figure 2. Public maize research stations per million tons of maize production, developing and industrialized countries, 1992.

Source: CIMMYT Maize Seed Industry Survey, 1993.

Table 3. Public and private sector maize breeders per thousand tons of seed sales, 1992

	Breeders per thousand tons of seed sales[a]		
Region	**Public sector**	**Private sector**	**Total**
Sub-Saharan Africa	1.3	1.3	1.3
West Asia and North Africa	10.6	4.0	7.8
Asia, less China	4.3	3.6	4.1
China	0.6	0.0	0.6
Latin America	2.5	1.0	1.6
Developing countries	1.2	1.5	1.2
Developing countries, less China	2.9	1.5	2.2
Industrialized countries	4.2	1.1	1.3
World	**1.3**	**1.2**	**1.3**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: Includes data from 51 developing and 11 industrialized countries.
[a] Public sector breeders per 100 t of public seed sales (OPVs and hybrids), private sector breeders per 1,000 t of proprietary hybrid seed sales, and total breeders per 1,000 t of all seed sales in region.

When the level of investment in maize seed production is analyzed based on the number of seed companies per million tons of maize grain production, Asia again shows the largest numbers, with 30 seed enterprises (Table 4). The number of seed companies per million tons of maize grain production is large in Africa as well (19), but it is relatively low in Latin America (6), which shows a relatively balanced presence of all types of seed companies. The numbers of seed enterprises in Africa and Asia are large mainly because these regions have so many small-scale seed organizations — NGOs, seed cooperatives — and individual seed producers. This is especially the case in India, which has hundreds of small-scale seed producers. Public seed enterprises are also relatively important in Africa, whereas national private seed companies have a modest presence there. Compared to developing countries, in industrialized countries there are only two seed companies per million tons of maize grain production. It is also interesting to note the low number of multinational seed companies per million tons of grain production.

Farmers' Use of Improved Maize Seed

The preceding description of the structure and function of the maize seed industry has told only half of the seed production story. The other half, told in the sections that follow, lies with the farmers who use the seed.

Maize Growing Environments

Maize is grown in more than 130 countries all over the world, and of these countries, 84 produced at least 100,000 t of maize in 1992. World maize area in 1992 totaled 133 million hectares and production was 527 million tons, for a global yield of 4 t/ha (Table 5).

Table 4. Seed companies per million tons of maize produced in the world, by company type and region, 1992

	Number of seed companies per million tons				
Region	Multi-national	Private national	Other non-public[a]	Public/ parastatal	Total
Sub-Saharan Africa	1.0	0.9	12.3	4.7	18.9
West Asia and North Africa	1.0	5.8	0.1	0.8	7.7
Asia, less China	0.7	7.0	20.4	1.4	29.5
China	**0.0**	**0.0**	**0.0**	**0.3**	**0.3**
Latin America	0.6	1.8	2.7	0.6	5.7
Developing countries, less China	0.7	3.3	8.2	1.3	13.5
Developing countries	0.4	1.8	4.5	0.8	7.5
Industrialized countries	0.3	1.3	0.3	0.1	2.0
World	**0.3**	**1.5**	**2.1**	**0.4**	**4.3**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: Includes data from 50 developing and 11 industrialized countries, accounting for 118 million ha of maize in 1992.
[a] Includes NGOs, seed producers' cooperatives, and individual seed producers.

The world's maize is produced in an immense range of growing environments. Although virtually all maize in industrialized countries is grown in temperate environments, the prevailing growing environments for maize in developing countries are the tropical lowlands and mid-altitudes and the subtropics. Only about 25% of the maize area in developing countries is located in temperate environments, nearly all of it in a few countries, notably China and Argentina.

Many maize materials have been developed for temperate environments; in fact, hybrid maize was first developed in these environments early in this century (Appendix D). Although breeding techniques can and have been transferred from temperate to non-temperate regions, differences in growing conditions make it difficult to transfer seed directly from temperate to non-temperate environments. These differences in growing conditions are one of several important reasons for the substantial contrast in maize productivity in developing and industrialized countries (Table 5); other reasons include the different stages of development of the seed industries and the related low use of improved germplasm and other inputs. When China, Argentina, and Brazil (where maize yields average nearly 4 t/ha) are excluded from the group of developing countries,[5] the average maize yield for the remaining countries is less than 2 t/ha, compared to more than 6 t/ha in industrialized countries.

Trends in Maize Area and Farmers' Use of Improved Maize Seed

Worldwide, the area sown to improved maize seed rose by about 4 million hectares between 1985 (the time of the previous maize seed industry survey) and 1992 (Table 6). All of these gains occurred in developing countries, where total estimated maize area under improved seed increased by 12 million hectares, from 37 million in 1985 to 49 million in 1992. As a result, the share of maize area under improved seed rose from 45% to 58% in developing countries. Almost all maize area in industrialized countries is planted to improved seed, but

Table 5. World maize area, yield, and production, 1992

	Area (million ha)	Yield (t/ha)	Production (million t)
Developing countries	84	2.6	218
China, Argentina, and Brazil	37	3.7	137
All other developing countries	47	1.7	81
Industrialized countries	48	6.4	309
World	**133**	**4.0**	**527**

Source: FAO Agrostat data files.

[5] Maize production differs substantially in these three countries compared to other developing countries. More than 80% of China's maize area is located in temperate environments, use of single-cross hybrid seed is almost universal, and maize is used mainly as an animal feed. Also, the Chinese maize seed industry is dominated by the public sector. In Argentina and Brazil (except northeastern Brazil), maize is a commercial crop produced on large farms where high levels of hybrid seed and other purchased inputs are used. The private sector dominates the maize seed industries of these two countries. Because of these differences, throughout this paper we present data on the maize seed industry with and without China, Argentina, and/or Brazil as appropriate.

a substantial reduction in total maize area in industrialized countries offset some of the gains in improved maize area in the developing world, for a net gain of only 4 million hectares.

A large proportion of the gains in improved maize area in developing countries resulted from the increased use of improved OPVs, although gains in area under hybrid seed were also reported (Table 6).[6] But the increase is also the result of a concerted effort, beginning in the early 1970s and lasting until the mid-1980s, by many public research systems in developing countries to produce improved OPVs. The relatively greater emphasis placed on hybrid maize materials since the late 1980s has stimulated the release of many high yielding hybrids in developing countries in recent years (López-Pereira and Morris 1994), which should be reflected in rapid increases in the area under hybrid maize in the medium term. Another reason behind the increased area under improved OPV seed is that China, which reported no area under improved OPVs in 1985, reported sowing some area to improved OPVs in subsequent years.

The area under improved maize seed in 1992 was divided equally between developing and industrialized countries. There were 30 million hectares of maize under improved seed in China, Argentina, and Brazil, and 19 million hectares in all other developing countries

Table 6. Area planted to different types of maize seed, developing and industrialized countries, 1985 and 1992

	Percent of maize area under:			Maize area under improved seed (million ha)
Region	**Local varieties**	**OPVs**	**Hybrids**	
1985				
Developing countries	55	7	38	37
Argentina, Brazil, China	27	2	71	24
Other developing countries	73	11	16	13
Industrialized countries	2	0	98	56
World	**33**	**4**	**63**	**93**
1992				
Developing countries	42	15	43	49
Argentina, Brazil, China	18	9	73	30
Other developing countries	61	20	19	19
Industrialized countries	1	0	99	48
World	**27**	**10**	**63**	**97**

Source: CIMMYT Maize Facts and Trends Survey, 1986, and CIMMYT Maize Seed Industry Survey, 1993.
Note: Totals may not sum exactly due to rounding.

[6] Although estimates of the area under hybrid maize seed are fairly easy to make based on reported seed sales, estimating the area planted to improved OPVs is complicated because estimates can be based on commercial OPV sales alone or on seed sales and estimates of OPV seed recycling by farmers. The way in which area under improved OPVs was estimated for this study may differ slightly from the procedure used to develop the estimates reported in CIMMYT (1987).

(Table 7). Within the latter group, improved maize area was distributed equally among Africa, Asia, and Latin America. The area sown to local maize and other non-commercial seed in developing countries is still very large, totaling 35 million hectares in 1992. Increasing maize productivity in many of these areas (e.g., through the use of improved seed and other inputs) is one of the primary challenges for maize researchers and seed enterprises in the developing world.

Total Maize Seed Used and Its Value

Farmers in developing countries used about 2.5 million tons of maize seed in 1992, for an average seeding rate of 29 kg/ha (Table 8). This compares to one million tons of seed used in industrialized countries, for an average seeding rate of 20 kg/ha. Commercial seed of

Table 7. Area planted to different types of improved maize seed in developing countries, by region, and in industrialized countries, 1992

Region	Percent area under improved seed			Total maize area under improved seed (million ha)
	OPVs	Hybrids	Total	
Sub-Saharan Africa	17	20	37	6
West Asia and North Africa	6	20	26	1
Asia, less China	29	13	42	7
Latin America, less Argentina and Brazil	14	27	41	5
China, Argentina, Brazil	9	73	82	30
Developing countries, less China, Argentina, and Brazil	20	19	39	19
All developing countries	15	43	58	49
Industrialized countries	0	99	99	48
World	**10**	**63**	**73**	**97**

Source: CIMMYT Maize Seed Industry Survey, 1993.

Table 8. Maize seed used in developing and industrialized countries, 1992

	Developing countries (000 t)	Industrialized countries (000 t)	Total (000 t)
Local varieties	1,051	8	1,059
Recycled OPVs[a]	264	0	264
Commercial OPVs	118	3	121
Hybrids	1,022	960	1,982
Total	**2,454**	**971**	**3,425**
Commercial seed[b]	1,140	963	2,103
(Share of total)	(46%)	(99%)	(61%)

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] "Recycled" seed is saved from the maize harvest for planting in the subsequent season.
[b] Sum of commercial OPVs and hybrid seed.

improved OPVs accounted for only 5% of all the seed used in developing countries; when recycled OPV seed is added to this, the proportion for OPVs increases to 15%. Total commercial seed (OPVs and hybrids) accounted for only 46% of all the maize seed used in developing countries, compared to virtually 100% of the seed used in industrialized countries. The 5 million hectare decline in world maize area between 1985 and 1992 did not result in a reduction in the total amount of improved seed used. The reduction in seed use in industrialized countries (due entirely to reductions in total maize area) was more than offset by substantial increases in seed use in developing countries.

The global maize seed industry sold about 2.1 million tons of improved seed in 1992. Of this, 94% (2 million tons) was hybrid seed and 6% (120,000 t) commercial seed of improved OPVs (the OPVs were sold mostly in developing countries) (Table 8). The total amount of hybrid seed produced in developing countries was slightly higher than in industrialized countries. The commercial seed sold in the world was valued at US$ 4.4 billion[7] (Table 9). When the seed produced by farmers for their own use (local varieties, recycled OPVs, and advanced generation hybrid seed) is included, the total value of seed comes to US$ 4.7 billion. The value of commercial seed used in 1992 represents a 35% increase over the total value of commercial seed used in 1985, and exceeds the percentage increase in total seed used. This indicates that the average unit price of commercial seed has risen rapidly, especially in industrialized countries.

On average improved seed is about five times more expensive in industrialized countries, where one kilogram of seed costs almost four dollars (US$ 3.72/kg), than in developing countries, where it costs less than one dollar (US$ 0.75/kg) (Table 10). In contrast, in 1985 the average ratio of the price of improved seed in industrialized countries to the price of

Table 9. Value of the maize seed used in developing and industrialized countries, 1992

	Value of seed used in 1992 (million US$)[a]		
	Developing countries	**Industrialized countries**	**All[b]**
Local varieties	195	1	196
Recycled OPVs[c]	43	0	43
Commercial OPVs	64	2	66
Hybrids	787	3,576	4,362
Total	**1,088**	**3,579**	**4,667**
Commercial seed[d]	850	3,578	4,428
(Share of total)	(78%)	(100%)	(95%)

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Numbers may not sum due to rounding.
[b] Constant 1992 US dollars (based on the US producer price index).
[c] "Recycled" seed is saved from the maize harvest for planting in the subsequent season.
[d] Sum of values of commercial OPVs and hybrid seed.

[7] All monetary figures in this report are in constant 1992 US dollars.

improved seed in developing countries was four. As a result of these price differentials, only 19% (US$ 0.85 billion) of the global value of commercial maize seed is derived from the seed industry in developing countries, versus 81% (US$ 3.6 billion) in industrialized countries.

One country — China — accounts for about 21% of the commercial OPV seed and over two-thirds of the hybrid seed sold in developing countries (Table 11). Commercial seed sales by all other developing countries are only 88,000 t of OPVs and 330,000 t of hybrid seed. Overall, hybrid seed constitutes 90% of seed sales in developing countries (79% when China is excluded). Asia —excluding China — is the region among developing countries where the OPV market share is highest and where more OPV seed is sold. After Asia, sub-Saharan-Africa has the highest OPV market share, while Latin America, with its larger overall market, sells more OPV seed. Virtually all of the commercial seed sold in industrialized countries is hybrid seed.

Table 10. Commercial maize seed sales and value of seed, worldwide, 1985 and 1992

	Developing countries	Industrialized countries	World[a]
Total commercial seed used		(000 t)	
1985	901	1,011	1,912
1992	1,140	963	2,103
Total value of commercial seed		(million US$[b])	
1985	587	2,695	3,282
1992	850	3,578	4,428
Change from 1985 to 1992		(%)	
Commercial seed	+27	-5	+10
Value of commercial seed	+45	+33	+35

Source: CIMMYT Maize Facts and Trends Survey, 1986, and CIMMYT Maize Seed Industry Survey, 1993.
[a] Includes countries not participating in the seed industry survey.
[b] Constant 1992 US dollars.

Table 11. World maize seed sales by type of seed, 1992

Region	Commercial seed sales: OPVs (%)	Commercial seed sales: Hybrids (%)	Total seed sales (000 t)
Sub-Saharan Africa	27	73	88
West Asia and North Africa	15	85	15
Asia, less China	48	52	80
China	3	97	688
Latin America	11	89	237
All developing countries	10	90	1,109
All developing countries, less China	21	79	421
Industrialized countries	0	100	776
World[a]	**6**	**94**	**1,885**

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Includes 51 developing and 11 industrialized countries.

Shares of Commercial Seed Sales

Commercial OPVs — Overall, public sector seed companies sold 48% (34% excluding China) of all the commercial OPV seed sold in 1992 (Table 12). Private national companies, NGOs, cooperatives, and individual seed producers accounted for 41% (52% excluding China) of all OPV seed sales. Thus commercial OPV seed is produced and distributed mainly by national seed companies, public and private. Virtually all of the OPV seed sold by multinationals was sold in Thailand, where multinationals have long produced and distributed the Suwan materials (Appendix E).

A few countries account for the bulk of commercial OPV seed sales in developing countries (Table 13). The main producers are located where the seed industry is more advanced and capable of delivering new seed to replace old OPVs (e.g., China, Thailand, Brazil).[8] India and Indonesia are also important OPV seed producers. Other countries selling more than 1,000 t of commercial OPV seed in 1992 were Ethiopia (1,785 t), Côte d'Ivoire (2,950 t), Nigeria (1,817 t), Pakistan (1,210 t), Mexico (3,550 t), and Argentina (3,714 t).

Hybrids — Depending on its origin, hybrid seed can be either public or proprietary.[9] Public hybrids are developed by public sector organizations; their pedigrees are public knowledge and their parent inbred lines are available to all, either for free or for a fee. Proprietary hybrids are developed by private sector organizations. Their pedigrees are normally not known (they are "closed pedigrees"), and proprietary hybrids may or may not contain

Table 12. Sales of seed of commercial maize OPVs in developing countries by type of company, 1992

	Share of commercial OPV sales by company type				Total commercial OPV seed sales
Region	**Multi-national (%)**	**Private national (%)**	**Other non-public[a] (%)**	**Public (%)**	**(000 t)**
Sub-Saharan Africa	0	18	17	65	24
West Asia and North Africa	0	0	0	100	2
Asia, less China	33	25	24	18	38
China	0	0	0	100	24
Latin America	0	53	26	21	25
All developing countries	11	24	17	48	113
Developing countries, less China	14	30	22	34	89
Industrialized countries	0	0	100	0	3
World	**11**	**23**	**19**	**47**	**116**

Source: CIMMYT Maize Seed Industry Survey, 1993.

[a] Includes NGOs, seed producers' cooperatives, and individual seed producers.

[8] Mozambique is a special case of commercial OPV seed sales. Until a few years ago, the civil war had virtually ended seed production and sales, but since then Mozambique has substantially increased its seed production capabilities, and has imported substantial amounts of seed, especially from Zimbabwe.

[9] In this paper, all commercial OPV seed is assumed to have been developed by public sector organizations.

inbred lines developed from public germplasm. These hybrids are "proprietary" because they are commercially exploited exclusively by the seed company that developed them. Many private companies in developing countries, especially countries where maize is grown in tropical and subtropical environments, use public germplasm in their breeding programs (López-Pereira and Morris 1994). Thus public germplasm products are used to a greater extent than is indicated by the use of public hybrids alone.

Table 13. Developing countries with the largest shares of commercial OPV seed sales, 1992

	Sales of commercial OPVs (000 t)	Share of total commercial OPV sales in developing countries (%)
China	24.0	21
Thailand	19.0	17
Brazil	12.8	11
Mozambique	12.6	11
India	9.0	8
Indonesia	7.5	7
Total	**84.9**	**75**
Other countries	28.5	25
All developing countries	**113.4**	**100**

Source: CIMMYT Maize Seed Industry Survey, 1993.

At the global level, only 20% (200,000 t) of hybrid seed sold in developing countries is classified as proprietary, compared to about 800,000 t classified as being of public origin. The global figures are again dominated by China (Table 14), one of the largest hybrid maize seed producers in the world, where all seed is of public origin. But even when China is excluded, about 40% of all hybrid seed sales in developing countries are of public origin. In the developing world, the public sector still plays an important role in maize breeding. Publicly developed hybrid seed is especially important in Africa, and proprietary hybrids are more important in Latin America and Asia (except China). More publicly developed hybrid seed is sold in sub-Saharan Africa (almost 50,000 t) than in any other region. Sales of hybrid seed developed by the public sector are

Table 14. Sales of hybrid maize seed in developing countries by origin of the germplasm, 1992

Region	All hybrid seed sales (000 t)	Percent public	Percent proprietary
Sub-Saharan Africa	64	76	24
West Asia and North Africa	13	49	51
Asia, less China	42	30	70
China	664	100	0
Latin America	212	30	70
All developing countries	996	80	20
All developing countries, less China	332	40	60
Industrialized countries	774	5	95
World[a]	**1,769**	**47**	**53**
World, less China	**1,105**	**15**	**85**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: See text for definition of public and proprietary hybrids.
[a] Includes 51 developing and 11 industrialized countries.

especially high in Zimbabwe, Kenya, and Brazil, countries with strong public and private breeding programs oriented towards hybrids. In contrast to developing countries, in industrialized countries almost all the seed sold is proprietary hybrids.

The importance of public sector breeding research for private seed organizations becomes evident when we examine the extent to which seed developed by the public sector (OPVs and public hybrids) is produced and sold by private organizations.[10] In developing countries, excluding China, publicly developed hybrids are produced and sold mainly by private national seed companies (61%), followed by public seed companies (16%) and NGOs, producer cooperatives, and individual producers (12%) (Table 15). The share of publicly developed hybrid seed sold by NGOs, seed cooperatives, and individual producers as a group is especially large in Africa and Latin America. Multinational companies sell only 11% of all the publicly developed hybrid seed sold in these countries, and the proportion drops to only 2% when China is included. Hence the public maize breeding system mainly supports national seed enterprises. National and multinational seed companies sold 75% of all publicly developed hybrid seed in industrialized countries. As expected, proprietary hybrids are produced and sold mostly by national and multinational companies in developing as well as industrialized countries (Table 16). When sales of public and proprietary hybrid seed are combined, the share of the private sector is 93% in developing countries (excluding China) and 97% in industrialized countries (Table 17).

Table 15. World sales of maize hybrids developed by the public sector, by type of seed company, 1992

Region	Share of public hybrid sales by company type[a]				Share of public hybrid sales by non-public companies (%)
	Multi-national (%)	Private national (%)	Other non-public[b] (%)	Public (%)	
Sub-Saharan Africa	7	43	25	24	76
West Asia and North Africa	0	83	2	15	85
Asia, less China	0	71	0	29	71
China	0	0	0	100	0
Latin America, less Argentina and Brazil	17	70	6	7	93
Developing countries	2	10	2	86	14
Developing countries, less China	11	61	12	16	84
Industrialized countries	43	33	9	16	84
World	4	11	2	83	17

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Percentages may not sum to 100 due to rounding.
[b] NGOs, seed producers' cooperatives, and individual seed producers.

[10] Although proprietary hybrids are rarely sold by public sector organizations, a few cases have been documented (in Asia).

These results indicate that while the market share of *public seed companies* may be very low, the significant proportion of *publicly developed materials* in total seed sales tells a different story about the public sector's participation in the seed industry, especially public breeding

Table 16. Sales of proprietary hybrid maize seed in developing and industrialized countries by type of seed company, 1992

Region	Share of proprietary hybrid sales by company type[a]				Total share of non-public companies (%)
	Multi-national (%)	Private national (%)	Other non-public[b] (%)	Public (%)	
Sub-Saharan Africa	71	1	27	1	99
West Asia and North Africa	58	38	0	4	96
Asia[c]	60	32	0	8	92
Latin America	63	34	2	0	100
All developing countries	63	32	4	1	99
Industrialized countries	57	39	2	3	97
World	**58**	**38**	**2**	**2**	**98**

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Percentages may not sum to 100 due to rounding.
[b] NGOs, seed producers' cooperatives, and individual seed producers.
[c] There is no proprietary maize seed production in China.

