IMPROVING MAIZE PRODUCTION IN LATIN AMERICA

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CIMMYT

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C I M M Y T

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Maize is a staple food for millions of people living in many countries of Latin America and other parts of the developing world, where diet is deficient in protein. For millions of others, it is an important ingredient in the production of their milk, eggs, poultry, and meat (Figure 1). Yet in many countries of Latin America, maize production lags behind maize utilization. Consequently, imports are required to fill the gap.

Imports are a fact of life in most countries of Latin America and an important source of maize. Table 1 shows the situation in some of the important countries of the region—Argentina, Brazil, Chile, Honduras, and Mexico. Imports as a percent of utilization have increased for Mexico, Central America, the Caribbean, and the Andean Region. In the Southern Cone, however, production has kept pace with utilization, and Argentina is one of the world's major exporters. Of the sixteen major maize-producing countries, thirteen have increased their dependence on imports. With increasing populations and rising incomes, that dependence will increase unless advances in production can be achieved. Such a dependence on imports can be a serious drain on valuable foreign exchange and can leave a country vulnerable to a shortage of grain at a certain time and place.

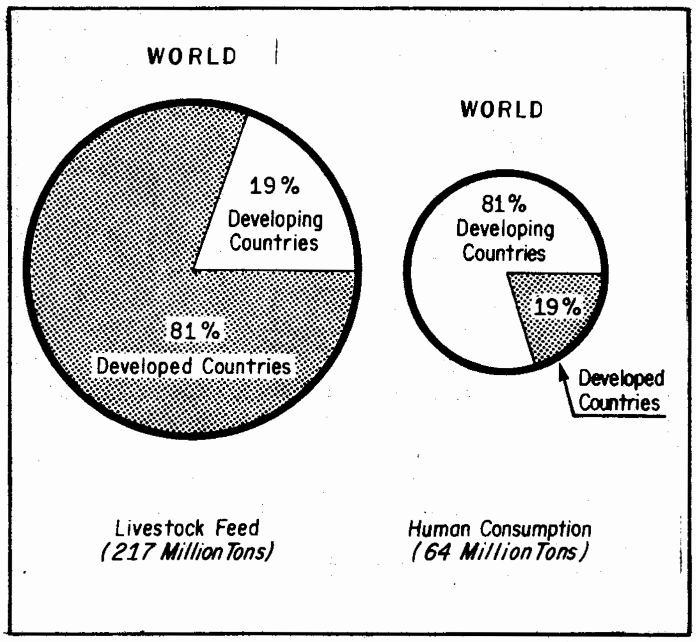

Figure 1. Maize use for livestock feed and human consumption by developed and developing countries

Maize utilization in Latin America continues to rise. In some countries, such as Honduras, Guatemala, and Paraguay, direct human consumption is high and continues to grow along with rapidly increasing populations. For countries like Venezuela and Mexico, incomes are growing rapidly and the use of maize as livestock feed also is increasing rapidly. Maize utilization will continue its upward trend. With population growth, direct human consumption of grain increases. However, as real per capita incomes grow, individuals substitute livestock products for grain in their diets. Figure 2 shows that in certain Latin American regions, despite

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Table 1. **Maize requirements, maize production, and population growth rate for selected Latin America countries**

	TOTAL MAIZE UTILIZATION* (1977-79)	AVERAGE MAIZE PRODUCTION (1978-80)	NET IMPORTS (1977-79)	POPULATION GROWTH RATE (1970-78)
ARGENTINA	3,072,000	8,203,000	–5,762,000	1.3
BRAZIL	16,832,000	16,784,000	448,000	2.8
CHILE	546,000	384,000	179,000	1.7
HONDURAS	451,000	422,000	31,000	3.3
MEXICO	11,406,000	10,055,000	1,306,000	3.3

* Production plus imports less exports (metric tons per annum)

a deficit of maize for human consumption, there is a considerable proportion of grain being channeled into livestock feed in order to satisfy the diet preferences of the more affluent. The grain supply in poor crop years is thus channeled to the more affluent segments of the population who can afford to satisfy their preferences for meat and dairy products. For this reason, the shock resulting from a sudden disruption in the world supply of grain is felt most sharply by people in low-income groups, whose diet depends more directly on food grains. Many of these low-income areas are found in Latin America.