Table 17. Total hybrid maize seed sales in the world by type of seed company, 1992

Region	Share of all hybrid sales by company type[a]				Total share of non-public companies (%)
	Multi-national (%)	Private national (%)	Other non-public[b] (%)	Public (%)	
Sub-Saharan Africa	23	33	26	19	82
West Asia and North Africa	30	60	1	10	90
Asia, less China	42	43	0	15	85
China	0	0	0	100	0
Latin America	49	45	4	2	98
Developing countries	14	14	3	69	31
Developing countries, less China	42	43	7	7	93
Industrialized countries	56	39	2	3	97
World	**33**	**25**	**2**	**40**	**60**
World, less China	**52**	**40**	**4**	**4**	**96**

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Percentages may not sum to 100 due to rounding.
[b] NGOs, seed producers' cooperatives, and individual seed producers.

systems (Table 18). Information is not available on sales of public and proprietary hybrid maize seed by different types of companies in previous years. However, data from the *1986 World Maize Facts and Trends* (CIMMYT 1987) can be used to compare seed market shares of public and private sector seed enterprises. Since the mid-1980s, when the private sector's share of the commercial seed market in developing countries was 85%, it has further consolidated its position (it had 88% of the market in 1992) (Figure 3). Thus private organizations and NGOs have maintained and even strengthened their participation in seed production and distribution in the developing world. The collaboration between public breeding organizations and private seed production and distribution enterprises, especially national private seed companies and small-scale national seed producers, has also become very strong.

The Maize Seed Trade in Developing Countries

Whereas the amount and value of maize seed exported from the USA to the rest of North America and Europe and among European countries is well documented (Figure 4), maize seed trade among developing countries remains something of an enigma. Our survey elicited some information on countries involved in the maize seed trade and the amounts of seed traded in 1992 (Table 19).[11] Not surprisingly, the seed trade among developing countries is largely regional, concentrated in Eastern and Southern Africa and South America. According to these gross estimates, total seed trade among developing countries amounted to about 10,000 t in 1992, with Zimbabwe as the leading exporter. Among

Table 18. Hybrid seed sales in developing countries by origin of the germplasm and type of company, 1992 (excluding China)

Type of seed company	Market share in hybrid seed sales (%)	Percent of hybrid sales that is of public origin
Multinational companies	42	10
National private companies	43	56
Other non-public[a]	7	68
Public seed companies	7	88
Total or average	**100**	**40**
All non-public companies	93	36
	(000 t)	
Total hybrid sales	**332**	**132**

Source: CIMMYT Maize Seed Industry Survey, 1993.

[a] Includes NGOs, seed producers' cooperatives, and individual seed producers.

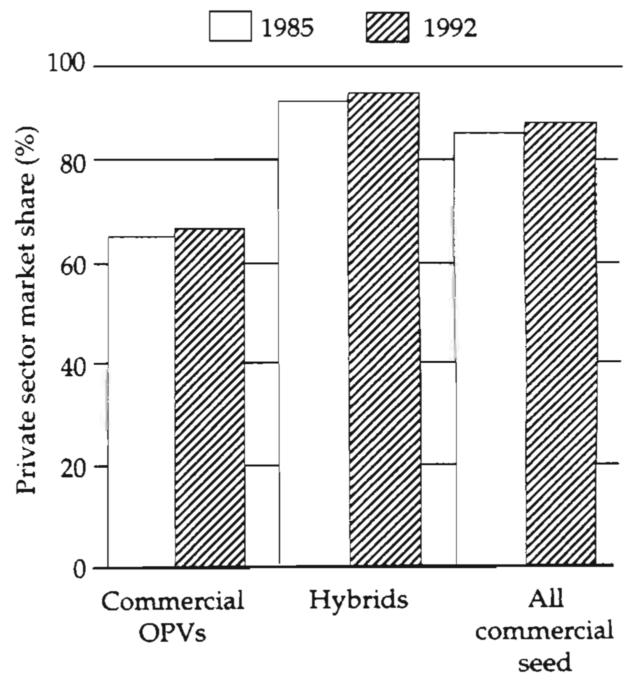

Figure 3. Private sector share of the maize seed market in developing countries (excluding China), 1985 and 1992.

Source: CIMMYT (1987) and CIMMYT Maize Seed Industry Survey 1993 .

industrialized countries, South Africa is an important supplier of hybrid maize seed to neighboring countries, but the USA accounts for the vast majority of hybrid maize seed exports, mainly to Western Europe, Canada, and Mexico.

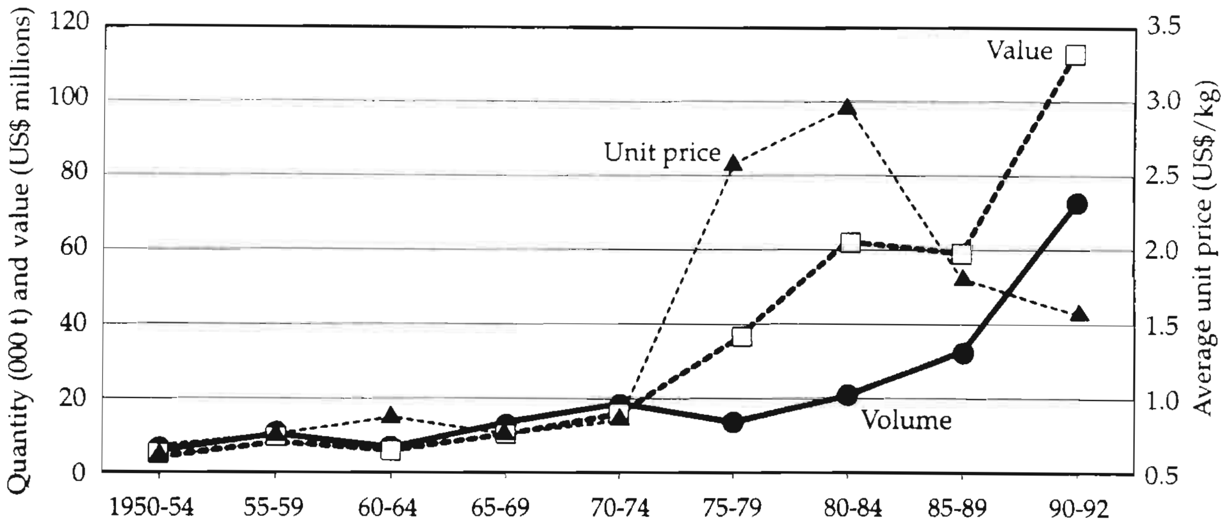

Figure 4. Volume (000 t), value (million 1985 US$), and average unit price (1985 US$/kg) of US maize seed exports, 1950-92.

Source: Echeverría (1985), USDA-FAS (various years).

Table 19. Hybrid seed exports worldwide, 1992[a]

Exporting country	Estimated hybrid maize seed exports (t)	Main countries to which hybrid seed is exported
Kenya	450	Ethiopia, Uganda
Zambia	850	Zaire, Malawi
Zimbabwe	3,500	Mozambique
Mexico	250	Central America
Argentina	200	Uruguay, Paraguay
Chile	900	USA
Brazil	500	Uruguay, Paraguay, Bolivia
South Africa	1,500	Lesotho, Mozambique
Germany	2,500	Netherlands
France	15,000	Germany
USA	60,000	Western Europe, Mexico, Canada, Japan
Total estimated hybrid seed exports	**70,000-95,000**	

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Includes data from 51 developing and 11 industrialized countries.

[11] The maize seed survey was not designed to gather information on the seed trade in each country. These estimates are based on information from survey respondents and also from secondary sources (Echeverría, 1985, and USDA-FAS, various issues). Also, large amounts of hybrid maize seed are traded among European countries. Hungary and Austria, for example, are important seed exporters in Europe (McMullen 1987), but no recent information was available from these countries. The figures in the table should thus be considered rough estimates.

The Economics of Commercial Maize Seed Supply

As discussed earlier, producing and selling commercial maize seed is the last stage in a lengthy process. Each step in the process requires substantial investment in human and capital resources, discussed below.

Research and Development (R&D)

The research and development phase is a very costly and time-consuming stage of seed development and production. Years of painstaking work are required to develop an improved variety or hybrid. The research time involved varies depending on how much basic germplasm is available and the degree to which it has already been improved. If germplasm can be obtained from public sources, such as the public breeding institutions, R&D time can be reduced substantially, especially when inbred lines have been advanced to a high level of inbreeding and information on their combining ability and adaptation is available (Table 20).

Table 20. Time required to develop OPVs and different types of hybrids with and without public germplasm

	Years required to develop:			
		Inbred lines for:[a]		
Availability of germplasm and stage of breeding	Open pollinated varieties	Single-cross hybrids	Three-way hybrids	Double-cross hybrids
A. Public germplasm collections not available[b]				
Collection/classification	1	1	1	1
Improvement/adaptation	2	3	3	3
Selfing		2	3	4
Testing	2	5	5	5
Total	**5**	**11**	**12**	**13**
B. Public germplasm collections available[c]				
Obtain public material/classify	1	1	1	1
Improvement/adaptation	1	1	1	1
Selfing		1	2	3
Testing	2	4	4	4
Total	**4**	**7**	**8**	**9**
C. Highly homozygous public inbred lines and information on their GCA[d] and SCA[d] available	**na**	**3**	**3**	**3**

Source: Interviews with breeders from CIMMYT and private companies in Brazil and Mexico.

Note: Assumes that materials used to start breeding program are adaptable in the region for which OPVs and hybrids are being developed and that two selection cycles per year are possible. This does not include highland areas, where only one cycle of selection is possible.

[a] The development of inbred lines for all types of hybrids is done simultaneously; in fact the lines are developed without a specific objective and then the decision is made to use them in single-cross, three-way, or double-cross hybrids depending on their characteristics.

[b] Assumes the breeding program starts with collections of land races and materials other than those available from public germplasm banks.

[c] Assumes materials from public germplasm banks are readily available and may can be brought into the country easily and legally.

[d] GCA = general combining ability; SCA = specific combining ability.

na = not applicable.

The costs of R&D are considered "fixed" or "sunk," because they must be incurred by the seed company to develop improved varieties and hybrids for sale. Unless the company has alternative sources of germplasm developed by others, these large costs cannot be avoided. Once the variety or hybrid has been developed, most of the remaining costs are "variable" costs related to field operations for growing the seed crop; cleaning, classifying, treating, and packing the seed; and marketing and distributing it.

Starting an R&D program thus requires a certain minimum initial human and capital investment. However, expanding the breeding operation beyond this minimum level is less expensive and can make the breeding program more efficient. Breeding is thus an activity in which "economies of scale" prevail: as the scale of the operation is increased, the unit costs of producing improved varieties and/or hybrids decrease, up to a certain level. This is the main reason why R&D in maize seed industries often is dominated by a few enterprises with large-scale breeding programs. For example, in the USA and Canada eight large companies control more than 60% of the total maize seed market (a single US company controls more than 40%). The situation is similar in developing countries that have large seed industries (Table 21).

The actual R&D costs incurred in developing a given variety, inbred line, or hybrid are difficult to estimate. Breeding is a continuing activity in which many materials are crossed and tested, but only a few become commercial products. Seed companies with R&D programs often assign a given percentage of total seed sales for R&D expenditures; R&D costs appear to average 8-15% of the total value of seed sales in the seed industry in a given country. Total maize R&D expenditures in the USA amounted to about US$ 110 million in 1990, which was about 8% of the total value of seed sales that year (Appendix D). In comparison, in 1992 total R&D expenditures were 12% of the total value of seed sales in Brazil and 9% in Mexico (López-Pereira and García 1994). In Zimbabwe, R&D costs were about 12% of the total value of seed sales.

Table 21. Maize seed industry concentration in the USA, Brazil, and Mexico, 1981 and 1992

Country/year	Total maize seed production (000 t)	Market share, four largest companies (%)	Market share, eight largest companies (%)
USA			
1981	591	56.9	67.1
1992	584	51.4	62.5
Brazil			
1981	115	70.2	89.6
1992	120	66.0	84.0
Mexico			
1981	31	90.0	93.0
1992	40	83.0	90.0

Source: Estimated from Silveira (1984); Matus Gardea, Puente González, and López Peralta (1990); McMullen (1987); and interviews with public and private seed sector officials in Brazil, Mexico, and the USA in 1992.

Production, Processing, and Marketing
This stage of commercial seed production consists of three distinct activities. The first is the production of the seed crop up to harvest; the second is harvesting and subsequent conditioning of the seed to prepare and package it for sale; the third is marketing and distributing the seed. These activities are very different from R&D, especially with regard to the time and skills involved.

Seed production costs — Several factors affect the total costs of growing a maize seed crop, including the price of maize grain, the type of seed, and the seed yield.

Maize grain price. The seed crop is often produced under contract with maize farmers ("contract growers"), especially in the case of large seed companies. The company pays a pre-determined price for the seed crop based on the price of commercial maize grain. To attract the best and most reliable maize farmers located near their seed conditioning plants, the seed enterprise often offers a premium over the price of commercial grain as well as guarantees to pay a minimum seed yield. Hence in countries where maize grain prices are very high (e.g., Mexico and the countries of Central America), maize seed production costs are high relative to countries where maize grain prices are lower. In addition, the seed company normally assumes some of the extra costs involved in growing the seed crop, such as detasseling, eliminating off-type plants, harvesting, and technical assistance and supervision by company staff, all of which raise the total cost of producing seed.

Type of seed and seed yield. Seed production costs vary greatly with the kind of seed being produced (Appendices F and G). Seed of improved OPVs is the least costly to produce, mainly because seed yields are high and detasseling is unnecessary. Producing improved OPV seed requires only two procedures that differ from those used in growing a regular maize crop: the field is carefully isolated to avoid contamination by other maize varieties, and the grower eliminates plants that do not have the desired physical attributes. The relatively simple production techniques and low production costs explain why seed of improved OPVs is popular in some developing countries. Furthermore, the lower cost of producing OPVs is normally reflected in lower seed prices.

Another important factor in the per-unit production cost of maize seed is the yield of the seed crop. Because inbred lines are used to produce hybrid seed (the inbreds are weaker than their offspring), yields of hybrid seed are usually lower than yields of OPV seed. The seed yield of parent inbred lines varies depending on the type of hybrid, resulting in large differences in production costs across hybrid types. Single-cross hybrids yield less seed than most other conventional hybrids, making them the most expensive to produce. Seed of non-conventional hybrids (e.g., top-cross hybrids) usually incurs the lowest production costs.[12] Hybrid seed yields are also lower because plants from the male parent (which can cover as

[12] The difference between conventional and non-conventional hybrids is discussed in Appendix F.

much as one-third of the total seed crop area) are not harvested for seed, thus raising the per-unit production cost. In addition, some hybrids (e.g., double-cross and three-way hybrids) require two cycles for commercial seed production because single-cross parents have to be produced first, whereas other types of hybrids (e.g., single-cross hybrids) require only a single season.

Seed conditioning costs — The main factor affecting seed conditioning costs is the difference between the *gross* seed yield (total seed harvested) and the *net* seed yield (the amount of seed left after conditioning). This difference is also somewhat related to the type of seed and its characteristics. Although a large amount of seed may be harvested, if a large proportion of this seed has to be discarded because of defects in size, shape, and other characteristics, the net seed yield will be low and unit production costs higher. In the development and identification of inbred lines for maize hybrids and also for developing improved OPVs, high net seed yield is an important characteristic (López-Pereira and Espinosa 1993).

Marketing and distribution costs— Marketing and distribution costs include promotion, discounts, storage, and shipment of seed to distributors. These costs can vary substantially among companies in the industry. In general, when competition is more intense, companies have to invest more resources in emphasizing their products' advantages over their competitors' — for example, by running yield trials of all the materials in the market. Another strategy is to provide better customer service — offering technical assistance, holding field days, and distributing free seed. Hence in highly competitive seed industries, marketing and distribution costs normally constitute a high proportion of the total price of seed, compared to industries dominated by one large seed enterprise.

Other factors affecting marketing and distribution costs are related to the geographical distribution of the farmers served by the seed enterprise and the size of their maize fields. Seed delivery costs increase if farmers are more dispersed, because more outlets must be established, and they also increase if farmers require seed in small quantities and packages. These factors are important for effective seed distribution in many developing countries, where maize is produced by a wide variety of farmers and under a wide range of growing conditions. This is one major reason why private seed companies concentrate their marketing efforts on large-scale maize farmers and on areas where production conditions are favorable (such conditions also reduce R&D costs as materials with wide adaptation can be developed more easily). Seed companies usually assign a percentage of the total seed price for marketing and distribution costs, just as they do for R&D costs.

All of these costs, along with general and administrative costs, form the total production cost of commercial maize seed.

Seed Prices

A profit margin is added to the total production cost of commercial seed to arrive at the commercial seed price. A typical breakdown of the total price of seed into cost components and gross margin resembles that presented in Figure 5. Direct production and conditioning costs make up less than 50% of the total price of seed, and R&D costs about 15%. The remainder of the seed price covers marketing and distribution (15%), overhead costs (15%), and gross margin (15%). While this breakdown may not apply to all seed industries in developing countries, it is relevant because of the private sector's increasing presence in seed industries in many countries, and it is useful for comparing the cost and pricing structure of seed companies across countries. For example, the similarity in maize seed production cost structures in Brazil, Mexico, and India (Table 22) is remarkable, given the differences in size and sophistication of the maize seed industry in each country (López-Pereira and García 1994). Note that the seed cost structure in these three countries resembles that presented in Figure 5.

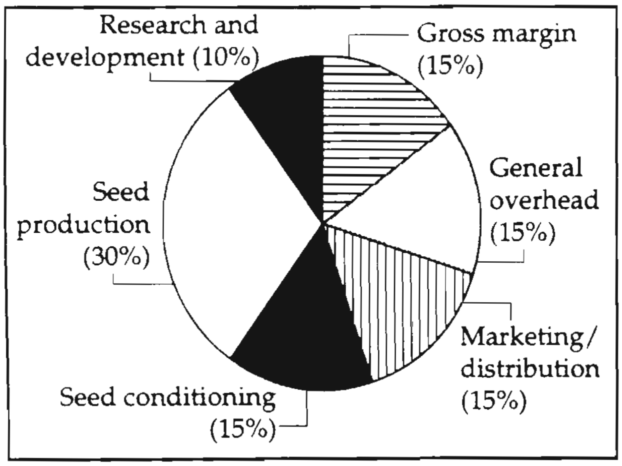

Figure 5. Typical breakdown of the price of hybrid maize seed.
Source: Pioneer (1992), Sehgal (1992).

Other factors affecting the price of seed — As noted earlier, differences in seed prices can be explained partly by variation in production costs. For example, a highly competitive seed industry with many seed companies is likely to be more efficient than an industry dominated by one or two companies. In such a competitive setting, firms will have to exploit every opportunity to reduce production costs, although marketing and distribution costs may actually increase. For example, the current high seed prices in the USA reflect the widespread use of single-cross hybrids, which are expensive to produce. However,

Table 22. Costs of producing and processing seed of double-cross hybrids by small private seed companies in Brazil, Mexico, and India, 1992

	Brazil		Mexico		India	
	(US$/kg)	(%)	(US$/kg)	(%)	(US$/kg)	(%)
Basic seed[a]	0.18	16	0.20	12	0.08	14
Seed production	0.36	33	0.63	38	0.19	32
Seed conditioning	0.08	7	0.11	7	0.08	14
Total production and processing	**0.62**	**56**	**0.94**	**57**	**0.35**	**60**
Sale price of hybrid seed	**1.10**	**100**	**1.66**	**100**	**0.58**	**100**

Source: López-Pereira and Espinosa (1993), for Mexico; López-Pereira and García (1994), for Brazil; and CIMMYT-Indian Agricultural Research Institute survey, for India.

[a] Parent seed sold by public sector organizations to private seed companies. This cost can be considered part of the R&D cost for these companies.

factors unrelated to production costs *per se* also contribute to high seed prices. Seed production costs constitute only about 30% of the final sale price of hybrid seed in the USA. The remaining 70% consists of R&D, marketing, seed conditioning, promotion costs, and profit margins. By contrast, more than 80% of the final sale price of seed in Zimbabwe consists of production and on-farm processing costs. Until recently, the R&D, promotion, and marketing costs borne by the seed companies in Zimbabwe were negligible, since the private sector largely performed these functions. In Mexico, where seed prices are higher than in Zimbabwe, seed production and processing account for about 60% of the final sale price.

Costs covered by the price of seed. If improved seed is produced from basic germplasm developed by the public sector, research and development costs do not have to be reflected in the price that a given company charges for seed. Likewise, if commercial seed is promoted through public sector extension programs, marketing and promotion costs borne by private companies are generally low. In these cases, the role played by the public sector resembles that played by foundation seed companies in mature seed industries, with the important difference that public organizations charge less than the full cost of production for their parent seed. When the public sector performs these functions, as is common in many developing countries, private firms can charge lower prices for improved seed.

The structure and competitiveness of the seed industry. Competitive small-scale seed companies can develop if the public sector provides improved germplasm and supports extension and promotion. The presence of small-scale companies increases competition in the seed market and helps to keep seed prices low. For example, one reason that seed prices in Brazil are low compared to those in other countries is that many medium- and small-scale seed companies sell public sector hybrids (López-Pereira and García 1994, Appendix H).

General economic policies. Commodity price support policies, input price policies, and credit policies influence not only the profitability of commercial maize production but also the cost of seed production and thus seed prices. For example, high guaranteed prices for maize in Mexico in the 1990s made maize production very attractive, raising the demand for hybrid seed (Appendix I). At the same time, seed production costs are quite high in Mexico, making seed correspondingly expensive.