Finally, the problem of supplying sufficient maize for human consumption, at reasonable prices, will become more critical if additional grain is diverted to other uses--ethanol production, for example. Realistically speaking, Latin America must improve its maize production; logically, there is every reason that it should and can achieve this goal.

Argentina is in the lucky position of being a maize-exporting nation, mainly due to the large areas under maize production. However, actual average yields are below 3 tons/hectare. Argentina could benefit itself and the world by improving its maize yields. While maize exportation may not be desirable or even practical for many countries in Latin America (other crops having a productive and/or economic advantage), most countries would benefit if they could economically produce sufficient maize for their own needs.

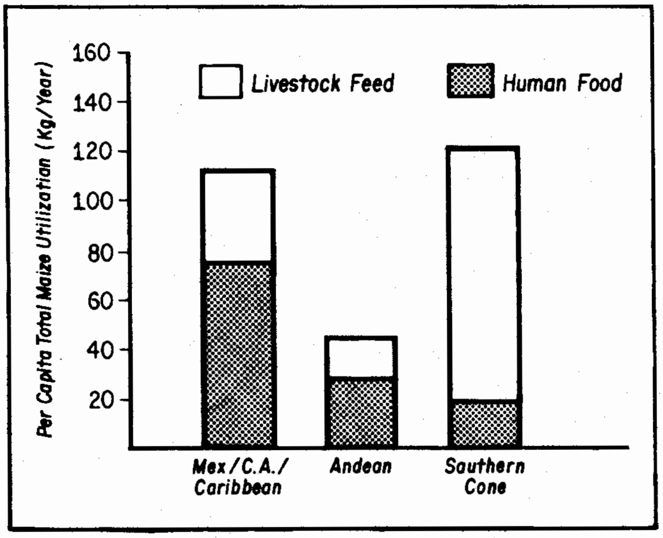

Figure 2. Recent maize utilization by region

How is it possible to increase maize production in Latin America? One way is to increase the area of land under cultivation. At present, there are 120 million hectares of underdeveloped savannah lands in South America. However, only a few countries in Latin America have this potential land reserve, and it must be remembered that as more and more land is opened up for cultivation, there will be less and less virgin land. The only possible long-term answer is to improve maize yields on land already under cultivation; in some countries this need is urgent.

Raising Average Maize Yields

The average maize yields obtained in Latin America are below 1.5 t/ha, as opposed to average yields of 6.5-7.0 t/ha in the USA. The world record is over 21 t/ha. Materials with superior yield potential are or can be made available which, combined with suitable production technology, can double or triple the yield per hectare in most Latin American countries.

Yield potential in a given agroclimatic region is determined by the genetic make-up of plants. However, environmental factors influence the expression of this potential. Materials with superior yield potential alone cannot increase production. They make higher yields possible only with effective use of inputs and agronomic practices. Also, the variety with the highest yield potential in the world is totally useless if it does not meet the needs of the producer and consumer.

To improve maize production, it is necessary to integrate and organize the research system so that its results flow into the fields where maize is actually produced. This requires the input and analytical capability of several disciplines, and people who are able to adopt a holistic approach which addresses the total concept, not just one aspect. Integrated team work requires the skills of various disciplines. The breeder, the pathologist, the entomologist, the agronomist, and the economist must be involved in all aspects and stages of agricultural research.

CIMMYT's Efforts in Improving Maize Production

CIMMYT scientists work closely with scientists from most maize-growing countries of the world in germplasm development and exchange of superior germplasm and research information. A number of regional programs have emerged among various maize-growing countries, including the Central American and Andean regional maize and economics programs with seven CIMMYT-assigned scientists. In the Andean region, one maize breeder is headquartered in Ecuador with responsibilities for highland floury maize improvement, and two maize scientists are stationed in Colombia, from where they support tropical maize breeding and production research activities throughout the region. Two maize scientists are assigned to the Central American and Caribbean region. The regional economists assigned to both these programs work with national scientists in on-farm research programs, focusing their work on farm-level survey research.

CIMMYT's program is aimed primarily at realizing increased maize production in the developing world. It was designed with the following topics or factors in mind:

A. Germplasm development
B. Production technology
C. Seed industry
D. Government policy

A. Germplasm Development

When one looks at the best yields in the world—in North America, Europe, and New Zealand—one sees that they are produced by hybrids. In an attempt to imitate these results, many countries of the world, including those of Latin America, have turned to hybrid maize production. I would like to point out that there are often serious problems associated with this approach.

First, the need for timely availability of quality seed to the farmer, and the ability of the farmer to pay for the seed and service, are essential factors in the hybrid maize approach. The organization necessary for a hybrid seed industry—adequate seed multiplication and distribution systems, and cash availability to the farmer—is lacking in many Latin American countries.

The second point I would like to raise concerns the supposedly-inherent high yields of hybrids over open-pollinated varieties. Sprague and Eberhart suggest that the rate of improvement of hybrids from improved populations will be proportional to the improvement of the population cross between two breeding populations[1/]. They indicate that with a 4 percent selection intensity, the superiority of double-cross hybrids is 9.4 to 12.4 percent over the mean of the population cross. The superiority of a single-cross hybrid ranges from 15 to 20.4 percent. The yield superiority of hybrids will increase with an increase in selection intensity.

Gardner suggests that if population improvement can be achieved without a significant reduction in genetic variability—a very important point—the best double-cross and single-cross

1/ Sprague, G.F. and Eberhart, S.A. 1977. "Corn Breeding." *Corn and Corn Improvement* (Ed. G.F. Sprague), American Society of Agronomy, Inc., pp. 305-362.

hybrids from a series of random lines derived from the improved population will exceed the population mean by at least 20-30 percent[2/].

Emphasis on Developing Open-Pollinated Varieties

CIMMYT works with open-pollinated varieties. The selection intensity exerted for families to regenerate sequential cycles for population improvement is 30-40 percent, and the selection intensity for families to generate experimental varieties is 4 percent. The performance of eight open-pollinated varieties in comparison with their parental populations of the same cycles, tested at 12 to 19 locations, is presented in Table 2. The mean gains across locations range from 7 to 20 percent. The superiority in yield of experimental varieties over their parental populations is evident.

With CIMMYT's methodology, experimental varieties are extracted following each cycle of improvement. Figure 3 shows (1) the time lag, in seasons, in the development of varieties and hybrids, and (2) their expected performance level, based on the selection pressure exerted in CIMMYT's program for open-pollinated materials, and for hybrids, as indicated by Sprague and Eberhart and Gardner. A 40 percent selection intensity within an open-pollinated population should give 5 percent progress each cycle. In CIMMYT's program, a variety would be 15 percent superior to the parent population, whereas a hybrid would show an approximate 25 percent superiority. However, hybrids require a substantial time lag (11 cycles) for their development. CIMMYT's program can provide usable materials of superior performance at each cycle of development. Both populations and varieties improve proportionally with each selection and, after the same number of cycles, there is very little difference in the performance of hybrids versus varieties. In fact, provided that adequate selection has been practiced in each cycle, varieties can be superior to hybrids in performance after any fixed period of time.

An important advantage of varieties over hybrids is that the farmer can use his own seed for the following two or three succeeding crops. This should not discourage the development of a seed industry nor the development of an adequate transportation system, both of which are essential to maximize and utilize maize production. Both of these are clearly lacking in most developing countries.

Table 2. Yield gains in open-pollinated varieties over the original populations

Variety		Population	Yield of Variety as Percent of Population Mean Across Locations
Gemiza	7421	Tuxpeño 1	112
Poza Rica	7422	Mezcla Tropical Blanco	107
Tocumen	7428	Amarillo Dentado	117
Rampur	7433	Amarillo Subtropical	111
Yousafwala	7435	IDRN	115
Tlaltizapan	7443	La Posta	119
Tlaltizapan	7444	AED x Tuxpeño	120
Pirsabak	7448	Compuesto de Hungary	108

2/ Gardner, C.O. 1978. "Population Improvement in Maize." *Maize Breeding and Genetics* (Ed. D.B. Walden), John Wiley and Sons Inc., pp.207-228.