Average seed prices in developing countries — Given the many factors affecting seed production costs and prices, how do actual commercial maize seed prices vary across regions in the world? It has been shown that seed prices can vary by the type of seed and its origin and that seed derived from public sector materials generally is priced lower than proprietary hybrids developed by the private sector. Double-cross hybrids are one of the most popular kinds of hybrids in most developing countries, whereas single-cross hybrids are favored in industrialized countries. On average, in developing countries excluding China, double-cross hybrid seed costs about US$ 1.69/kg and commercial OPV seed

US$ 0.61/kg; in industrialized countries, the price of single-cross hybrids is US$ 3.70/kg (Table 23). Expressing the seed price as a ratio of the price of maize grain removes local price distortions and enables comparisons of prices across countries and regions. The seed:grain price ratio averages 5:1 for OPVs and 10:1 for double-cross hybrids in developing countries (excluding China) (Figure 6). In industrialized countries, double-cross hybrids sell at 28 times the price of grain and single-cross hybrids at 33 times the maize grain price. In China, the world's largest producer of commercial OPV and hybrid seed (single-cross hybrids only), the seed:grain price ratio is about 2:1 for OPVs and 4:1 for hybrids. These are some of the lowest seed prices in the world. At US$ 0.35/kg, single-cross hybrid seed in China costs much less than the average price of improved OPV seed in the rest of the developing world. Low seed prices in China and in many other developing countries reflect in part low labor costs, low R&D costs associated with the use of public germplasm, and substantial subsidies provided by the government to maize seed producers.

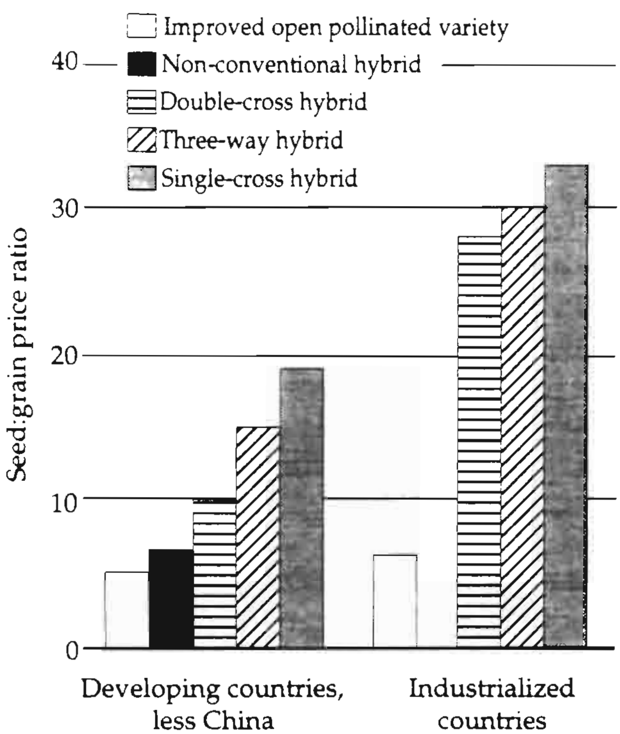

Figure 6. Maize seed prices by type of seed, developing and industrialized countries, 1992.

Latin America and Asia show the highest seed:grain price ratios for OPVs (Table 24). Public seed companies, NGOs, and cooperatives sell OPV seed for

Table 23. Prices and seed:grain price ratios of different types of maize seed in developing and industrialized countries, 1992

	Developing countries, less China		Industrialized countries	
	Seed price (US$/kg)	Seed:grain price ratio	Seed price (US$/kg)	Seed:grain price ratio
Improved open pollinated varieties	**0.61**	**5.1**	**0.78**	**6.1**
Non-conventional hybrids[a]	0.82	6.5	-	-
Double-cross hybrids	1.69	10.1	3.70	28.0
Three-way hybrids	1.27	14.7	4.23	30.1
Single-cross hybrids	2.60	19.1	3.81	32.8
Average for all types of hybrids	**1.68**	**11.7**	**3.86**	**32.2**

Source: CIMMYT Maize Seed Industry Survey, 1993.
Note: Includes data from 51 developing and 11 industrialized countries.
[a] Top-cross hybrids, varietal hybrids, etc.

substantially less than private seed companies. The highest seed:grain price ratio for double-cross hybrids is in Latin America, and prices of any kind of hybrid seed are generally lower in Africa than in other regions (Table 25). Multinational seed companies sell hybrid seed at higher prices compared to other seed enterprises, and private national seed companies, NGOs, and cooperatives price double-cross hybrid seed about the same (Figure 7).

Table 24. Ratio of the price of commercial OPV seed to the price of maize grain in developing countries by region and type of seed company, 1992

Region and type of seed company	Seed:grain price ratio
Region	
Sub-Saharan Africa	4.9
West Asia and North Africa	4.2
Asia[a]	5.1
Latin America	5.4
Type of company	
Multinational	6.6
Private national	6.2
Other non-public[b]	4.6
Public	4.5

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Excluding China, where all seed is produced and sold by public organizations.
[b] Includes NGOs, seed producers' cooperatives, and individual seed producers.

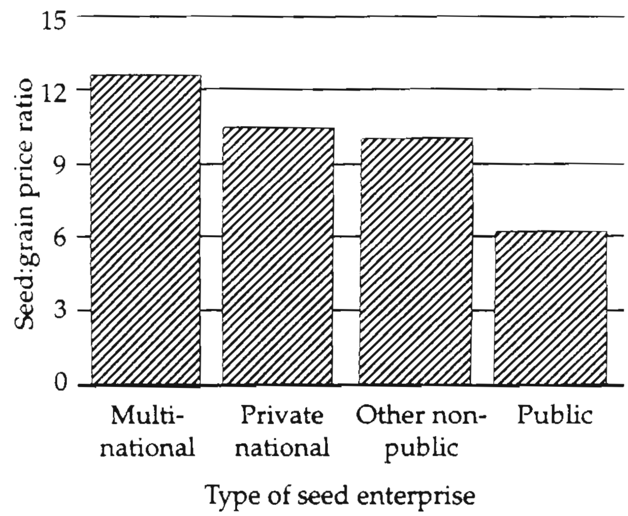

Figure 7. Seed:grain price ratio for seed of double-cross maize hybrids sold by public and private enterprises in developing countries (excluding China), 1992.

Table 25. Ratio of the price of hybrid maize seed to the price of maize grain in developing countries, excluding China, 1992

Region and type of seed company	Seed:grain price ratio			
	Non-conventional hybrid	Double-cross hybrid	Three-way hybrid	Single-cross hybrid
Region				
Sub-Saharan Africa	6.6	6.8	5.2	6.1
West Asia and North Africa	-	8.4	8.6	16.1
Asia, less China	4.4	6.8	10.8	24.1
Latin America	-	10.3	26.3	23.3
Type of company				
Multinational	8.1	12.7	14.7	23.6
Private national	6.3	10.4	20.3	19.9
Other non-public[a]	-	10.0	5.3	6.5
Public	4.3	6.2	8.6	12.0
All developing countries, less China	**6.5**	**10.1**	**14.7**	**19.1**

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Includes NGOs, seed producers' cooperatives, and individual seed producers.

The wide variation in seed prices across developing countries (excluding China) can be seen in Figure 8, where lowest, average, and highest seed:grain price ratios are presented for different types of seed. On average, the price of non-conventional hybrid seed is only slightly higher than that of OPVs (about 5:1 for both), and the price of three-way hybrids is only slightly higher than that of double-cross hybrids (about 10:1 for both). Single-cross hybrids are the most expensive of all, averaging over 15:1, and can be as high as 30:1 as in Argentina. Zambia reported the lowest seed:grain price ratios for conventional hybrids, and Côte d'Ivoire the highest seed:grain price ratio for double-cross hybrid seed. The increase in seed prices from OPVs to non-conventional hybrids to conventional hybrids, as well as the differences in seed prices across countries, can be seen in Figure 9. In many countries the price of conventional hybrids is less than 10 times the price of grain, although prices are very high in Pakistan, Thailand, and Mexico. In most developing countries, the price of OPVs is less than five times the price of grain.

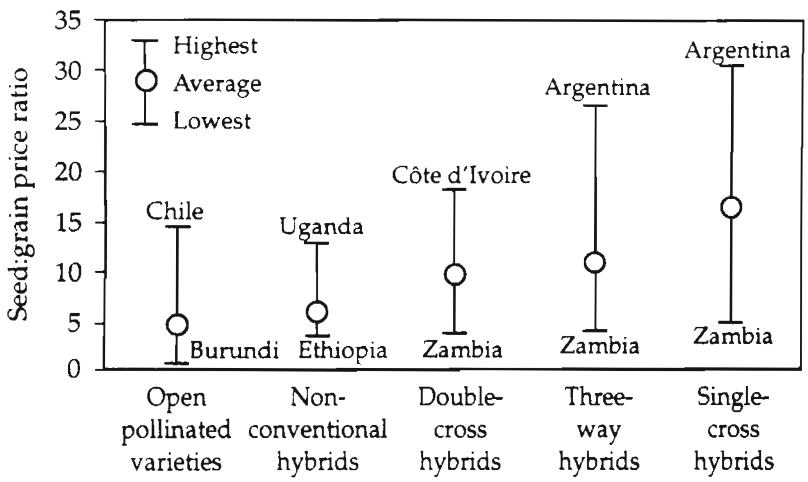

Figure 8. Seed:grain price ratios in developing countries in 1992, by type of seed.

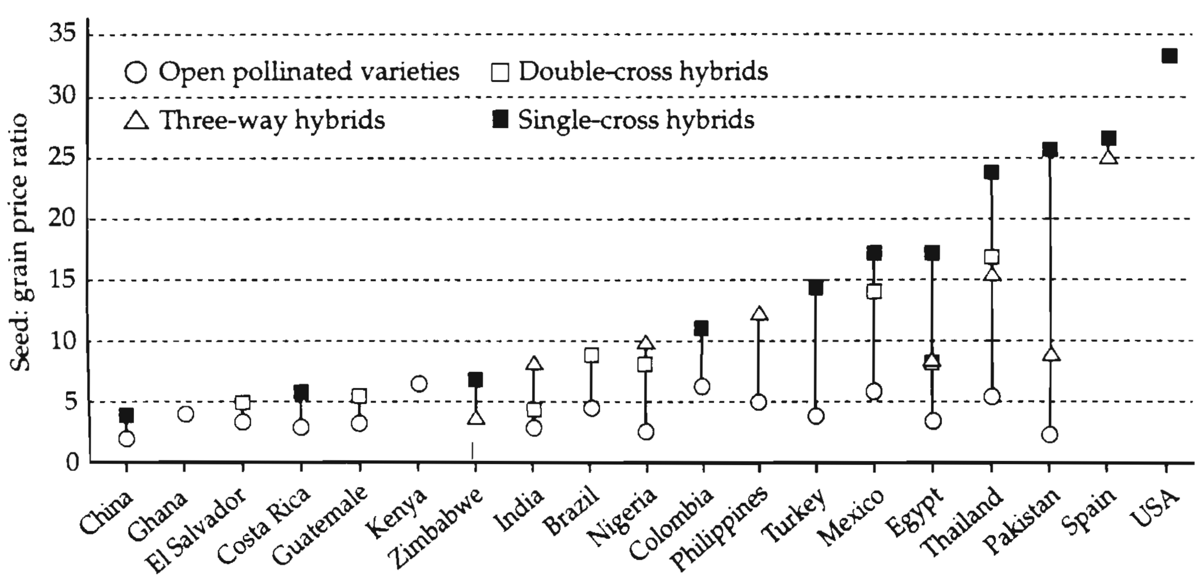

Figure 9. Maize seed:grain price ratios in selected countries by types of seed, 1992.

Source: CIMMYT Maize Seed Industry Survey, 1993.

The Economics of Adopting Improved Seed

Many factors influence farmers to use commercial seed. Information on the availability and characteristics of improved seed affects farmers' knowledge of new seed and their access to it, as well as their perceptions of the risk involved in using it. Other important factors include the difference in cost between the improved seed and the seed currently used, the yield advantage of improved seed over the current seed, and the cost of capital for financing the new purchase.

The Cost of Seed

Maize farmers have different seed options, each with different cost implications. If a farmer opts to use seed selected from the previous maize harvest (which can be a local variety, a recycled OPV, or an advanced generation hybrid), the price of this seed will normally be slightly higher (e.g., 20%) than commercial maize grain to account for the extra care taken by the farmer in selecting, drying, and storing the seed for several months. A second option is to use commercial seed. As noted earlier, the price of seed (and thus the total seed cost to the farmer) will vary depending on the type of seed, its origin, and the type of company that sells it. In those developing countries where hybrid maize seed:grain price ratios are relatively low, farmers tend to plant a larger percentage of their maize area to hybrids (Figure 10). Low initial seed:grain price ratios (on the order of 10:1 or less) thus appear to be necessary to encourage farmers to adopt hybrids during the development phase of the seed industry. This price-adoption relationship is not unique to developing countries. Although

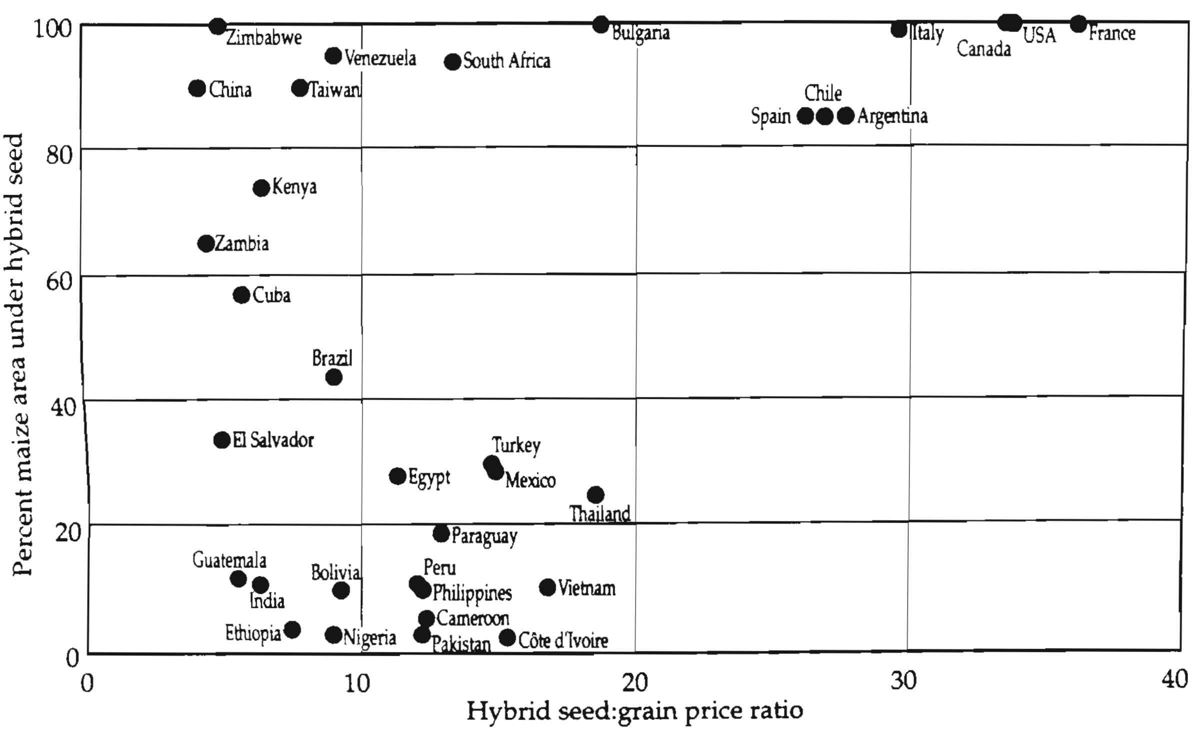

Figure 10. Maize seed:grain price ratios and adoption of hybrid maize seed in selected countries, 1992.

in the USA seed:grain price ratios for (single-cross) hybrids are currently 33:1, during the 1930s and 1940s, when (double-cross) hybrids were initially adopted, the ratio was less than 10:1 (Byerlee and López-Pereira 1994) (Figure 11), and these low prices were due in part to the availability of publicly developed hybrids.

Low seed prices may be necessary to encourage farmers' initial adoption of hybrids, but a low price alone is not sufficient to achieve high adoption rates of improved seed (Figure 10). Low seed prices may actually discourage private companies from investing in seed production. For example, in India public and parastatal seed corporations produce and market improved seed, which they sell at low prices with the help of government subsidies. Large private seed companies in India are reluctant to produce and market seed of public materials, because profit margins are negligible. In other situations (Argentina, for example), high seed prices are accompanied by high adoption. Developing a national seed price policy thus becomes a question of balancing farmers' budgetary needs with the profitability required for private seed enterprises to develop.

Although low seed prices appear to have been an important incentive for farmers to start using improved seed (especially small-scale farmers), as the seed industry matures and a continuous stream of higher quality improved varieties and hybrids becomes available, farmers will be willing to pay higher prices for seed if it offers sufficient productivity gains or cost reductions (e.g., germplasm with better resistance to insects will reduce the need to use pesticide) to make it economically attractive. Because farmers in many developing countries continue to pay a relatively low price for seed, the total cost of seed is still a small part of the total variable costs of maize production. Even when hybrid seed is used, the total seed cost is usually less than 10% of total costs (see Table 26 for some examples). In the

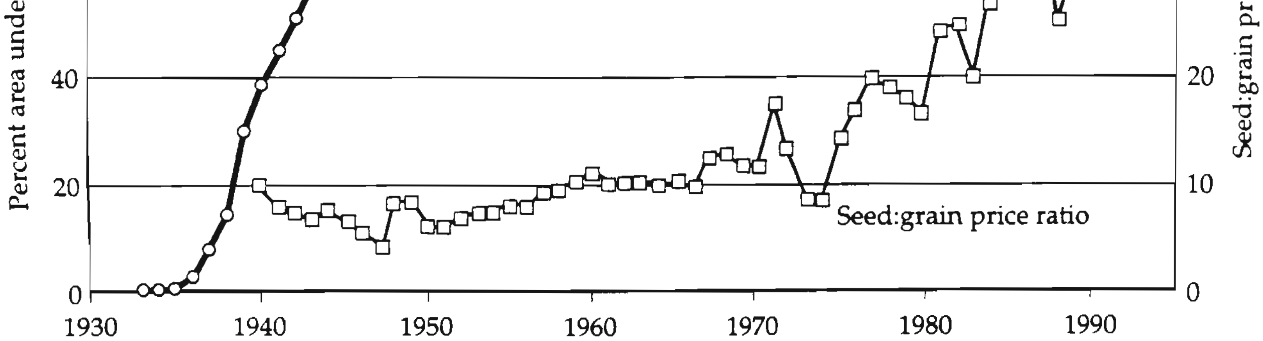

Figure 11. Hybrid maize seed adoption and seed prices in the USA, 1930-92.

Source: USDA (various years), Sundquist, Menz, and Neumeyer (1983), and Munson and Runge (1989).

future, as seed markets mature and private R&D and production, processing, and marketing costs increase, developing country farmers will probably have to pay higher prices for improved seed if the seed offers enough of an economic advantage to make it a profitable investment (Byerlee and López-Pereira 1994).

The other element in the total cost of seed is the amount of seed planted per hectare (the seeding rate). Seeding rates for monocropped maize average around 25 kg/ha across developing countries, but there is wide variation across regions, between countries, and within localized production zones. Seeding rates in certain areas of Indonesia average over 40 kg/ha because farmers overplant to compensate for expected losses to insects during the seedling stage (Krisdiana et al. 1991). In the mountains of northern Pakistan, farmers frequently sow 80-100 kg/ha of seed to obtain fodder from maize thinnings in addition to grain (Byerlee, Khan, and Saleem 1991). Using improved seed may be unprofitable in these situations, unless the need for high seeding rates is reduced. On the other hand, average seed rates in Central America and Mexico are around 19 kg/ha, and the total cost of seed is lower. Also, seed size varies depending on the type of seed used, which affects the total weight of seed planted per hectare. Since commercial maize seed is sold by weight in most developing countries, this also affects total seed costs.

Seed Recycling: A Strategy for Reducing the Cost of Seed?

In most developing countries, farmers recycle seed of commercial OPVs and occasionally even hybrids. The reasons for this include the lack of cash or credit to purchase commercial seed or the fact that commercial seed simply may not be available on time. However, the main reason for seed recycling may be that it makes economic sense; commercial seed may not offer a high enough yield advantage or reduction in production costs to make it attractive to farmers. The extent of maize seed recycling, the degree to which seed becomes mixed through out-crossing with other varieties, and the seed management practices of farmers who recycle seed are not well understood, as most of the evidence is anecdotal. One comprehensive study in Pakistan compared maize grown from improved OPV seed with maize grown from seed of the same improved OPV, recycled by farmers for up to four years (Longmire and Mohammed 1994). The authors found that the yield of maize grown from

Table 26. Cost of hybrid maize seed as a share of total production costs, selected countries

Country	Year	Hybrid seed cost as a percent of total production costs[a]	Source
USA (Iowa)	1990	11.7	ISU (1989)
New Zealand	1984	12.9	Lough (1985)
Indonesia	1982	13.2	Mink, Dorosh, and Perry (1987)
Mexico	1991	6.7	Sagarnaga (1991)
Zimbabwe	1986	6.0	Morris (1988)
Brazil	1988	5.1	Resende et al. (1990)
India (Punjab)	1992	5.1	Singh (1992)
Kenya	1992	5.0	Ministry of Planning (1993)

[a] Excludes land costs.

the recycled seed had declined by 14% and plant height had increased by 10%. They concluded that the rate of cross-pollination of improved OPVs with other varieties is very rapid. By the fifth year of recycling, improved OPV seed may have been so contaminated with other varieties that it may be indistinguishable from local varieties. A study in Nepal found that although farmers using recycled OPV seed notice changes in the maize crop, they do not associate these changes with the effects of cross-pollination (Seeley 1988). The the study stressed the need for farmers to have access to new seed every year, to make farmers aware of the effects of using recycled OPV seed on agronomic and yield characteristics, and to develop a long-term strategy for continuous OPV seed supply. A study in southern Mexico found that maize fields exhibited substantial mixtures of improved OPVs distributed in an earlier period, other varieties introduced from elsewhere, and local varieties (Bellon and Brush 1993). A significant admixture of maize seed in farmers' fields, resulting from out-crossing between an introduced hybrid and local varieties, was also reported in Tanzania (Friis-Hansen 1988).

Though inconclusive and highly dependent on local conditions, these examples suggest that recycled seed deteriorates quickly, after only a few seasons, and that the deterioration may be so extensive after the fifth year of recycling that the seed may no longer be considered improved seed. Hybrid seed recycling, although reported less frequently than OPV recycling, does occur in some countries and under certain conditions, especially when commercial seed is not available. Fewer than 10% of the small-scale farmers using hybrid seed in Malawi recycled it (Cromwell and Zambezi 1993). A recent study by Espinosa, López-Pereira, and Tadeo (1994) examined the yield effects and the economics of using recycled seed of OPVs and hybrids over a two-year period in central Mexico. The study found that, given conditions in the study area, the best alternative would be to use commercial seed of double-cross hybrids in both years, and that recycling OPVs or hybrids was uneconomical.

The average recycling periods of improved OPVs across countries or regions can be estimated if information is available on the average seed rates for improved OPVs, the estimated area under commercial OPVs, and the total area under improved OPVs (i.e., area under commercial and recycled OPV seed). Analysis of the survey data indicated that about 26% of all improved OPV seed used by developing country farmers in 1992 was commercial seed (Table 27). Overall, the (weighted) average recycling period for improved OPVs was 5.7 years; that is, on average maize farmers in developing countries purchase commercial seed of improved OPVs every six years. This average recycling period appears to be high given the evidence presented above. However, regional recycling periods are dominated by a few countries that produce large volumes of improved OPV seed and report relatively low recycling periods (e.g., Thailand, Brazil), indicating that there may be many countries with very large recycling periods. Regional average recycling periods vary from 4.2 years in West Asia to 6.4 years in Asia (excluding China), although wide variation is found in all regions. Of the 46 countries where improved OPVs are grown, 50% had recycling periods surpassing five years, 17% between three and five years, and 33% less than three years. Within the last group, six countries reported that farmers purchased commercial seed of OPVs every year.

Table 27. Average recycling period for improved OPV seed in developing countries, 1992

Region	Improved OPV seed used (000 t)		Recycling period (years) [a]		
	Total	Commercial	Lowest	Average	Highest
Sub-Saharan Africa	44	11	1.4	5.7	12.0
West Asia and North Africa	4	2	1.0	4.2	7.1
Asia	155	39	1.1	6.4	13.4
Latin America	91	25	1.0	4.6	7.2
All developing countries	**294**	**77**	**1.0**	**5.7**	**13.4**

Source: CIMMYT Maize Seed Industry Survey, 1993.

[a] The recycling period is estimated as the ratio of total improved OPV seed to commercial OPV seed used in each country. Regional averages are weighted by total improved OPV seed used in each country. Excludes China and Mozambique.

Clearly, a large proportion of developing country farmers choose to recycle OPV seed, even though the savings from recycling may be more than offset by the losses resulting from lower yields of recycled seed. Where seed industries are developed and seed is available on time and at a fair price, farmers purchase OPV seed every year. Hence seed recycling may be linked more to an institutional environment that hinders the regular supply of commercial seed than to farmers' attempts to reduce the cost of maize production.

Yield Advantage of Improved Seed

One very important variable affecting adoption of improved maize seed is the yield advantage it offers compared to a farmer's current material. The yield advantage depends on whether one is comparing a local variety versus an improved OPV, two improved OPVs, an improved OPV versus a hybrid, or two hybrids. The yield advantage of improved OPVs and hybrids over local varieties can vary greatly depending on growing conditions (Appendices F and G). Single-cross hybrids generally offer the greatest yield advantage, followed by three-way crosses, double crosses, top-cross hybrids, and finally OPVs; but harsh growing conditions may reduce the yield difference between different types of maize germplasm. In areas where improved OPVs and hybrids are replacing local varieties (e.g., parts of Eastern and Southern Africa, Central America) yield increases on the order of 40-50% may be expected. However, in areas where hybrids are replacing improved OPVs (e.g., Thailand, parts of India), it may be difficult to achieve yield increases of more than 20-25% over the yields currently obtained by farmers (Byerlee, Morris, and López-Pereira 1993). Tests of several varieties in Thailand showed hybrids had an 18% yield advantage over OPVs. Using various test sites throughout Mexico and Central America to reflect different growing conditions, researchers found that single-cross hybrids yielded only 14% more than OPVs (Córdova 1986). In the USA, where single-cross hybrids are now widely used, the first hybrids that were tested (double-cross hybrids) yielded only 10-15% more than the best improved OPVs, but the relative yield advantage was much greater during drought years (Iowa State Department of Agriculture 1935). More recent single-cross hybrids yielded 30% more than genetically similar OPVs (Jugenheimer 1976). The new single-cross hybrids being released in the USA yield only 1-3% more than the hybrids they replace (see, for example, Duvick 1992b). On-farm demonstrations in Malawi illustrate that even in marginal environments and under low management practices, hybrids can be profitable (Appendix E). These results suggest that a yield advantage in the range of 15-20% can be expected from replacing OPVs with hybrids under low-input conditions.

These and other recent data shed more light on the debate over the yield advantage of hybrid seed under low-input conditions and farmer management (Byerlee et al. 1994). These studies appear to indicate that even in marginal conditions and under low inputs and farmers' management, on average hybrids perform better than local varieties, most notably during drought years. However, firm conclusions cannot yet be drawn about the situations in which improved seed performs better than farmers' materials. More on-farm studies under farmers' complex growing conditions are needed, as well as more extensive testing of improved OPVs and hybrids under farmers' conditions.

In comparing the performance of improved materials and farmers' materials, it is important to note that the criteria normally used by farmers to measure performance may differ (sometimes substantially) from those of researchers. Farmers usually think of grain yield in terms of *net yield*, i.e., the yield remaining after processing and storage losses are deducted. Processing and storage losses in hybrids have been sufficiently large in some cases to offset advantages of 40% or more in gross grain yields (for example, see Smale et al. 1991). If part of the maize crop is sold in the market, grain quality differences reflected in price discounts may need to be considered when estimating the yield advantage of hybrids and OPVs. Price discounts because of undesirable characteristics having to do with grain texture, grain color, storage quality, difficulty of processing, or eating quality may fail to compensate farmers for a simple yield advantage. Even if maize is produced solely for home consumption, these undesirable characteristics may also hinder adoption.

Risk and Cost of Capital

For improved seed to be attractive to farmers, it must not only generate additional income to repay the higher cost of seed and any other costs (such as the grain price discounts discussed above), but it must also provide an extra return to compensate the farmer for the risk taken in using a new technology. Improved seed may promise higher *average* yields but yields also may show *greater variability* from season to season. Among small-scale farmers especially, increased yield variability, actual or perceived, can be seen as an important disadvantage, particularly when farmers depend on the maize crop for home consumption and family subsistence and thus place a high value on food security. Studies have found that a marginal return of at least 100% may be needed to make investing in a new technology attractive to farmers (CIMMYT 1988) (i.e., for every additional dollar invested in seed, the new technology will have to generate at least two dollars in additional revenues). Seed companies estimate that their improved seed has to offer a much higher marginal return, on the order of 300%, to make it attractive to farmers, and they use this in setting seed prices (McMullen 1987, Sehgal and Rompaey 1993). This strategy allows seed companies with outstanding materials to charge higher than average prices for them (see Table 28 for an illustration) and, at the same time, meet farmers' requirement for a (very high) minimum rate of return.

Partial budget analysis — Partial budget analysis looks at the costs and benefits associated with different seed options and can be used to compute the marginal rate of return (MRR) associated with the adoption of improved maize seed. An example of this analysis is presented in Table 29. Three comparisons are illustrated: 1) an OPV versus a local variety, 2) a hybrid versus a local variety, and 3) a hybrid versus an OPV.

Table 28. Illustration of average-plus-share-of-value-added pricing for improved maize seed

Item	Quantity	Price per kg (US$)	Total per ha (US$)
Seed cost (average for double-cross hybrids)	20	2.00	40.00
Average yield for double-cross hybrid (t/ha)	4.0		
Average yield of new hybrid (t/ha)	4.2		
Yield advantage (kg) and value added ($) offered by the new hybrid	200	0.11	22.00
Value of extra yield per kg of new hybrid seed		1.10	
Distribution of value added:			
Farmer (75%)		0.82	16.50
Seed company (25%)		0.28	5.50
Price of new hybrid: average double-cross hybrid seed price + share of value added		**2.28**	**45.50**

Table 29. Hypothetical partial budget analysis for the use of improved maize seed

	Local variety	Improved OPV	Double-cross hybrid
Yield (kg/ha)	1,500	2,000	2,500
Adjusted yield (-10%)	1,350	1,800	2,250
Gross revenues ($/ha)[a]	162	216	270
Price of seed ($/kg)	0.15	0.30	0.90
Total costs that vary ($/ha)[b]	3.75	7.50	22.50
Net revenue ($/ha)	158.25	208.50	247.50
Marginal costs ($/ha):			
Local variety to OPV or to hybrid		3.75	18.75
Improved OPV to hybrid			15.00
Marginal net revenues ($/ha):			
Local variety to OPV or to hybrid		50.25	89.25
Improved OPV to hybrid			39.00
Marginal rate of return (%)[c]			
From local variety to OPV or to hybrid		**1,340**	**476**
From improved OPV to hybrid			**260**

[a] Based on a field price for maize grain of US$ 0.12/kg.
[b] Based on a seed rate of 25 kg/ha for all types of seed.
[c] The marginal rate of return (MRR) is calculated by dividing the marginal net revenues by the marginal costs and expressing the result in percentage terms.

Several points are worth noting in this example. First, the maize price used is the "field price," which is the final price after adjusting for harvesting, shelling, bagging, and post-harvest transportation costs. Using the field price is important for taking into account the additional costs of harvesting higher yielding hybrid maize. Second, if average yields are obtained from trials, they normally have to be adjusted downward to account for actual farm conditions. Third, the analysis includes only costs and revenues that vary across the different alternatives, and should not be interpreted as reflecting the total costs or revenues from maize production.

For the specific conditions in the example, switching from a local variety to an improved OPV would be extremely profitable, given that the MRR exceeds 1,300%, surpassing any reasonable minimum rate of return required by farmers. However, switching to hybrid seed would also be highly profitable for farmers who are growing the unimproved local variety, as the MRR of that change exceeds 475%. For farmers who are already growing the improved OPV, switching to hybrid maize would be somewhat less profitable, given the MRR of 260%. Nevertheless, even the latter MRR is likely to be considered attractive by most farmers, indicating that hybrid seed is the most attractive alternative of all. Note that the best alternative *is not* the one with the highest MRR (moving from a local variety to an improved OPV), but the *last* alternative with the MRR that surpasses the *minimum* required by the farmers in a region (moving from OPV to hybrid).[13] Therefore under these conditions it would be highly profitable for farmers who grow local varieties as well as farmers who grow improved OPVs to switch to double-cross hybrid seed.

Even with the assurance that average yields will be higher and the marginal rate of return attractive if they use improved maize seed, farmers may have to take other factors into account when deciding whether to purchase improved seed. When cash is a constraint, financing the seed purchase becomes risky. With improved seed, especially hybrids, a complete package of complementary inputs is often recommended, and farmers must gauge whether they can afford these inputs and whether they will be available when needed. Continued access to improved seed is another important factor affecting adoption, particularly where the seed industry is underdeveloped and/or run mainly by the public sector. If multinational companies are the main suppliers of either seed or other inputs, the foreign exchange situation of the country may also create bottlenecks in seed supply.

Break-even yield curves — The main factors influencing the attractiveness of improved maize seed are its estimated yield advantage and its price. The break-even yield curves in Figure 12 show the minimum yield advantage required from improved seed (relative to a given base yield) to compensate the farmer for the extra investment and the risks taken in using the seed. The curve for a seed:grain price ratio of 2.5:1 corresponds to a situation in which seed of OPVs is recycled every three years. The price of seed is thus spread over three years, resulting in a very low seed price and very low yield advantage needed over the local seed.

[13] Note that the technological alternatives are ranked in increasing order of total costs that vary before the partial budget analysis is performed (see CIMMYT 1988).

Break-even yield curves illustrate two important characteristics of the economics of adopting improved seed. First, for a given price level, the yield advantage required from improved seed decreases as the current yield level increases. At very high yields, the required yield advantage is less than 20% in most cases. Second, at relatively low current yield levels, the required yield advantage of improved seed increases substantially as the price of seed increases, to the point where it is impractical to use improved seed because it is highly unlikely to provide the needed additional yield. In the hypothetical example presented in Figure 12, a current yield level of 2 t/ha would require a yield advantage of slightly more than 20% if the seed:grain price ratio is below 10:1. On the other hand, at a seed:grain price ratio greater than 10:1, a yield advantage of at least 30% would be required to make changing varieties profitable for farmers whose current yields are low.

This analysis supports the evidence that small-scale farmers are more likely to adopt improved seed where prices are less than 10:1. It also helps to explain how, as farmers' yields and incomes rise, smaller relative yield advantages are required to make the use of improved seed attractive, even if seed prices are high. This is a major economic reason why farmers in areas with favorable growing conditions are more likely to use improved seed and other inputs than farmers who produce maize under marginal growing conditions.

The Future World Maize Seed Industry

In the coming years, several factors will strongly influence the structure and size of the world maize seed industry, as well as the types of products that are developed. The most important factors are technological advances in developing varieties and the institutional arrangements needed to best serve the world's maize farmers.

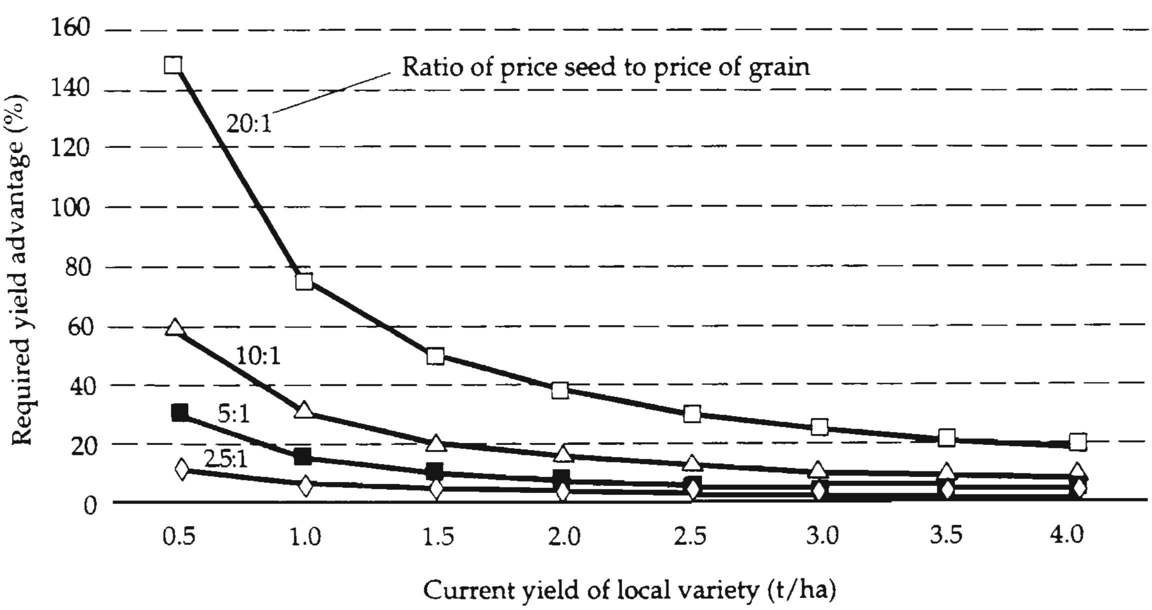

Figure 12. Required yield advantage over seed of a local variety to compensate the additional cost of seed of an improved variety, including a 100% return to investment, for different prices of improved seed and current yield levels.

The Technological Environment

Biotechnology — Although it is difficult to predict when biotechnology might begin having an impact on maize production, the products of biotechnology may not become a standard option for maize farmers in industrialized countries before the start of the next century, and perhaps another 5-10 years later in developing countries. But no matter when they are introduced, most products of biotechnology research on maize will be embodied in improved seed, especially seed that is resistant or tolerant to herbicides or to insects and other pests, and this is likely to have profound impacts on maize seed industries. It is generally agreed that molecular biology techniques will not replace conventional breeding methodologies but rather will make them more efficient and less costly in at least two ways (Byerlee 1994). First, the time needed to develop superior materials will be reduced through the use of molecular markers and improved diagnostics for more precise selection of plants that carry genes for desirable traits (or rejection of plants that that carry unwanted genes). This would substantially reduce the R&D costs of producing a variety or hybrid (see earlier discussion). Second, molecular biology techniques enable the transfer of genes from unrelated species to provide traits that would not be available through conventional breeding techniques. The complexity of this process of genetic transformation makes it likely that the first products will emphasize traits that are transferred through a single gene, and current research on genetic transformation of cereal crops therefore emphasizes pest resistance, herbicide resistance, quality traits, and genetically-induce male sterility to facilitate hybrid seed production (Byerlee 1994).

Much controversy surrounds the genetic transformation of maize for herbicide tolerance. Some argue that herbicide-tolerant materials will foster dependence on specific herbicides (for example, see Just and Hueth 1993), discourage reductions in herbicide use, especially in commercial maize production, and ultimately harm human and environmental health.[14] Others caution that herbicide-tolerant maize will favor commercial farmers over small-scale farmers (and laborers) who control weeds by hand (see, for example, Hobbelink 1991). However, in some cases herbicide-tolerant maize may benefit both small-scale farmers and the environment. For example, some small-scale farmers in parts of Mexico and Central America now use herbicides for land preparation and weed control in lieu of traditional slash and burn methods. This practice makes it possible to maintain a mulch of crop residues and weeds on the soil surface, which reduces erosion and improves moisture retention. However, these farmers typically use paraquat, a dangerously toxic herbicide. Maize varieties genetically engineered for tolerance to less toxic herbicides could encourage those farmers to use the less toxic chemicals (Byerlee 1994).

Materials possessing genetic tolerance to insects and other pests, mainly through the incorporation of special Bt[15] genes and proteins, could also substantially reduce the use of chemicals in agriculture. This approach is being emphasized by some private enterprises

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[14] Views on the potential effects of using herbicide-tolerant crops in the US can be found in Harrison, Jr. (1992) Duvick (1992), and Wyse (1992).

[15] "Bt" stands for *Bacillus thuringiensis*, a soil bacterium that produces insecticidal proteins that are active against specific insect groups. Molecular biology techniques have been used to transfer Bt genes to crop plants such as maize, resulting in transgenic plants carrying resistance to specific insect pests (e.g., Vaeck et al. 1987).

and by national public sector organizations and international agricultural research centers (IARCs) and is expected to bring substantial benefits to developing country farmers (for example, see CIMMYT 1994 for details on the advancement of such research oriented towards the needs of developing country farmers).

Another line of research, for which results remain uncertain and will be much less immediate, involves *Tripsacum*, a species related to maize. Its objective is to transfer a trait called "apomixis" from *Tripsacum* to maize (CIMMYT 1994). Apomictic plants reproduce asexually; nearly all seeds produce an exact clone of the mother plant. If apomictic products become available commercially, they have the potential to lower seed prices dramatically, because farmers will be able to recycle hybrid seed without loss of genetic purity (or, of course, yield potential). The use of biotechnology tools will be instrumental to this research. Researchers predict that production of the first apomictic maize could be achieved within the next 3-5 years, although it will take several more years to find practical ways to transfer the gene into farmers' varieties.

The potential utility of these and other products and processes of biotechnology is apparent, but it does not dispel the uncertainty over how their introduction will affect seed prices. It is not yet clear whether the potential cost savings (e.g., through reduced pesticide use) or revenue increases (e.g., through higher yields) will offset possible increases in seed prices. While the relatively low seed prices in developing countries provide some scope for absorbing part of the price increase expected if this seed reaches the market, it is possible that it could be priced out of the reach of many small-scale farmers in the developing world. This reinforces the importance of public sector NARSs and IARCs in underwriting the cost of R&D for maize hybrids directed at small-scale farmers.

The Legal Environment: Intellectual Property Rights

In the 1970s and 1980s only a few developing countries, notably Argentina and Chile, enacted intellectual property rights (IPR) legislation. However, in recent years many countries, especially in Latin America, Eastern Europe, and the former Soviet Union, have decided to introduce legislation on IPRs to provide incentives for further development of their economies (including seed industries). Other countries are seriously considering doing so, including India, China, Kenya, and Brazil. This interest in IPRs is also the result of an increasingly interrelated world, linked through regional free trade blocs such as the North American Free Trade Agreement (NAFTA), the Southern Cone Common Market (MERCOSUR), and the European Union (EU). Now that the so-called Uruguay Round of the General Agreement on Tariffs and Trade (GATT), which includes provisions requiring the introduction of intellectual property laws, has been signed, the interest in IPRs is expected to grow even more.