CIMMYT's Maize Improvement Program

But let us return to CIMMYT's maize program and how it can help improve maize production in Latin America. This program is designed to (a) provide an overall strategy that can effectively serve different maize-growing areas of the world which have diverse levels of capability; (b) serve as a mechanism for continuous development and improvement of maize germplasm in order to meet current and future needs; (c) provide a smooth and efficient delivery system of improved germplasm to and from the national programs, and (d) meet the needs for exploratory and innovative maize research.

There are three main stages in the CIMMYT system:

1. Development and improvement of broad-based gene pools for different specific areas of the world.
2. Continuous improvement and refinement of populations with upgraded material from the corresponding pools.
3. Development of superior experimental varieties from populations.

Let us look more closely at each stage of the system, beginning with the development and improvement of broad-based gene pools for different specified areas of the world.

Genetic diversity and variability are basic requirements for any successful population improvement program. A gene pool is a mixture of diverse germplasm, undergoing continuous recombinations, from which materials can be taken out and to which materials can be added. CIMMYT has a total of 27 gene pools to accommodate preference in grain type and color, maturity requirement, and environmental adaptability. We have 12 gene pools for the tropical lowland zone, eight for the subtropical temperate zone, and seven for the tropical highland areas.

Each pool is a reservoir of genetic variability necessary to serve a range of known conditions. It is a source of germplasm for a dynamic improvement program, which selects and fine-tunes populations for more and more specific conditions as the program advances. The stage of pool management is considered the Back-Up Unit, and the subsequent fine-tuning is carried out by the Advanced Unit.

Due to a concern with the danger of genetic erosion and the narrow genetic base of germplasm currently in use in Europe and the USA, CIMMYT has developed four new gene pools of