Maize hybrids (although, obviously, not OPVs) generally have been protected by keeping the identity of the parent lines secret, which has been sufficient to stimulate private sector investment in hybrid maize breeding in many countries, even in developing countries without legal forms of protection (see, for example, Byerlee and López-Pereira 1994; López-Pereira and García 1994). Thus one of the questions generated by the debate over IPRs is to what extent intellectual property legislation will foster the development of a maize seed industry beyond what would have been the case without IPRs. It is likely that the effectiveness of IPRs as a mechanism for encouraging private sector R&D and the development of maize seed industries in developing countries will vary with the sophistication of the industry. An emerging private sector benefits from the free availability of public germplasm from the NARSs and IARCs,[16] so initially local private firms do not demand IPRs. As private sector investment in R&D grows, proprietary materials begin appearing in the market.

In countries where small-scale farming systems predominate, IPRs may actually be ineffective for protecting maize materials because of the high costs of enforcement and low potential for revenues from royalties (Byerlee 1994). However, it could be argued that IPRs would increase private R&D in maize, since R&D is likely to be at less than optimal levels in the absence of such protection.

A related and more disturbing question is whether IPRs are needed for developing countries to gain access to the products of biotechnology research. Of course, a patent on a variety or gene in industrialized countries does not deny access by small-scale farmers in developing countries to that variety or gene, even in the absence of IPRs in developing countries. Once a variety is released in any country, it is only a matter of time until it is available to breeders in other countries who can transfer useful genes through conventional breeding.

Does this imply that developing countries can ignore the current pressure to implement IPRs for plants and biological processes? There are at least three reasons why this may not be the best strategy (Platais and Collinson 1992). First, there will be a delay of several years in obtaining and adapting useful germplasm to local needs. With IPRs, it is possible that an agreement could be negotiated, and suitable varieties made available to farmers, at a much earlier stage. Second, access to biotechnological processes, useful for creating new varieties more efficiently, may be more important than access to germplasm. These processes will have to be purchased under some licensing or royalty system. Without access to these processes, a country might limit its potential to develop and export its own biotechnological innovations (Byerlee 1994). Third, IPRs for biological processes and products are now an integral part of international agreements such as the GATT. If a country, as part of its overall economic policy, wishes to benefit from these agreements, IPRs may be needed.

One of the issues being debated in many national and international fora is which form of IPRs to use. The two basic forms under review are plant variety protection (or plant breeders' rights) and the patenting of genes, biological processes, and varieties (known as "utility patents" in the USA). The USA is one of the few countries where plant varieties can be patented, and patents have been used to protect maize inbreds. The US Plant Variety Protection Act (PVPA) can also be used to protect inbred lines (not hybrid varieties). However, resorting to this type of protection makes the inbred line publicly known to potential competitors, so US seed companies rarely use it to protect their commercial hybrids. Most developing countries prefer plant breeders' rights over patents.

[16] See Barton and Siebeck (1994) for an analysis of the possible effects of intellectual property protection on materials developed by seed organizations with source germplasm originating in the IARCs and alternatives that the IARCs are considering to achieve unrestricted access to the genetic resources in their safekeeping.

While recognizing that plant breeders' rights are not perfect, advocates of this form of IPRs argue that it adequately guarantees that the owner can exploit any protected material and, at the same time, allows protected materials to be used widely for research. Recent advances in molecular biology techniques for gene mapping should help simplify the application and enforcement of plant breeders' rights, and should open opportunities for alliances between different players in the seed industry. The second option, utility patents, is a more controversial approach to IPRs. Patents are expensive to obtain and have not been widely tested in the courts. In addition, many groups oppose the idea of patenting living organisms. As a result, patents have not been used to protect maize hybrids in developing countries; in fact, in some countries maize hybrids are specifically excluded from patent protection under standard industrial patent laws (Evenson 1991).

The Institutional Environment

Along with the technological and legal issues discussed earlier, a series of institutional issues will strongly influence the further development of maize seed industries in developing countries. These issues are largely related to the enhanced opportunities for private seed sector development resulting from public sector restructuring and agricultural policy changes, and the need to find strategies for effective seed distribution systems in marginal maize production regions.

Efficiency versus equity — An important issue in maize breeding in developing countries is the need to balance equity and efficiency when setting objectives in breeding and seed production and delivery. Even where the private seed sector is strong, public intervention may still be needed to reduce biases in the kinds of farmers and regions served by the seed industry. The private seed sector understandably concentrates its efforts where profit opportunities are greatest, usually seeking to reach large-scale commercial farmers who normally grow hybrids rather than improved OPVs. Thus public sector organizations can have an important role in generating improved maize germplasm for small-scale maize farmers in marginal areas, especially materials adapted to local growing conditions.[17] Public research systems can also help foster the development of small-scale seed producers, often the main source of improved seed for resource-poor farmers. Alternatively, public support to private sector varietal development and seed production targeted at small-scale farmers at times may be the most effective way to ensure that these farmers have access to suitable maize hybrids and improved OPVs. However, given the recent sharp reductions in support for public national research programs in many developing countries, as well as for IARCs in recent years, it is not clear how the public research system will accomplish this research agenda.

Two potentially controversial activities that the public sector is experimenting with in some countries are selling public inbred lines at close to full price (including the recovery of R&D costs) and receiving royalties on sales of seed of public hybrids (Table 30). The financial crisis has led some public research institutes to generate funds by selling public germplasm, mainly basic seed for producing commercial seed of public varieties and hybrids. Some national programs also receive royalties from the sale of public materials. One drawback of

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[17] That is, after a careful analysis of alternative uses of marginal lands including the potential of other crops, so that public funds are invested in activities with the greatest potential for social benefits.

such arrangements is their potential for biasing the research objectives of public institutes towards the development of materials for high-potential regions and away from the needs of small-scale farmers. However, public sector research oriented to small-scale farmers has in some cases been supported through sales of public improved germplasm. In Brazil, for example, the national maize breeding institute uses some of the funds obtained from selling improved germplasm to private companies in the Cerrados region to support breeding activities for the northeast, where growing conditions are much more difficult, small-scale farmers predominate, and adoption of improved seed has been limited (Table 31). In addition, there is evidence that these initiatives help to increase competition in the private sector, which results in lower maize seed prices to farmers (López-Pereira and García 1994). Nevertheless, the potential for controversy exists, and it will be interesting to see the outcome of these initiatives.

Table 30. Prices of basic seed and royalties paid by private companies for maize OPVs and hybrids developed by the public sector in Brazil and Mexico, 1993

	Brazil	Mexico
Improved OPV seed:		
Price of basic seed (multiple of commercial seed price[a])	10	5
Royalties on seed sales (%)	2-3	5
Hybrid seed:		
Price of basic seed (multiple of commercial seed price)	20	7
Royalties on seed sales (%)	5	5

Source: Interviews with public and private seed sector officials in Mexico and Brazil.

[a] For example, if the price of double-cross hybrid seed is US$ 1/kg, the private company pays US$ 20/kg of the single-cross parents to produce the commercial seed in Brazil, and US$ 7/kg in Mexico.

Future roles of the public and private seed sectors — Maize seed industries clearly have evolved in a direction that places more responsibility in the hands of private sector organizations, especially in seed production and marketing. As noted earlier, public sector organizations played a key role in the development of seed industries in industrialized countries, primarily by assuming a substantial portion of the initial R&D investment. In fact, the breeding methodologies and improved germplasm resulting

Table 31. Improved maize seed adoption in Brazil by region, 1992-93

	North-Northeast	South-Central	All Brazil
Maize area (million ha)	2.6	9.7	12.3
Total seed demand (000 t)[a]	52.0	195.0	247.0
Commercial seed sales (000 t)			
OPVs	6.3	7.3	13.6
Hybrids	0.5	107.8	108.3
Total seed sales	6.8	115.1	121.9
Area under improved, commercial seed (million ha)[a]	0.3	5.7	6.0
Improved seed adoption (%)	13.1	58.8	49.1

Source: CIMMYT Maize Seed Industry Survey, 1993.

[a] Assuming an average seed rate of 20 kg/ha for both OPVs and hybrids.

from this public investment were the basis for private seed sector development in industrialized countries (Huffman and Evenson 1993; Appendix D). In many developing countries, the greater diversity of growing environments, maize farmers, and maize farming systems, combined with the still incomplete establishment of the R&D phase of maize seed industries, make it less likely that private companies will be able to serve the needs of all farmers and still be profitable. This implies that there is still a need for active public sector participation in maize R&D to complement private sector R&D and seed production and distribution.

Each country will have to seek the institutional arrangement that fit its specific conditions best, especially regarding the stage of development of the industry, size of the seed market, types of maize farmers to be served, and diversity of maize production conditions. The basic infrastructure for seed industries to function effectively is often missing in many developing countries. Much remains to be done to ensure that most maize farmers have the option to purchase improved seed and to replace this seed periodically with seed of new, superior varieties and hybrids. Economic restructuring and changes in agricultural policies have resulted in the strengthening of private organizations in the agricultural sector, and they should be encouraged to develop further and collaborate closely with public sector organizations. There is evidence suggesting that when the public and private seed sectors collaborate there is a substantial positive effect on maize productivity (Echeverría, 1991). The success of seed industries in industrialized countries, and the strong public support they received during their early stages of development, suggest that an integrated public-private seed sector may be a good strategy for forming an efficient seed industry.

As private sector investment is substantial and growing in most commercial maize regions, especially in Latin America, public sector research has the opportunity to concentrate on basic and strategic research and production areas bypassed by the private sector, especially marginal maize production regions. However, increasing public sector research for marginal areas may be complicated by the growing trend towards the generation of revenues from royalty payments for the use of public varieties and hybrids. Public research programs in deep financial crisis could find these arrangements increasingly attractive, but a profit-oriented public sector may become a competitor to the private sector in commercial areas rather than complement private sector R&D efforts, and millions of small-scale farmers could potentially be excluded from the process of technological change (Byerlee 1994, Byerlee and López-Pereira 1994).

The need for a strategy for sustained OPV seed production and distribution — Adoption of improved seed is still low in large areas of maize production in the developing world. Many of these areas are characterized by small-scale subsistence farming systems and poor access to markets. Under these conditions, maize farmers may benefit more from the introduction of improved OPVs than from hybrids. Several characteristics make OPVs more suitable for these conditions:

- Maintaining improved OPV seed is relatively simple.
- New and better varieties extracted from a population improvement program (or improved versions of existing varieties) can replace old varieties when desired.

- Seed production costs for OPVs are relatively low.
- To some extent, OPV seed can be transferred from farmer to farmer and can be saved by farmers for several years, increasing the area sown to improved OPV seed.
- National programs can exchange germplasm of OPVs more easily than closed-pedigree materials that may involve proprietary rights.

These advantages led many breeding programs in developing countries to emphasize the development of OPVs almost exclusively from the early 1970s through the late 1980s. Unfortunately, only a few programs for producing and distributing seed of improved OPVs on a sustained basis have been established (Thailand and Guatemala are good examples). Despite the substantial breeding effort and the large number of OPVs released in developing countries, their impact has been less than anticipated; today commercial OPV seed accounts for less than 10% of all commercial maize seed sold in developing countries.

Public sector programs for producing and marketing OPVs usually have been short lived and fairly *ad hoc* (Smith et al. 1994, GGDP 1991, CIMMYT 1989). The performance of public seed companies in producing and distributing OPV seed has for the most part been unsatisfactory (CIMMYT 1987). These companies often do not sell the newest varieties developed by the breeding programs, so farmers find it difficult to replace their current cultivars with more recently released materials. In addition, seed supplies may be too limited for farmers to purchase OPV seed annually. As a result, adoption of improved OPVs is often a one-time event, and farmers do not benefit from the yield gains offered by the release of newer, higher yielding varieties. Private sector initiative has stimulated diffusion of hybrid seed, but the private sector has shown little interest in producing and distributing OPVs, which unlike hybrid seed do not represent a reliable (and profitable) annual market. The main impediment to diffusing improved OPVs thus appears to be the lack of suitable mechanisms for producing and marketing seed on a continuing basis (Byerlee and López-Pereira 1994),[18] and the public sector appears to have a key role to play in helping to remove this impediment.

Sustained improved OPV seed production and distribution could possibly be fostered by strengthening local seed organizations. Seed cooperatives, NGOs, and individual farmer/seed producers are increasingly prevalent in many developing countries, where they often concentrate on producing and/or distributing improved OPVs to regions and farmers that may benefit most from this kind of germplasm. As discussed above, it would be important for public research organizations to support these seed producers as a way of achieving their own goal of reaching small-scale farmers.[19] Support may take many forms, including the continuous supply of improved germplasm adapted to local conditions; technical assistance with seed production and conditioning; the provision of credit for seed production; and the promotion of improved OPVs and hybrids to encourage adoption.

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[18] Some novel strategies are being developed for producing and distributing seed developed by the public sector, including OPVs. See Appendix H for an example from Brazil.

[19] CIMMYT (1984) and Córdova, Quemé, and Rosado (1992) describe the technical requirements and programs for small-scale production and distribution of maize seed — improved OPVs as well as hybrids.

Conclusion

Several conclusions may be drawn from this analysis of the global maize seed industry and the evolving relationship between the public and private seed sectors. First, the structure of maize seed industries has changed over the last 10 years, especially the nature of the interaction between the public and private seed sectors. Changes in seed laws and regulations in many countries have strengthened the participation by private seed organizations in seed production and distribution. After being the major (in some cases the only) presence in the seed industries of developing countries, public seed companies retain only a minor role. Private national seed companies, seed cooperatives, NGOs, and individual seed producers have gained in importance. The mostly public nature of the materials produced and distributed by these seed organizations is evidence that public breeding organizations have played a key role in the development of domestic private seed sectors. The share of multinational companies in seed production and distribution is less than anticipated (CIMMYT 1987); they control under 50% of the total commercial seed market in developing countries.

The renewed emphasis on hybrid breeding in many developing countries suggests that the private sector should continue to strengthen its participation in the industry, not only in seed production and distribution but also in R&D. However, public breeding programs are likely to continue playing an important role in stimulating the development of domestic private seed sectors.[20] A system of public sector R&D, combined with private sector R&D and seed production and marketing, seems to be the most likely institutional arrangement for increasing the efficiency of public breeding research.

The right mix of public-private sector participation and interaction is thus critical to the development of seed industries and to delivering improved seed to all kinds of maize farmers in an efficient manner. Obviously, the availability of public sector germplasm is crucial for developing private initiative in seed production and marketing. The added benefit of using public sector germplasm is that companies can make improved seed available to farmers at a lower cost. The public sector can also assist the development of private initiative in emerging markets by providing credit and technical assistance for investment in seed production and processing facilities. As the maize seed industry develops, the public sector will need to introduce realistic policies for seed certification. It will also be important to establish flexible regulations and incentives for foreign investment and seed trade. Once local private initiative starts to develop, these activities by the public sector become important factors in the further development of the industry, eventually leading to a more efficient and competitive seed industry.

When the private sector is well established and competitive, public research institutes must be ready to let the private sector take over other activities in the industry. The activities performed by each sector are thus complementary. Eventually, the public sector should

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[20] In many cases, public research organizations in developing countries have been instrumental in training maize breeders, some of whom eventually move into the private sector.

emphasize activities that do not attract the private sector because of limited profit opportunities, and continue to encourage private sector competition. Thus in mature and developed maize seed industries, the public sector should function so as to bring about a more balanced distribution of the social benefits generated by the use of improved seed.

In mature seed industries, the public sector has an additional role to play in ensuring fair treatment for all involved in the industry. This role includes the fair evaluation and approval of private sector hybrids in a timely fashion and the implementation of IPRs to encourage private investment in R&D and the transfer of technologies across countries. Local research programs are likely to become more effective at developing improved germplasm if they are exposed to a wider range of agricultural technologies, and this can be accomplished in part through the testing and release of improved technologies developed in other countries.

As interesting as the continuing transformation of the maize seed industry may be, it should not make us lose sight of the challenges ahead. Use of improved maize seed and crop management practices is still very low in many developing countries. The fact that only four out of every 10 ha of maize in the developing world (excluding Argentina, Brazil, and China) are sown to improved seed represents both a formidable challenge to the maize seed industry as well as an opportunity for growth. As we have seen, total maize area in industrialized countries is stable or even declining, and growth of the global maize seed industry will come from bringing as much of developing country area as possible under improved seed. Most of the area sown to local materials is in tropical growing environments where breeding challenges are more difficult, and both public and private sector initiative and ingenuity will be required to bring this area under improved seed. Public sector participation will be especially important, given that many of these areas are best suited for improved OPVs rather than hybrids. Outstanding OPVs with resistance or tolerance to biotic and abiotic stresses common in these areas are needed to increase the use of improved seed there. This in turn implies the need for mechanisms that ensure the sustained production and distribution of improved OPV seed. The public sector may have a crucial role to play in the development of these mechanisms, perhaps by supporting local seed production initiatives. The public sector should draw upon the experience of local/regional seed producers' cooperatives and NGOs and seek to develop the potential for establishing local farmers as seed producers. Regional alliances of public breeding programs in countries that share similar production environments will also be important in addressing these difficult challenges and making the most of scarce public research resources.

Over the next 15 to 20 years, the global maize seed industry will continue restructuring. To varying degrees, the public and private sectors are likely to interact even more closely than in the past. This study has indicated that alliances (rather than competition) between the public and private sectors, both locally and internationally, are important for increasing efficiency, reaching large numbers of maize farmers, and ensuring the greatest possible attention to the needs of the poorest of these farmers. It is hoped that the end result will be a more competitive seed industry and greater options for the developing world's maize farmers to obtain improved seed at lower prices.

Appendix A
Sources of Information for This Report

A substantial amount of data is presented in this report, and it is important to describe the data sources and their degree of reliability. Most of the data were obtained through a worldwide survey of maize seed industries conducted by CIMMYT during the second half of 1993 (Appendix B). The survey requested information on maize seed production, sales, and prices, classified by seed origin, type of seed, and type of seed company. Information was also requested on the number of public research stations, the number of full-time-equivalent maize breeders working there, estimates of area planted to different seed types, prices of maize grain and nitrogen fertilizer, and agricultural wages.

The survey was sent to leaders of public maize research organizations in the 54 developing countries and 17 industrialized countries that had planted at least 100,000 ha to maize in 1992. These countries accounted for 95% of the world maize area in 1992. Questionnaires were returned from 51 developing and 11 industrialized countries (an 85% return rate) (Appendix B). Total maize area in the countries responding to the survey accounted for 89% of the world maize area, 95% in developing countries and 79% in industrialized countries.[1] The averages reported for each region are the best estimates to date on maize seed industries in developing countries. These estimates are supported by data from other CIMMYT studies of the economics of improved maize seed production and use in developing countries. Readers are referred to Byerlee and López-Pereira (1994); Byerlee, Morris and López-Pereira (1994); López-Pereira and García (1994); López-Pereira and Morris (1994); López-Pereira and Espinosa (1993); and CIMMYT (1987). Other publications containing information on the economics of seed production, the organization of seed industries, and policies affecting seed industry performance include Jaffee and Srivastava (1994); Pray and Ramaswami (1991); Cromwell, Friis-Hansen, and Turner (1992); Sharanjit and Douglas (1992); and Douglas (1980).

[1] The response rate from Eastern Europe and the former Soviet Union was poor owing to recent political changes and economic restructuring. However, data on the most important maize-producing countries in Eastern Europe were available from previous CIMMYT surveys, although estimates based on these data should be interpreted with caution.

Appendix B

The CIMMYT Maize Seed Industry Survey and Participating Countries

CIMMYT 1993 Survey of Maize Seed Production, Sales, and Prices

Country: ______________________________

Name of respondent: ______________________________

Position of respondent: ______________________________

Organization: ______________________________

Address (please include fax if available): ______________________________

____

____

____

Date: ______________________________

Please return to:

Maize Seed Industry Survey
CIMMYT Economics Program
Apdo. Postal 6-641
Mexico, D.F. 06600, Mexico
Tel: 52 - 595 - 42100
Fax: 52 - 595 - 41069

CIMMYT Survey of Maize Seed Production, Sales, and Prices

1. **Please complete the following information for the most recent crop year. If official statistics are unavailable, please give your best estimates.**
Year for which estimates correspond: ____________________

Type of maize seed enterprise or producer	Total number of enterprises producing and selling maize seed	Total number of seed enterprises that have maize breeding programs[a]	Total number of maize breeders working in these breeding programs in the development or testing of varieties / hybrids[b]	Commercial maize seed sales[c] for the year (tons)		Percent of hybrid seed sales that is proprietary[d]
				Improved open pollinated varieties (OPVs)	Hybrids	
1. Public sector or parastatal company						
2. Private seed company, mostly national ownership						
3. Multinational seed company[e]						
4. Farmers' seed cooperative						
5. Individual farmer /seed producer[f]						
6. NGO,[g] development project, etc.						
7. Other (specify): ________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________
TOTALS						

[a] A breeding program is defined as having the objective of developing varieties or hybrids, rather than testing varieties/hybrids developed by others.
[b] Please *do not include* breeders employed only in seed production. Please include only breeders with at least a B.Sc. degree or equivalent. Give numbers in *full-time equivalents.* For public seed enterprises, please include *only* breeders working at these public seed enterprises, as opposed to breeders at research institutes (see question 2).
[c] Please provide *actual amounts of seed sales,* as opposed to seed production. If seed production figures provided (rather than sales), please indicate so and provide an estimate of the percent of this production which is actually sold in a normal year.
[d] A proprietary hybrid is one developed by a private company and whose parentage is usually not disclosed, although it may contain one or more inbred lines from the public sector. A private seed company may produce and sell public OPVs and hybrids (purchasing basic seed from the public sector), its own proprietary hybrids, or a combination of both.
[e] A multinational seed company is one with majority ownership by a company that operates in many countries (e.g., Pioneer, DeKalb, Cargill, Asgrow, ICI, etc.).
[f] Please *do not include* under this category those farmers who grow maize seed crops under contract for seed companies. Include only those farmers who grow their own maize seed crop and sell the seed themselves to other farmers.
[g] NGO = non-governmental organization.