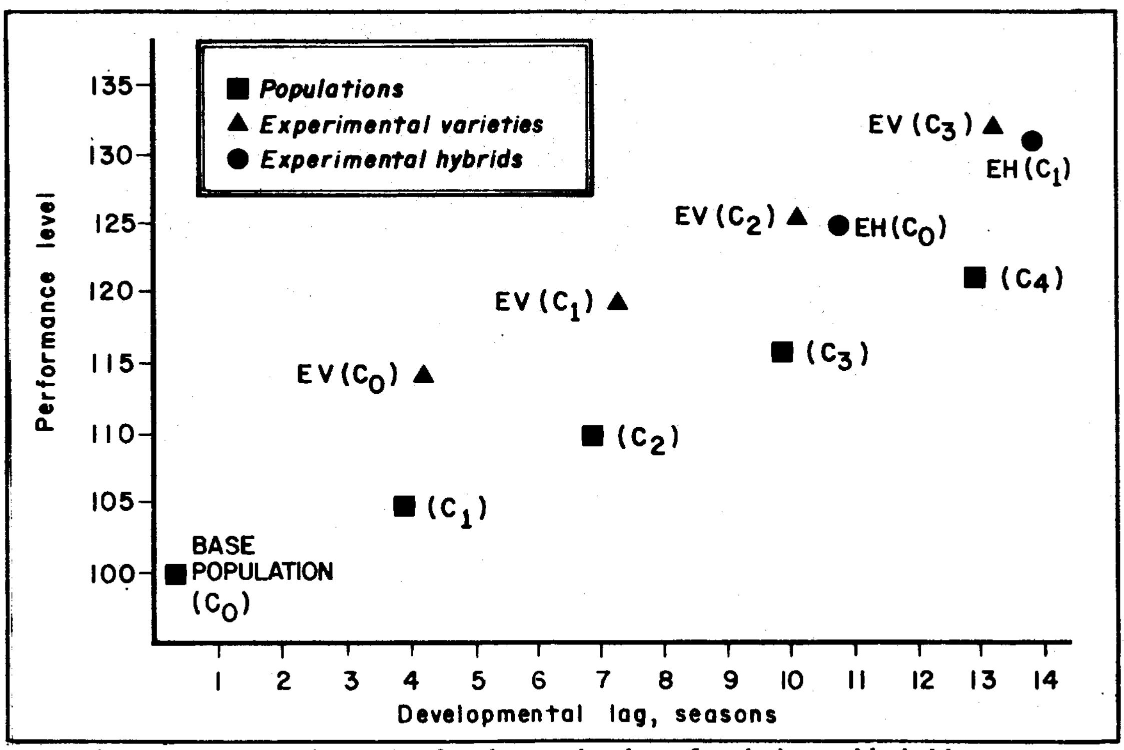

Figure 3. Developmental time lag for the production of varieties and hybrids

wide genetic diversity which will facilitate the introduction of exotic germplasm in temperate base materials. This in turn will serve to transfer superior characters from the temperate germplasm into the tropical lowland and highland materials. After thorough recombination, they are being subjected to multilocational screening, evaluation, and selection, followed by recombination of selected families at CIMMYT. Some of these materials may prove useful in various parts of Latin America.

Population Improvement

The farmers' conditions usually demand material of specific adaptability, maturity, and seed type. To serve this demand, the Advanced Unit is currently handling 26 maize populations: 23 normal, and three quality protein maize populations carrying the opaque-2 gene. At this stage international testing in the different environments becomes necessary. One full-sib cycle of selection with international testing of progenies from each population can be completed every year. However, the retrieval of trial data from cooperating countries located both in the northern and southern hemispheres makes it difficult to complete the full cycle in one year, and therefore a two-year cycle is used. Figure 4 summarizes the steps involved in CIMMYT's maize population improvement program.

Development of Experimental Varieties

A selection intensity of four percent is used in the selection of families from populations for the development of experimental varieties. Experimental varieties are developed both on the basis of site-specific and across-site progeny test data. These varieties show considerably higher performance as compared to the population mean. In addition to those characters that distinguish each variety, uniformity for maturity and plant and ear height are also important considerations in the selection of the ten families so that the resultant variety is uniform in appearance.