2. **For public sector maize breeding programs, including Ministry of Agriculture (MOA), provincial / regional / state programs independent of the MOA, and university programs:**

   - How many publicly funded research stations conduct breeding research to develop improved maize varieties/hybrids (please include only stations where maize breeders are permanently located)? ________

   - About how many maize breeders (**B.Sc. degree and above**) are employed by these programs (please give number in full-time equivalents)? ________

     (Please *do not include* here the maize breeders working at public seed enterprises and reported in Question 1).

3. **Where applicable, please provide average prices of seed for the most recent crop year in a major maize producing region.**[a]

Type of seed producer	OPVs	Public hybrids		Proprietary hybrids[b]	
	Retail price of seed of open pollinated varieties (per kg)	Most *common* type of public hybrid seed sold[c]	Retail price of this hybrid (per kg)	Most *common* type of proprietary hybrid seed sold[c]	Retail price of this hybrid (per kg)
1. Public sector or parastatal company					
2. Private seed company, mostly national ownership					
3. Multinational seed company					
4. Farmers' seed cooperative					
5. Individual farmer / seed producer					
6. NGO, development project, etc.					
7. Other (specify): ________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________	________ ________ ________

[a] Please provide seed prices for a "normal" year, which can be defined as a year when there were no acute shortages or surpluses of seed that may temporarily increase or decrease prices.

[b] A proprietary hybrid is one developed by a private company and whose parentage (pedigree) is usually not disclosed. A proprietary hybrid may or may not contain one or more inbred lines from the public sector.

[c] Please use the following codes for hybrid types: TC=top-cross hybrid; ONC=other non-conventional hybrid; SC=single-cross or modified single-cross hybrid; TW=three-way cross or modified three-way cross; DC=double-cross hybrid.

Question 3 (continued)

Year to which estimates of seed prices correspond: ______________

In order to compare seed prices across countries, it is convenient to convert them to a (unitless) common measure such as the seed-to-grain price ratio. Please provide an adequate average price of commercial maize grain (not seed) in the same year to obtain seed:price ratios (price per kg of maize): ______________

Please provide an exchange rate to convert these prices to U.S. dollars (units of national currency per US$ 1): ______________

4. Please provide, for the most recent crop year, an estimate of the percent of total national maize area in the country planted to:

a. Percent area with hybrid seed (please include only commercial hybrid seed purchased the same year that it was planted). ______________ %

b. Percent area with commercial OPV seed, and with seed derived from such commercial seed (recycled OPV seed) *if it was originally purchased within the last five years.* ______________ %

c. Percent area with seed of local varieties, advanced generation hybrid seed, and seed derived from commercial OPVs (recycled OPV seed) *if it was originally purchased more than five years ago.* ______________ %

National total ____100____ %

Please provide an estimate of total national maize area (in 1,000 ha): ______________

Year to which total maize area and percentage estimates correspond: ______________

5. Please provide information on the following variables for this country for as many years as possible. A useful time period would be 1970-92, but any time-series data would be appreciated, especially most recent years. If possible, please provide prices in US$/kg. If price data provided in local currency, please provide an equivalent average exchange rate per year.

Year	Maize seed production		Maize seed sales		Retail price of maize seed		Maize grain price
	OPVs	Hybrids	OPVs	Hybrids	OPVs	Hybrids	
	(tons)	(tons)	(tons)	(tons)	(US$/kg)	(US$/kg)	(US$/kg)

Please make copies of this page if necessary. OPVs = open pollinated varieties.

6. **Producer prices for last maize season, and exchange rate.**

a) **Maize.** Average farm price, in national currency per kg, at which farmers in an important producing region sold maize grain (not seed) during the month following the last harvest.

- Region for this price: ______________________
- Farm price received by producers: __________/ kg
- Month and year for this price: __________ __________

b) **Nitrogenous fertilizer.** Average field price (price plus transport costs), paid by farmers for a common nitrogenous fertilizer during the last maize season. If possible, please provide the price for a single-nutrient fertilizer product such as urea.

- Commercial name of fertilizer: ______________________
- Nitrogen content (%): % N: __________
- P and K content, if applicable (%): % P: __________ % K: __________
- Price paid for this product: ________ / kg of commercial product
- Month and year for this price: __________ __________

c) **Farm labor:** Average daily wage, in national currency, paid for unskilled farm labor during the last maize season:

- Daily wage (local currency per day): ________________ (include payments in kind, e.g., meals)

d) **Exchange rate**. Please provide an appropriate exchange rate to convert the prices given in this section to US dollars.

- Name of national currency: ______________________
- Official exchange rate: ________________ / US$ 1
- Month and year for this exchange rate: __________ __________

7. Register of maize seed producers.

Please provide, for each company/organization/individual producing maize seed in the country, the following information using the variable definitions and codes below and the attached form.

Country: ____________________

Date (day/month/year): ______ ______ ______

Name of respondent: ____________________

Organization and position: ____________________

Address (include fax if available): ____________________

Variable definitions and codes

1. **Full name of company, organization, or individual seed producer, including name of contact person if available.**

2. **Complete address of the seed producer, to which information can be sent.**

3. **Fax number, if available. Please include country and city codes.**

4. **Please indicate the type of maize seed producer using the following codes:**
   1 = Public or parastatal seed company, including state/regional seed companies, and universities (PUB).
   2 = Private seed company with majority capital ownership of national origin (PRN).
   3 = Private seed company with majority ownership by a multi-national seed company (MNC).
   4 = Farmers' cooperative producing seed for sale to members or to others (COO).
   5 = Individual farmer who produces maize seed for sale, or family-owned seed enterprise (IND).
   6 = Non-governmental organization which produces and/or distributes maize seed (NGO).
   7 = Other type of seed producer (please specify) (OTH).

5. **Please indicate if the company / organization /producer has a breeding program for the development of maize varieties / hybrids. Use the following codes.**
   1 = Full-fledged, modern breeding program with equipment, facilities, germplasm bank, and technical staff.
   2 = Foundation seed company breeding program. Develops inbreds and sells them to other seed companies.
   3 = Modest but complete breeding program, capable of producing its own commercial hybrids.
   4 = Simple breeding program, tests and uses advanced public materials for development of own hybrids.
   5 = No breeding program or testing capability. Only produces and sells commercial seed of public or proprietary maize materials developed by others.

6. **Please provide a category for total annual maize seed sales using the following codes (please add in parentheses the year for which seed sales category corresponds).**
   1 = < 50 tons/year
   2 = 50 - 100 tons/year
   3 = 100 - 500 tons/year
   4 = 500 - 1,000 tons/year
   5 = 1,000 - 5,000 tons/year
   6 = 5,000 - 10,000 tons/year
   7 = 10,000 - 20,000 tons/year
   8 = > 20,000 tons/year (for this category, please indicate an approximate range of seed sales)

CIMMYT register of maize seed producers (refer to previous page for definition of variables and codes)

Country: ______________________ Date: ______________________

Page No. ____ of ____ (number of pages)

(1) Name of seed producer	(2) Complete address of seed producer	(3) Fax and/or telephone number if available	(4) Type of seed producer (codes)	(5) Type of breeding program (codes)	(6) Annual maize seed sales category and year (codes)

Please make copies of this page if necessary.

Countries Participating in the CIMMYT Maize Seed Industry Survey, 1993

Developing countries, by region and sub-region				Industrialized countries
Sub-Saharan Africa	**West Asia, North Africa**	**Asia**	**Latin America**	
East and Southern Africa	**West Asia**	**South Asia**	**Mexico, Central America, and the Caribbean**	Bulgaria
Burundi	Syria	India	Costa Rica	Canada
Ethiopia	Turkey	Nepal	Cuba	France
Kenya		Pakistan	El Salvador	Germany
Lesotho	**North Africa**		Guatemala	Greece
Malawi	Egypt	**Southeast Asia and the Pacific**	Honduras	Italy
Mozambique	Morocco	Indonesia	Mexico	Netherlands
Rwanda		Philippines	Nicaragua	Slovak Republic
Tanzania		Thailand	Panama	South Africa
Uganda		Vietnam		Spain
Zambia			**Andean Region, South America**	USA
Zimbabwe		**East Asia**	Bolivia	
		China	Colombia	
West and Central Africa		Taiwan	Ecuador	
Benin			Peru	
Burkina Faso			Venezuela	
Cameroon				
Côte d'Ivoire			**Southern Cone,**	
Ghana			Argentina	
Mali			Brazil	
Nigeria			Chile	
Senegal			Paraguay	
Togo			Uruguay	

Appendix C
CIMMYT and the World Maize Seed Industry

CIMMYT Maize Program Mission and Organization

The mission statement of CIMMYT's Maize Program is to "help the poor in developing countries by increasing the productivity of resources committed to maize, while protecting natural resources. This will be accomplished through the preservation, improvement, and dissemination of genetic resources; the development of environmentally compatible crop management practices; the provision of research methodologies and information; and through training and consulting" (CIMMYT Maize Program 1994). CIMMYT concentrates its maize breeding activities on tropical and subtropical environments, where the vast majority of the world's poor farmers are located. The Maize Program is composed of three sub-programs: 1) Lowland Tropical Maize; 2) Sub-tropical and Mid-altitude Maize; 3) and Physiology, Agronomy, and Stress Resistant Maize. Several support units operate across sub-programs, including the Maize Germplasm Bank, International Testing,[2] Training, Pathology, and Entomology (CIMMYT Maize Program 1994). In addition to its headquarters operations in Mexico, CIMMYT has regional maize research programs based in seven countries in Asia, Africa, and Latin America.

CIMMYT neither produces nor markets commercial seed. However, to facilitate access to improved germplasm by the world's poor maize farmers, CIMMYT has established collaborative links with participants in the world maize seed industry — primarily the public national agricultural research systems in developing countries. Thus the main activity of the Maize Program is to develop a complete range of improved germplasm with high yield potential, good agronomic characteristics, and resistance/tolerance to important diseases and pests, for use mainly by public maize breeding programs. Private seed organizations also make use of CIMMYT's germplasm products in their breeding programs, and may in some instances produce seed directly from this germplasm. Once in the hands of the recipients, CIMMYT germplasm can be improved further, incorporated into breeding programs for the development of improved materials, or released directly as official varieties.

CIMMYT may therefore be seen as a catalyst for the development of all phases of the maize seed industry in developing countries, mainly through its collaboration with national agricultural research systems and, more indirectly, as a source of germplasm for all other seed organizations. CIMMYT also operates and maintains a maize germplasm bank, which contains more than 10,000 accessions of maize varieties and land races. The center does not restrict the availability of its maize germplasm; rather, CIMMYT strives to attain the widest possible use of this germplasm by all interested parties, especially maize breeders in developing countries and, through them, farmers.

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[2] Breeding for the tropical highlands is done by the breeder in charge of International Testing.

Impacts of CIMMYT's Maize Breeding Research with NARSs

In 1990-91, CIMMYT conducted a study of the impacts of maize breeding research in developing countries (López-Pereira and Morris 1994).[3] Between 1966 and 1990, 842 maize varieties and hybrids were released by public national programs in the 45 countries participating in the study (Figure C1).[4] Of this total, 445 or over 50% contained germplasm that could be traced to CIMMYT. Most (75%) of the CIMMYT-related materials released by public NARSs had been improved further, using germplasm from other sources, before they were released (Figure C2).

In 1990, 13.5 million hectares in developing countries were planted to maize varieties and hybrids that contained CIMMYT germplasm, representing over 50% of the total maize area under improved seed (Table C1). Most of the these materials are improved OPVs. Publicly released varieties containing CIMMYT germplasm have made the greatest impact in Asia and in Latin America, which account for 80% of the total maize area under these materials. This substantial area under public materials reflects the close collaboration between national programs and CIMMYT in maize breeding. The impact of this collaboration should be greater in years to come as newer, higher yielding varieties and hybrids find their way to farmers' fields.

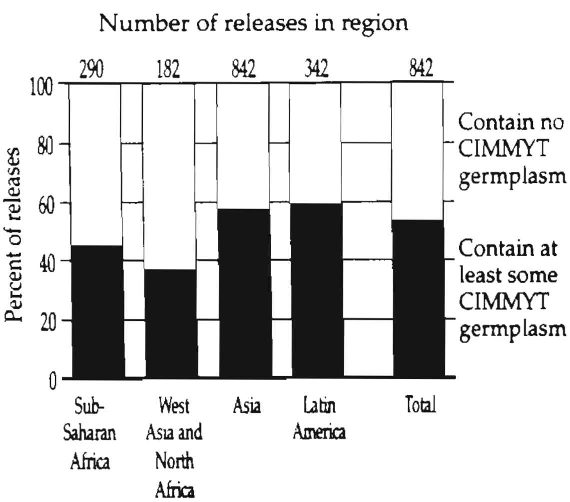

Figure C1. Maize OPVs and hybrids released by public national programs in developing countries by origin of the germplasm, 1966-90.

Source: López-Pereira and Morris (1994).

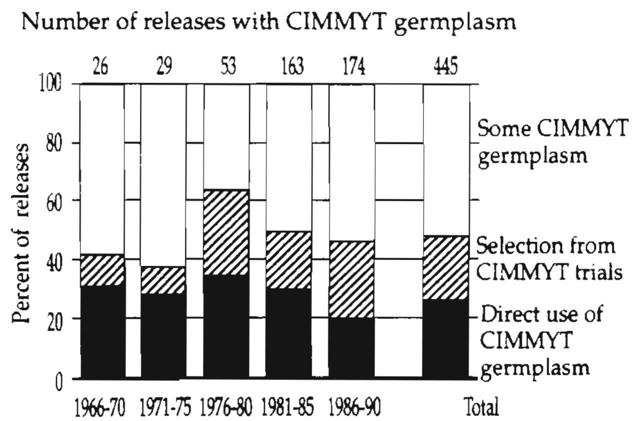

Figure C2. Use of CIMMYT germplasm in maize OPVs and hybrids released by public breeding programs in developing countries, 1966-90.

Source: López-Pereira and Morris (1994).

[3] Results of a similar study on the impacts of wheat breeding research by CIMMYT and NARSs are available in Byerlee and Moya (1993).

[4] The list of countries surveyed for the Maize Research Impacts study of 1991 is similar to the list of countries participating in the Maize Seed Industry study of 1993. Both groups of countries account for about 90% of the maize area in developing countries.

The emphasis on hybrid products by many national programs gained momentum only recently, in the late 1980s, and hence by 1990 was not clearly reflected in the composition of maize releases (Table C2). Nevertheless, the number of OPVs released began to decline in the late 1980s as numbers of hybrid releases increased. CIMMYT has also increased the strength of its hybrid program since the late 1980s. Official release of inbred lines by CIMMYT started in 1991, and by early 1994, 310 lines had been released (CIMMYT Maize Program 1994). The impact of hybrid products containing CIMMYT germplasm is expected to increase substantially in the near future as these lines are incorporated into the breeding programs of both public and private seed organizations.

Table C1. Maize area under improved materials containing CIMMYT germplasm, developing countries, 1990

Region	Maize area under improved materials containing CIMMYT germplasm (million ha)	Percent maize area planted to improved materials
Sub-Saharan Africa	2.0	33
West Asia and North Africa	0.5	96
Asia	5.3	66
Latin America	5.6	58
Total	**13.5**	**56**

Source: López-Pereira and Morris (1994).

Table C2. Trends in the types of maize materials released bv public research programs, 1966-90

Period	Total number of maize varieties and hybrids released by the public sector	Hybrids as percent of total
1966-70	100	42
1971-75	146	42
1976-80	134	28
1981-85	233	31
1986-90	229	37
Total	**842**	**35**

Source: López-Pereira and Morris (1994).

Appendix D
The US Maize Seed Industry, Past and Present

Modern hybridization techniques, developed in the USA in the early part of this century, revolutionized maize production and the seed industry, first in the USA and then in other parts of the world, especially in Europe, Brazil, Argentina, and China. Although the private sector dominates both R&D (breeding) and seed production and marketing in the USA, in the early stages of development the US seed industry depended heavily on public sector research by the state agricultural research stations. Many of the first commercially produced materials were developed by the public sector. Private sector R&D began some time after the first private firms appeared. Eventually private R&D came to dominate the industry.

Today the US maize seed industry is the most sophisticated in the world. More than 500,000 t of seed were sold in 1992, valued at more than US$ 2 billion. The industry presents all the characteristics of a mature industry, exhibiting no growth (rather, a slight declining trend, owing to reductions in maize area, is evident) and strong competition among seed companies. Seven large seed companies hold about a 68% share of the hybrid maize seed market, and one of these companies has a 45% market share (Pioneer 1994). The rest of the market is divided among numerous (estimated at over 300) medium- and small-scale seed enterprises. In many cases these small enterprises are family businesses, producing and selling a few hundred tons of seed. The two main players in the seed market, have been able to make substantial gains in market share in the last two years (Table D1). As total seed sales decrease with planted maize area (from 591,000 t of hybrid seed in 1981 to about 525,000 t in 1992), these gains in market share have been obtained at the expense of smaller seed organizations. Nevertheless, this market concentration is still low compared to that in other countries such as Brazil and Mexico (López-Pereira and García 1994).

Investment in maize R&D by the private sector is substantial in the USA, representing about 10% of the total value of seed sales (Figure D1). Although the hybrid maize seed:grain price ratio is high by world standards, the cost of seed in the USA is still a relatively small percentage of total maize production costs, making it an attractive investment for US maize farmers. Seed prices have increased because of the increased cost of producing seed,

Table D1. Maize seed industry concentration in the USA, 1973-93

Year	Market share of four largest seed companies (%)	Market share of eight largest seed companies (%)
1973	60	73
1978	57	69
1983	55	64
1991	51	62
1993	59	69

Source: McMullen (1987), Pioneer (1994), and authors' estimates.

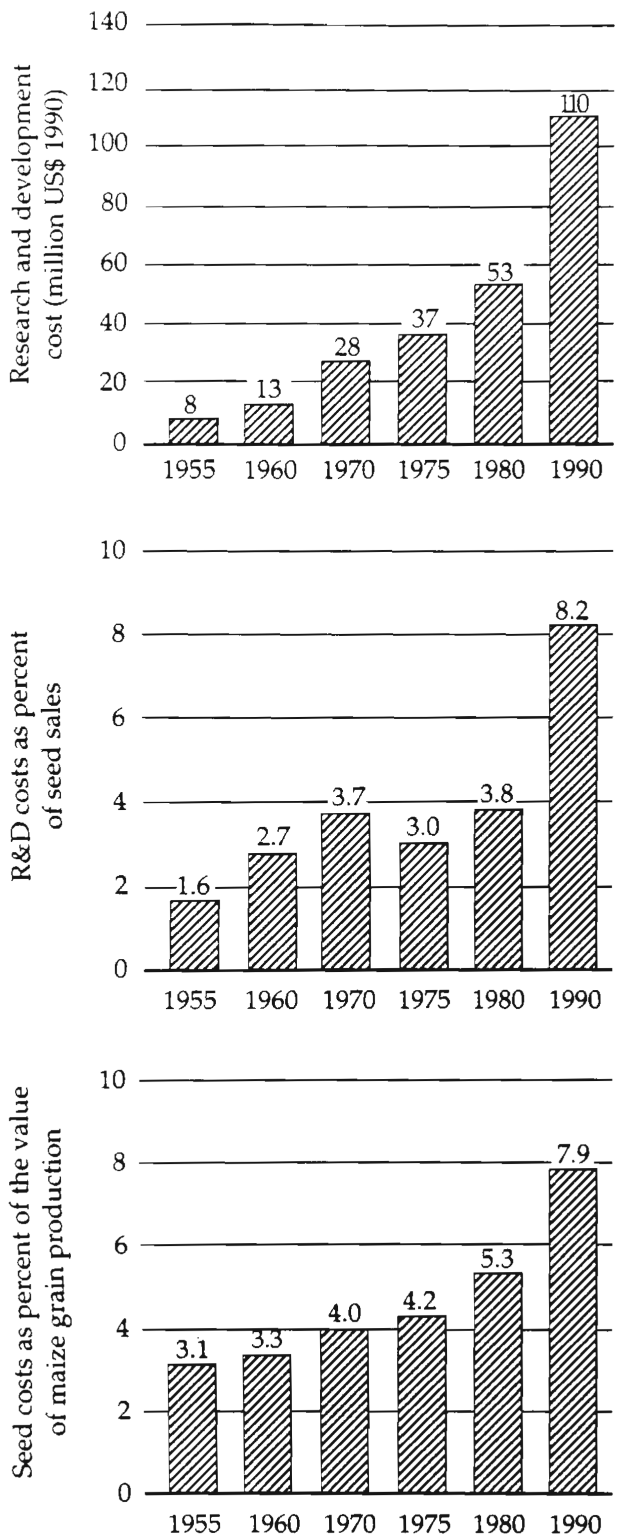

Figure D1. Private sector investment in maize breeding research and the cost of hybrid maize seed, USA, 1955-90.
Source: Seed cost from USDA (various years). Costs of R&D constructed from Perrin, Kunnings and Ihnen (1983); Kalton, Richardson, and Frey (1989); and authors' estimates.

especially substantial increases in R&D and promotion and marketing costs. Nevertheless, the constant flow of new, ever higher yielding hybrids to replace old hybrids ensures that US maize farmers are adequately provided with good seed.

The public maize seed sector, composed of university research programs and federal and state breeding research stations (both United States Department of Agriculture and state agricultural experiment stations), conducts basic research related to germplasm improvement and provides training for maize breeders. These public sector seed organizations specialize in R&D and do not participate in seed production and marketing. Public inbred lines resulting from these R&D programs are usually made available at no change to all seed organizations. Although not highly visible as in developing countries, the public research system in the USA has traditionally been, and still is, a key contributor to the maize seed industry (Huffman and Evenson 1993). As recently as the late 1980s, inbred lines developed by public breeders accounted for over half of the hybrid maize seed production in the country (McMullen 1987). However, some public organizations, especially universities, have attempted to charge royalties to private companies for the sale of hybrids based on the inbred lines they release. As in developing countries, this is a response to the increasingly difficult financial situation of public sector organizations.

Foundation seed companies are a common form of private seed organization in the USA, usually concentrating on R&D and releasing elite inbred lines which are sold under special agreements to other, usually medium- and small-scale, seed companies. These companies can avoid most of the large investment necessary to have an efficient breeding program and can concentrate on testing advanced lines to identify and release good hybrids. Foundation seed companies thus function as breeding programs for many seed companies, increasing the efficiency with which any one company can develop its own materials. Foundation seed companies are not common in developing countries, partly because their maize seed industries are small and partly because the public sector makes many materials available to private enterprises, and partly because of the absence of legislation to enforce contracts involving the use of improved germplasm across companies.

The structure of the seed industry in industrialized countries has changed dramatically in the wake of mergers and acquisitions that began in the early 1970s. Traditional seed companies were acquired by larger companies, some not previously in the seed business, including chemical, pharmaceutical, food processing, and petroleum companies. The conglomerates' interest in seed companies resulted from several events in the late 1960s and early 1970s that made seed companies good alternatives for diversification (McMullen 1987, Kent 1989). As a result of these mergers and acquisitions, names such as ICI, Sandoz, Upjohn, Limagrain, and Rhône-Poulenc are now common in the seed business. In 1970 virtually all the large seed companies in the USA were independent or owned by another seed company, but by the early 1990s, with a few notable exceptions, most seed companies were owned by non-seed enterprises. Of the 14 companies holding at least a 1% share of the US hybrid maize seed market in 1991, only six were dedicated exclusively to the seed business. The rest were owned by chemical, pharmaceutical, and commodity trading companies. It is not clear if the period of acquisitions is complete, but the seed industry has been characterized by a strong dynamism, and mergers and alliances in the business are likely to continue, especially with the likely advent of biotechnology products into the market in the next 10-20 years.

Appendix E
Small-Scale Farmers' Use of Hybrid Maize Seed

There is increasing evidence in many developing countries that small-scale farmers are willing to adopt hybrid maize seed and that hybrids have performed surprisingly well under low-input, small-farm conditions. Some specific examples follow.[5]

Zimbabwe

One of the most widely reported examples of extensive adoption of hybrid maize seed by small-scale farmers is Zimbabwe. Established in the 1930s, the maize research system was oriented towards the commercial sector, and after obtaining evidence in the 1940s that hybrids outperformed OPVs even under low-input conditions and limited rainfall (Mashingaidze 1991), breeders focused exclusively on hybrid development. Large-scale commercial maize farmers were the first to adopt hybrid seed after the single-cross hybrid SR-52 was released in 1960; SR-52 is thought to be the first commercial single-cross hybrid released in the world. Adoption of hybrid seed by commercial farmers in Zimbabwe grew from virtually zero in 1950 to 55% in 1975. During the 1980s, hybrid seed spread to small-scale farmers, so that by 1990 nearly all of the maize produced in the country was reported to have come from hybrid seed.

As maize area continues expanding into semi-arid regions in Zimbabwe, the appropriateness of using hybrids in these regions is being examined by national researchers. Trials have been done to determine the yield performance of hybrids under low-input conditions relative to improved OPVs. In one such study by Shumba (1990), two popular hybrids and a variety, and their second generations, were tested on the experiment station for yields under zero and low levels of N-P-K fertilizer. The hybrids yielded better than the variety under both treatments by an average of 30%. The study did not find a significant genotype X generation interaction. Second-generation hybrid seed yielded better than the second-generation OPV seed by about the same proportion as first-generation seed (20-35%).

In another study, Chiduza et al. (1994) conducted on-farm experiments for two years to test the yields of 10 experimental varieties and five commercial hybrids in a semi-arid region of Zimbabwe. The hybrids yielded consistently better than the OPVs, both at zero levels of fertilizer (20% yield advantage for hybrids) and at high fertilizer levels (18% yield advantage for hybrids). The authors argue, however, that despite the yield advantage of hybrids, OPVs may be more practical for cash-constrained farmers and should be made available.

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[5] See Byerlee and Heisey (1993) for a discussion of the relative advantages of maize hybrids versus OPVs under low-input conditions.

Malawi

Recent data from Malawi present probably the most convincing evidence that hybrids perform well under low input levels and drought stress. Most of Malawi's 1.3 million hectares of maize is cultivated by small-scale farmers. Until recently, adoption of improved maize seed in the country was very low, partly because Malawi's small-scale farmers, who produce maize primarily for home consumption, prefer the on-farm processing and storage characteristics of flint maize types. All of the hybrids previously released by the national research system (and by other research systems in the region, including Zimbabwe, South Africa, and Zambia) were dent types. In 1990, Malawi's national research system released two new hybrids (MH17 and MH18), with on-farm processing and storage characteristics similar to the local flint varieties, but with yields as high as those of dent hybrids.

Evidence from farmer surveys (Smale et al. 1993) suggests that MH17 and MH18 will be acceptable to small-scale farmers, and adoption is accelerating rapidly. The relative performance of these two hybrids was better than that of the local varieties even in the drought year of 1991-92 (Figure E1). The widespread popularity of these hybrids has revolutionized the maize sector in Malawi. Hybrid seed sales jumped from about 2,000 t in 1988 to about 8,000 t in 1992 (enough seed for approximately 320,000 ha or 25% of the maize area in Malawi).

The success of the Malawi program in developing and delivering improved maize hybrids suitable for small-scale farmers is the result of two circumstances: 1) close collaboration between CIMMYT and national maize scientists and 2) the recent strengthening of the national private seed company's capacity to produce and distribute improved seed.

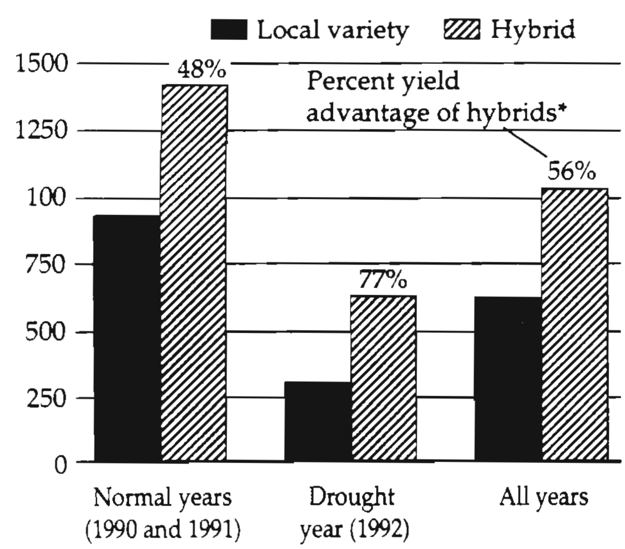

Figure E1. Yields of hybrid and local maize under low-input conditions (zero fertilizer) in on-farm demonstration trials, Malawi, 1990-92.

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

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

Kenya

The Kenyan national maize research program has had a dual strategy of developing hybrids for medium- and high-potential areas and improved OPVs for low-potential areas. By the early 1970s, the maize breeding program was well established and most of the maize area in the western region was planted to hybrid seed (Gerhart 1975). More recently, adoption of hybrid maize appears to be expanding into areas targeted for improved OPVs. Even in the dry Machakos District of eastern Kenya, where the maize program has emphasized OPVs, some farmers are now planting hybrids developed for the higher potential areas (Byerlee and Heisey 1993), and consequently the Kenyan maize program has started a hybrid program for this area. As in other countries, however, adoption of hybrid seed by small-scale farmers is not always accompanied with the use of other inputs, especially fertilizer (Byerlee and López-Pereira 1994). In Kenya in the early 1980s, 65% of all the maize area was estimated to be planted to hybrid seed, but only about 24% of the area received fertilizer (Ruigu and Schulter 1986), suggesting that hybrid seed is economically feasible at low input levels. The estimated area under hybrid seed in Kenya today is about 75% of the approximately one million hectares of national maize area. The seed industry produces more than 20,000 t of seed, mostly of hybrids developed by the public research system, produced by one national private seed company.

The Northern Guinea Savanna, West Africa

Smith (1993) has studied the agronomic, genetic, and socioeconomic potential of using hybrid seed in the Northern Guinea Savanna of West Africa, where farmers traditionally have not used improved seed. Acknowledging the need for further research, the author concludes that hybrids perform better than improved OPVs even at low fertilizer levels and that the yield advantage of hybrids may well be maintained at moderate fertilizer levels. The author also concludes that a yield advantage of around 50% may be necessary to make hybrids economically attractive to farmers. However, because seed systems in the region are still underdeveloped, OPVs have an important role to play in both commercial and marginal maize production areas.

El Salvador

El Salvador has been viewed as an important example of the successful collaboration between public and private sector organizations for the development and delivery of improved maize seed in developing countries (Morris, Clancy, and López-Pereira 1992). Most maize farmers in El Salvador are small-scale producers, who grow their maize with sorghum and/or dry beans on steeply sloping hillsides. Maize hybrids occupied about 70% of the maize area in El Salvador until recently (Walker 1981, CIMMYT 1990). Logistical and organizational problems, combined with the reassessment of priorities within the national research system, have substantially reduced the use of hybrid seed to below 50% of total maize area (H. Córdova, pers. comm.). Nevertheless, the national research program has released two new hybrids (H-53 and H-57), which are resistant to corn stunt virus, a potentially devastating disease of maize in Central America and the Caribbean. These new hybrids yield better than the very popular but susceptible hybrids H-3 and H-5 by a margin of 25-30%, and they are expected to replace them in the coming years (Aguilúz et al. 1991, Córdova 1991). Also, the national agricultural research system (Centro de Tecnología Agropecuaria, CENTA) has fully resumed its activities, including the production and supply of basic seed of public hybrids, and it is expected that the use of hybrid maize seed will soon return to the levels of the early 1980s.[6]

Venezuela

The maize seed industry of Venezuela is also an example of the successful collaboration between public and private sector organizations, resulting in the widespread adoption of improved maize seed by farmers. The public research system has traditionally emphasized

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[6] Most of the hybrid maize seed used in El Salvador is developed by CENTA and thus of public origin; CENTA provides the basic seed to private seed organizations, which produce and distribute commercial seed.

the development of maize hybrids, and has been able to pass the responsibility for commercial seed production and distribution to the private sector. About 90% of the maize area in the country is planted to hybrid seed today, most of it of public origin. This division of responsibilities results in the availability of hybrid seed at low prices; the ratio of the price of hybrid seed to the price of commercial grain was 6:1 in 1992. The public research system has been instrumental in the development of the private seed sector by assuming responsibility for R&D during the early years of the seed industry's development. About 10 private national seed companies produce and distribute the public hybrids, and some of them now have their own breeding programs. Multinational companies still have a relatively modest presence in the market.

Thailand

The case of hybrid seed adoption in Thailand, a country where improved OPVs are used extensively, is an interesting variation on the cases presented above. After the phenomenal success of the Suwan varieties (see Sriwatanapongse, Jinahyon, and Vasal, 1993, for details on the development of Suwan 1), the seed industry developed very quickly, especially the private seed sector, including multinational companies. At the beginning, private companies produced and marketed only public varieties. They started their own breeding programs in the early 1980s, oriented towards hybrids. Today an estimated 25% of all the maize produced in the country comes from hybrid seed and 75% from improved OPVs, especially the Suwan varieties. In comparison, 8% of the area was sown to hybrids in 1985 and 15% in 1989 (CIMMYT 1987, CIMMYT 1990).

Even though hybrid seed has been available for many years in Thailand, adoption has been slow owing to competition from improved OPVs. In the early 1980s, when private sector activity started to increase, private seed enterprises concentrated on non-conventional hybrids, which had a very small yield advantage (less than 10%) over Suwan-1, reducing the hybrids' competitiveness in a market dominated by OPVs (C. de León, pers. comm.). Even in the late 1980s, a study concluded that hybrids yielded only about 19% more than the OPV Suwan-1; this small yield difference, combined with substantial differences in seed prices, made hybrid seed only marginally more profitable than OPV seed (Wattanutchariya, Kao-ian, and Vonyordpun 1987). Since then, increased competition within the private sector and the development of higher yielding hybrids may have made hybrid seed more attractive to Thai farmers. Today's commercial hybrids outperform the popular Suwan variety both under drought stress and under normal conditions (see e.g., Prasatsrisupab et al. 1990). Nevertheless, current ratios of seed to grain prices in 1994 are 6:1 for Suwan-1, 15:1 for three-way hybrids, and 23:1 for single-cross hybrids, similar to those prevailing in the mid-1980s (CIMMYT 1987), so hybrid seed remains much more expensive than improved OPV seed.[7]

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[7] For a detailed discussion of prospects for improving the productivity of important cereal crops, including maize, through the use of hybrid seed and the support of hybrid breeding programs, and the coordination of research among the IARCs, national public breeding programs, and the private seed sector in Asia, see De León and Paroda (1993) and FAO (1993b).

Conclusion

All of these examples run contrary to the notion that hybrids are for commercial farmers only.[8] The fact that hybrids perform well under *some* low-input conditions does not indicate that they are the best strategy for *all* small-scale farmers; but the evidence provided by these examples suggests that hybrids should be considered as an option in all types of environments. In addition, the economics of adopting hybrid seed compared to local varieties or improved OPVs, as well as the institutional and policy environments, should be taken into account when setting priorities for maize breeding, especially with regard to the development of hybrids versus OPVs. However, more convincing evidence is required on the advantages of hybrids over improved OPVs (as opposed to local varieties) and the practicality of providing hybrid seed for low-input conditions and small-scale farmers. In many of the examples above, hybrid seed is priced very low compared to seed of improved OPVs, and it remains unclear whether hybrids would be economically advantageous in the absence of subsidies for seed and for other inputs, especially fertilizers (see Smith 1993). Other factors that should be considered include the mixed cropping systems under which much maize is produced in developing countries and the rigidity of technological packages, especially for hybrid seed.

[8] See Byerlee and Heisey, 1993, for a recent discussion and Friis-Hansen, 1988, for a strong position against using hybrid seed under low-input conditions.

Appendix F
The Continuum of Maize Seed Types[9]

The variation in the type of maize seed a farmer can plant is large, and the different seed types can be seen as parts of a continuum of increasing breeding sophistication. At one end of the continuum are local varieties or land races, which are selected, improved, and maintained by farmers. The evidence indicates that, when selecting maize ears for seed, farmers rarely select ears of the plants that performed best (i.e., selection *at* harvest). Instead, they choose the largest and healthiest looking ears *after* harvest or even at planting. Criteria for seed selection usually include large ears, absence of disease, and preferred grain texture. Thus farmers are usually good at selecting seed based on *grain type* but not *plant type*. Once the ears are selected, they are dried and saved until the next planting. Most farmers do not attempt to control pollination, permitting maize plants from neighboring fields to pollinate their own. If different varieties are present in the same area, intermixing and diversity may result.

Modern breeding methods have allowed scientists to increase the yields and prevalence of desirable traits in OPVs. When seed of improved OPVs is produced, pollination is controlled, and care is taken to minimize contamination. Precautions include growing the seed in isolation from fields of other maize varieties, eliminating non-variety and off-type plants (a process known as *roguing*), and taking care not to mix seed from different varieties after harvest. Farmers can recycle their improved OPV seed, provided pollination is controlled. If it is not, contamination may occur and the varietal characteristics are lost. Improved OPVs are considered sufficiently intermixed after five years of recycling to justify their classification as non-improved OPVs or local varieties. (However, this is by no means a hard and fast rule and can be altered in either direction, given local growing conditions).

Hybrid varieties are the next step on the continuum. Their production involves the most extensive use of modern breeding procedures and scientific techniques. Maize hybrids are produced by selectively crossing genetically diverse varieties or inbred lines; heterosis, or hybrid vigor, results. The first step in the process is securing desired traits within a variety by creating inbred lines. Lines may be inbred many times through self-pollination to insure that the trait eventually is expressed uniformly. The result of inbreeding (selfing) is usually a weak, short plant with low seed yields and possessing certain desired characteristics. Once lines have been sufficiently inbred, they are crossed to other inbred lines to develop experimental hybrids. Breeders ordinarily cross inbred lines or varieties that possess a combination of desirable traits. To insure the traits are expressed, pollination is strictly controlled. Usually the higher yielding parent is selected as the female and detasseled. Lines used as pollinators, or male parents, are left to tassel. They are planted in adjacent rows and in specific ratios to the female rows to guarantee complete pollination. The seed, produced and harvested from the female, is the F1 (first filial generation) hybrid and displays more hybrid vigor than the succeeding generations (F2, F3, F4, etc.). Since hybrid vigor decreases with each succeeding generation, recycled hybrid seed usually yields less. Annual purchases of new seed are thus important for obtaining the greatest benefit from a hybrid variety.

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[9] Some of this material was originally presented in CIMMYT (1987).

Among hybrids, the number of crosses and inbred lines used in producing the seed determines the hybrid type, the degree of homogeneity, and the complexity of seed production. Parents of conventional hybrids are derived from inbred lines. In non-conventional hybrids, at least one of the parents is a non-inbred, and the other parent (or parents) may or many not be an inbred. In general, non-conventional hybrids are lower yielding and less homogeneous than conventional hybrids.

When two inbred lines are crossed for the first time, the result is a single-cross hybrid, the most homogeneous of the hybrid group. Crossing two *single-cross hybrids* results in a *double-cross hybrid* (Figure F1), a type of hybrid common in many developing countries. *Three-way hybrids* are usually produced by selecting a single-cross hybrid as the female and a pure inbred line as the male. Because of their wider genetic bases, double- and three-way crosses are less homogeneous than single-cross hybrids. All of these crosses, however, use inbred lines as parental material and are thus considered "conventional" hybrids.

As noted earlier, "non-conventional" hybrids have at least one parent that is not an inbred. When one parent, usually the male, is an inbred line and the other is a variety, a *top-cross hybrid* is produced. When both parents are varieties and are genetically different enough to

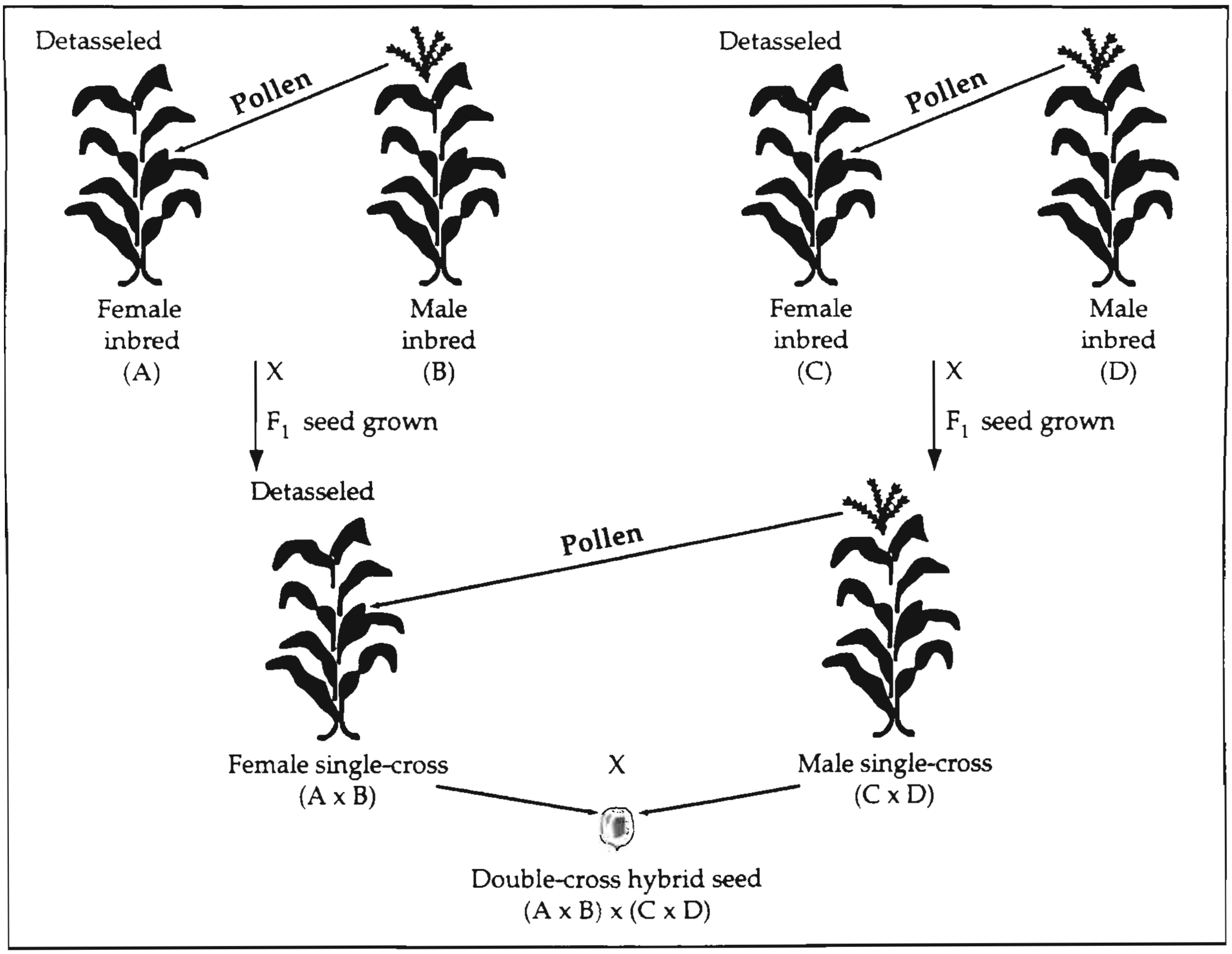

Figure F1. Production of seed of a double-cross hybrid.

express hybrid vigor, the result is a *varietal hybrid*. Since less time and money is spent on the inbreeding of lines, non-conventional hybrids can be developed more quickly and at a lower cost than conventional hybrids. In addition, non-conventional hybrids do not show as much of a loss in vigor from one generation to the next as conventional hybrids.

While growing conditions and stresses will affect the yield of the different seed types, some cautious generalizations can be made across types. The range of performance of different seed types seems to follow the seed continuum described above. How well a type will perform is roughly inversely related to the number of inbred lines used in its formation. In good growing environments, single-cross hybrids tend to perform better than three-way hybrids, which in turn perform better than double-cross hybrids, which yield better than non-conventional hybrids; yields of non-conventional hybrids are superior to those of improved OPVs, which tend to yield better than local varieties. Depending on the growing environment, level of management, and the situation for which particular hybrids were bred, yield differences among the groups may be substantial or trivial.

Appendix G
The Cost Differences of Producing Different Types of Improved Maize Seed

The costs of producing hybrid seed rise as the complexity of the production process increases. The range in costs closely follows the seed continuum discussed in Appendix F. Producing seed of local varieties is similar to producing maize grain; the only additional costs (which are not generally cash costs) are related to selecting, drying, and storing the grain that will be used as seed. At the farm level, commercial production of improved OPV seed is also similar to grain production, with substantial additional precautions to prevent varieties from intermixing. Precautions include isolating the maize seed fields from fields of other maize varieties, roguing, and keeping seed of different varieties separate after harvest. These processes may require considerable investments in labor and management and substantially increase the cost of producing commercial OPV seed compared to maize grain.

Producing hybrid seed involves the practices described above but requires higher levels of management, skill, and labor to control and monitor pollination. The complexity of seed production stems from the use of different lines, crosses, or varieties as male and female parents. Self-pollination of the female parent, or cross-pollination by plants other than the intended male parent, must be prevented to obtain the desired, true-to-type hybrid seed. To achieve this, hybrid seed fields are completely isolated from other maize fields. The male flowers (tassels) of the female parent are removed as soon as they appear. Some seed enterprises also use barrier rows of male plants placed along the periphery of the seed field to reduce the chances for pollination from maize varieties in other fields.

These special activities for hybrid seed production are skill intensive and costly, and they raise the total costs of production substantially relative to the production of improved OPV seed. In developing countries, detasseling increases labor costs since it is labor intensive, although relatively low agricultural wages help to keep detasseling costs lower than in industrialized countries. Seed companies, especially in industrialized countries, attempt to reduce the high labor costs of detasseling by using mechanical detasseling or male sterile lines as the female parent. Another component of hybrid seed production that must be managed with care is correctly timing the pollen shedding of the male with the silking of the female. Since the male and female parents are genetically different, they may flower at different times, and the male parent may need to be planted at a different date than the female parent (usually a few days later) to ensure pollination. If all goes well, the female plants are pollinated (only) by male plants and, upon maturation, harvested for seed. The male rows may or may not be harvested for grain and may be cut down as soon as their pollination function is accomplished. This procedure results in lower seed yields per hectare than in OPV seed production, since only female rows are harvested for seed. Depending on the required ratio of male to female rows, the effective area from which seed is obtained can be reduced by as much as one-third in hybrid seed production. If non-seed-producing barrier rows of male plants are also used, the seed yields per hectare are even lower.

Since inbred lines, the parents of conventional hybrids, are generally weak, they do not yield as much as the first filial generation(F1). In general, the smaller the number of inbred lines involved in the production of the hybrid and the more homogenous the lines, the lower the seed yield and the higher the cost of production. Therefore, single-cross hybrids are the most costly to produce, followed by three-way crosses, double-cross hybrids, and then non-conventional hybrids such as top-cross hybrids. In addition, the weaker the parents, the greater the risk of losing the seed crop. Higher production costs for hybrids are reflected in commercial seed price differences. In both OPV and hybrid seed production, *net seed yields* are further reduced by the post-harvest operations needed to ensure good seed quality, which also increase unit production costs. Seed from off-type plants and diseased ears must be discarded, as well as broken seed. Estimates suggest that, after the seed has been sorted and cleaned, the net seed yield may be as much as 25% lower than the *gross seed yield*.

Another factor influencing production costs is that the production of some types of hybrid seed requires more than one season. For example, to produce seed of double-cross hybrids, the single-crosses must be produced first, which requires two seasons altogether. In contrast, only one season is required to produce commercial seed of single-cross hybrids.

While actual production costs are higher for hybrids than for OPVs, the cost differences explain only part of the differential in eventual selling prices. The inbred lines used to produce hybrids must be developed over several growing seasons and carefully reproduced to ensure that pure, high quality parental seed is produced. This process ties up substantial amounts of land and capital. The research and development (R&D) involved in producing just one hybrid is extensive. Many commercial breeders figure that if one out of every 10,000 materials they test becomes a commercial inbred line, they are doing reasonably well. It has been estimated that the R&D costs of developing a maize hybrid can be as high as US$ 1 million (Kidd and Teweles 1987). In most developing countries, the R&D and production costs are largely assumed by the public sector, helping to reduce the price of seed to the farmer; to a lesser degree (specifically, for basic R&D) this is also true in industrialized countries. When inbred lines are developed mainly by private research systems, however, the R&D costs must be reflected in the price of seed. This helps explain part of the price difference between public and proprietary hybrid seed.

Appendix H
Brazil's Innovative Approach to Public-Private Sector Alliances in the Seed Industry

The late 1980s was a period of substantial expansion in maize area in the Cerrados region of Brazil, which encompasses parts of the central states of Minas Gerais, Goiás, Matto Grosso, and Matto Gross do Sul. This expanding maize area had become Brazil's main source of growth in maize production. Private seed sector activity was modest at that time in the Cerrados, as efforts were concentrated in São Paulo and other states in the southeast.

In 1987, the National Maize and Sorghum Research Center (Centro Nacional de Pesquisa de Milho e Sorgho, CNPMS), located in Minas Gerais, released BR-201, the first of a series of outstanding double-cross hybrids possessing tolerance to acid soils, high yield performance, and good adaptation to the Cerrados. (The CNPMS is one of the many research centers that comprise the Brazilian Agricultural Research Enterprise — Empresa Brasileira de Pesquisa Agropecuaria, or EMBRAPA). EMBRAPA developed an innovative scheme in which commercial seed of its maize hybrids would be distributed by private sector companies, starting with BR-201.

Initially, 17 small-scale regional seed companies were selected for the program, and the first commercial seed of BR-201 was produced in 1987 for sale in 1988. The program was modest at the beginning, selling 900 t of seed the first year, which represented less than 1% of the country's total maize seed market. Problems with quality control in seed production led EMBRAPA researchers and the seed companies to implement strict standards for commercial seed production. Companies producing substandard seed were expelled from the group, and others were added. In 1990, the companies in the program organized themselves into an association named UNIMILHO, whose objective was to maintain and enforce high seed quality standards, coordinate basic seed purchases from EMBRAPA, and promote BR-201. Following on these organizational changes, sales of BR-201 increased dramatically. In 1993, sales of commercial seed of BR-201 reached 18,000 t, capturing a 17% share of the hybrid seed market (Table H1). Private sector competition has increased since the UNIMILHO group was formed, and this has resulted in more options for maize farmers and lower seed prices (Table H2).

Table H1. Private seed enterprises participating in UNIMILHO and sales of BR-201 seed in Brazil, 1987-93

Year	UNIMILHO companies (no.)	Total sales of BR-201 (t)	UNIMILHO market share (%)
1987[a]	17	-	-
1988	24	923	0.9
1989	26	5,745	5.2
1990	28	12,646	11.0
1991	25	13,561	11.3
1992	25	15,000	15.0
1993	27	18,000	16.5

Source: EMBRAPA-CNPMS and EMBRAPA-SPSB, unpublished data.
[a] Commercial seed production started. Seed sales started in 1988.

The EMBRAPA-UNIMILHO collaboration has created a heated controversy, raised mainly by large seed companies. Although EMBRAPA does not restrict any company from entering the group (requiring only that a company demonstrate the technical capacity to meet minimum standards for seed production and distribution), large seed companies maintain that because the inbred lines are the result of investment in public sector research, they should be freely available to everyone.[10] On the other hand, EMBRAPA and UNIMILHO maintain that the large companies are welcome to join the system, as long as they abide by the rules, purchase basic seed from EMBRAPA, and pay royalties on seed sales, something that the large companies, with strong breeding programs, are not interested in doing. They are interested in obtaining the inbred lines and incorporating them into their own breeding programs to develop their own proprietary materials.

Despite the continuing controversy, EMBRAPA and UNIMILHO have developed a special breeding project within the CNPMS for the development of hybrids to replace BR-201. Two of these hybrids are already on the market. Two additional hybrids, this time single-cross hybrids, are already in yield trials and should be released within the next three years, according to EMBRAPA-CNPMS researchers.

Trying to capitalize on the success of the BR-201 program, EMBRAPA has established franchise systems to produce and market some of the outstanding improved OPVs that the CNPMS has developed. This program has already started with BR-106, the most widely used improved OPV in Brazil, which is being sold through a similar system. The program for OPVs calls for cooperatives to become franchisees for producing and distributing commercial seed of BR-106, with EMBRAPA-SPSB (EMBRAPA's basic seed production unit) supplying the parent seed. EMBRAPA-CNPMS will continue with improvement of BR-106, and each year a new breeding cycle will be available as basic seed. According to EMBRAPA, 25 franchisees produced about 10,000 t of commercial seed of BR-106[11] for the 1994-95 crop year. With this system, EMBRAPA hopes to reach small-scale farmers who use local maize seed, recycled OPVs, and even advanced generation hybrid seed. The goal is to provide high-quality, certified OPV seed at low prices so that these farmers can purchase seed every season.

Table H2. Maize seed prices in Brazil by origin and type of seed company, 1992-93 crop year

	Seed:grain price ratios[a]		
Type of seed company	**Improved OPVs**	**Public hybrids**	**Proprietary hybrids**
Multinational	na.	na.	10.6
Private national	6.0	9.2	9.8
Other non-public[b]	4.6	9.2	9.6
Public[c]	3.8	4.6	na

Source: CIMMYT Maize Seed Industry Survey, 1993.
[a] Based on a price of maize grain of US$ 0.125/kg.
[b] NGOs, seed producers' cooperatives, and individual seed producers.
[c] Includes only state-level public seed companies, notably in São Paulo. The national seed enterprise, SPSB, does not sell commercial maize seed; it sells only parent seed to private companies.
na = not applicable.

[10] Because EMBRAPA considers BR-201 a closed-pedigree hybrid, it does not reveal the name of the inbred lines that comprise it, nor does it make them publicly available.
[11] Some of these franchisees are members of UNIMILHO and also sell seed of BR-201.

Appendix I
Structure of the Maize Seed Industry in Mexico

The maize seed industry in Mexico is a good illustration of the way seed industries have evolved in many developing countries, for several reasons. Most types of seed enterprises are now active in Mexico. The Mexican maize seed industry has undergone rapid change in response to new legislation and the implementation of the North American Free Trade Agreement (NAFTA). Public sector enterprises have limited their seed marketing role and concentrate instead on breeding and varietal development, whereas the private sector has increased its role in seed production and marketing.

The numbers and kinds of players participating in the Mexican maize seed industry have increased substantially since the early 1980s. The public sector was given a head start in the maize seed industry as a result of legislation that restricted private sector activities. Until a few years ago, the Productora Nacional de Semillas (the national seed production enterprise, PRONASE), dominated the industry (Table I1). PRONASE was (and remains) involved only in seed production and marketing. In the past, PRONASE obtained its germplasm free of charge from the public national agricultural research institution, the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), but since 1991 PRONASE has had to pay a fee and royalties for using public germplasm.

Private seed enterprises began appearing in Mexico in the 1960s. They focused primarily on producing and marketing domestic varieties and importing hybrids developed outside of Mexico. At that time, investment in breeding research by these private enterprises was very limited.

Table I1. Trends in maize seed production and the private sector share of maize seed sales, Mexico, 1970-93

Year	Total seed production (000 t)	Private sector share of sales[a] (%)
1970-71	8.5	13
1980-81	30.1	22
1990-91	22.1	54
1992-93	40.0	91

Source: Constructed from Matus Gardea, PuenteGonzález, and López Peralta (1990); Polanco (1991); Barkin and Suárez (1983); interviews with public and private seed sector officials in 1992; and the CIMMYT Maize Seed Industry Survey, 1993.

[a] Private sector share of *seed production and distribution*, not necessarily of the origin of the germplasm from which the seed was developed.

In 1981, PRONASE was among Mexico's top four seed production enterprises, which together secured 90% of the market; PRONASE itself had over 50% of the seed market. At present, the four largest seed production enterprises, all private, capture 83% of seed sales, whereas PRONASE's share of the market is less than 10%. This trend is typical of maturing seed industries in developing countries were the seed industry has been privatized.

Some public organizations still participate in the Mexican seed industry. Antonio Narro University and PRONASE continue to produce and market seed.[12] Several other universities have breeding programs, but they are oriented mainly towards education and training (Table I2). Some of the public universities and INIFAP conduct basic research.

Table I2. Activities of organizations participating in the maize seed industry in Mexico, 1992

Type of organization	Activity		
	R&D[a]	P&M[a]	Seed trade
Public sector			
INIFAP	X	-	-
PRONASE	-	X	-
Universities:			
Universidad Autónoma Agraria Antonio Narro	X	X	-
Universidad Autónoma Chapingo	X	-	-
Universidad Nacional Autónoma de México	X	-	-
Colegio de Postgraduados	X	-	-
Universidad Autónoma de Nuevo León	X	-	-
Instituto Tecnológico de Estudios Superiores de Monterey	X	-	-
Universidad de Guadalajara	X	-	-
Private sector			
Multinational companies:			
Semillas Híbridas S.A. de C.V.	X	X	X
Híbridos Pioneer de México S.A. de C.V.	X	X	X
Asgrow Mexicana S.A. de C.V.	X	X	X
Cargill de México S.A. de C.V.	X	X	X
Northrup King y Cia. S.A. de C.V.	X	X	X
CERES Internacional S.A. de C.V.	X	X	X
Domestic companies:			
Semillas TACSA	X	X	X
ASPROS Comercial	X	X	-
Semillas Conlee Mexicana[b]	-	X	X
AAALPES/Berentsen	-	X	-
Semillas Correa	X	X	-
Semillas Máster de México[b]	-	X	X
Semillas WAC de México[b]	-	X	X
Semillas Agrícolas Mexicanas[b]	-	X	X
Cia. Beneficiadora del Bajío	X	X	-
Semillas Calber[b]	-	X	X
Others[c]	-	X	-
Social sector[d]			
Patronatos	-	X	-
Producers' unions	-	X	-

Source: López Pereira and García (1994).

[a] R&D = research and development; P&M = seed production and marketing.

[b] These companies started modest maize breeding programs in 1992-93.

[c] Includes approximately 10-15 small regional private companies and 40-50 individual farmers (seed micro-enterprises) producing and selling public OPVs and hybrids developed by INIFAP.

[d] About 10 *Patronatos* and several *Ejido* unions produce and market maize seed for their members.

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[12] It should be noted that, as opposed to PRONASE, Antonio Narro University has a strong maize breeding program and, in fact, the National Maize Institute is located there. Antonio Narro University also sells basic seed of its popular hybrids to medium-scale seed enterprises and cooperatives for production and distribution of commercial seed.

The private sector is much broader, albeit highly concentrated. Several multinational companies, most by of US origin, produce, market, and import seed, as well as conduct research. The list of private national companies is even longer. Most of these companies concentrate on seed production and marketing; a few have initiated modest R&D programs, based on public germplasm from INIFAP and CIMMYT. Some of the private national enterprises are also involved in the seed trade, especially in importing seed from the USA. Other national seed enterprises that do not develop their own germplasm rely on the public sector for their supply of basic seed. Cooperative unions and individual producers limit themselves mainly to seed production and marketing, also with the public sector as their source of basic seed. In 1992, the total investment in maize breeding in Mexico was estimated at US$ 11 million, equally divided between public and private sector organizations, which together employed 109 maize breeders (López-Pereira and García 1994). In comparison, in 1987 the investment in maize breeding was estimated at US$ 2.5 million, with a total of 89 breeders (Echeverría 1990).

Even though the private and public sectors' changing roles may result from a natural evolution of the seed industry, recent legislation has sped up this process. Mexico's new seed law of 1991, along with the regulatory decree of 1993, lifted many restrictions on the private sector, outlined the role the public sector was to play, and changed the rules governing the seed market. The private sector can conduct more intensive research and participate in all phases of the seed industry. Maize seed no longer must be submitted for government certification. Private enterprises can take responsibility for seed quality and sell it under the classification of "verified seed."

Since federal funding and special benefits, such as the sale of seed through official agricultural credit programs, have been removed, PRONASE must become self-sufficient and compete actively for a share of the seed market. Now that INIFAP has the right to sell its germplasm to any enterprise and collect royalties based on the use of that germplasm, the price of improved maize seed sold by PRONASE has risen sharply (Figure I1). As in the case of Brazil (Appendix H), the sale of public germplasm from INIFAP is motivated in part by the need for public sector organizations to find alternative sources of funding. The issue of royalties and the related (and more controversial) issue of plant variety protection may come to the forefront in the coming years as the Mexican Congress discusses legislation on the subject.

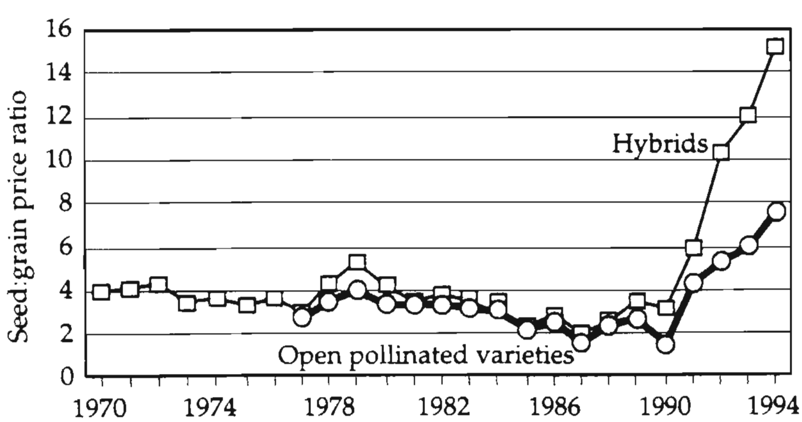

Figure I1. Ratio of the price of maize seed to the price of commercial grain, Mexico, 1970-94.

Source: SARH (PRONASE and Dirección General de Política Agrícola).

Other legislative changes have had a less direct effect on the maize seed industry. A revision of Article 27 of the Mexican Constitution grants communal farmers the right to sell, lease, or mortgage communal (*ejido*) land. This may lead to changes in crop patterns, especially in the production of basic crops. Another legislative change which may cause farmers to switch from maize to other crops, thereby affecting the maize seed industry's size and future growth, is the "Programa de Apoyos al Campo" (PROCAMPO). Previously, farmers received guaranteed prices for staple crops, including maize and beans; the guaranteed price for maize was relatively high. Under PROCAMPO, farmers instead receive direct payments based on land area rather than on a particular crop. The system of guaranteed producer prices is being phased out in the 1994 crop season, after which local prices will be based on international market prices. As a result, farmers may decide to switch to crops that are more profitable at prevailing free market prices and still receive the fixed subsidy per hectare of cropped land. The phasing out of the guaranteed prices and implementation of PROCAMPO match the timetable for NAFTA's implementation. Mexican maize imports from the USA will be increased under NAFTA, exerting downward pressure on domestic maize prices and, most likely, on maize area and production. Thus changes in both domestic and international trade policy have hastened the privatization of the Mexican maize seed industry.

One important question, given the substantial changes in the maize seed industry, the strong likelihood of lower maize prices in the near future, and the tremendous variation in growing environments and maize producers, is how the seed industry will respond to the needs of Mexico's small-scale maize farmers. Local initiatives for the production and delivery of seed by ejido unions, cooperatives, and individual seed producers (also known as "seed micro-enterprises" in Mexico) are likely to become important for delivering maize seed to small-scale farmers. The success or failure of these and other initiatives will depend very much on collaboration from public sector organizations such as INIFAP and the universities in supplying improved germplasm. The commercial maize production areas, located mainly in the northern half of Mexico, appear to be well served by the private seed sector. It would seem more appropriate to concentrate public sector breeding efforts on the central highlands and the southern lowland tropics, where growing conditions are more difficult, small-scale subsistence farmers predominate, and the support of initiatives for small-scale seed production and distribution may be important for increasing maize productivity.

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