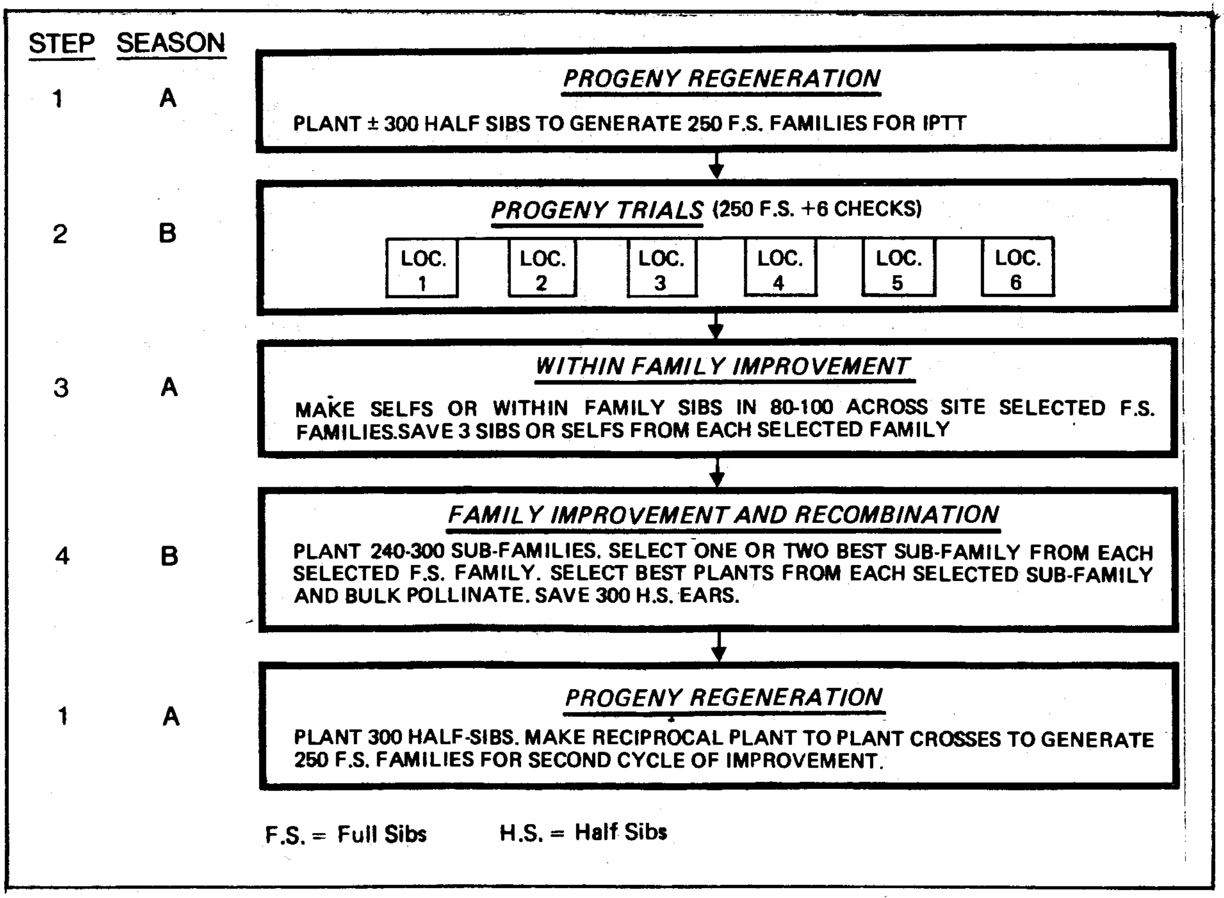

Figure 4. Population improvement scheme breeding sequence

Each experimental variety goes into a second-order seed increase in order to build-up a sufficient quantity of seed. Thus, if a variety proves to be promising in the Experimental Variety Trial, it can be used immediately in the second series, called the Elite Experimental Variety Trial.

Variety names are derived from the names of the station where the progeny test was conducted, and where, in fact, that variety was made. For pedigree purposes, this name is followed by two digits indicating the year in which the selection was made, then two digits showing the population number from which the variety was derived, e.g., Tocumen 7928.

The national programs then use these materials as they see fit. Some materials undergo seed increase and are released to the farmer. Others are further selected and fine-tuned, or incorporated at various stages into the breeding programs. Some national programs utilize the materials in hybrid development. Although the emphasis is on intrapopulation improvement with open-pollinated varieties as the end product, information is collected and made available to national programs on the heterotic patterns of various populations for interpopulation improvement and the development of hybrids.

CIMMYT's resident program in Mexico also concerns itself with the environmental adaptability of the maize crop. Selections for reduction in plant height, drought tolerance, and disease and insect resistance are incorporated into the overall program.

Reduction in Plant Height

A reduction in plant height reduces susceptibility to lodging, makes the maize crop more responsive to better management, and can improve yield efficiency through improvement of harvest index. Fifteen cycles of continuous recurrent selection for reduced plant height in a CIMMYT population called Tuxpeño-1 resulted in plants one-meter shorter and seven days earlier to 50 percent silking. Selection also was made for other characteristics relevant to plant improvement, and resulted in a 2.68 t/ha yield increase (at increased density) and harvest index improvement from 0.30 to 0.46. These results are summarized in Table 3. Similar selection is being practiced in all of CIMMYT's program because of the advantages conferred to the maize crop.

Drought Tolerance

Maize is usually grown as a rainfed crop in countries of Latin America and is often subject to fluctuating moisture conditions throughout the growing season.

CIMMYT staff have been studying the variation for performance under water stress situations and exploring the reliability of various selection criteria for the development of drought-tolerant types. A recurrent selection program for improved performance under drought was initiated in Tuxpeño-1, and the results to date show that (1) there is a genotype x water interaction, (2) selection under non-limiting moisture conditions does not adversely affect the performance of the material under stress conditions, and multilocation testing and the selection of

Table 3. Comparison of cycles of selection in Tuxpeño 1

Cycle of Selection	Plant Height (cm)	Grain Yield (t/ha)	Total dry matter (t/ha)	Harvest Index
0	273	4.05	14.94	0.30
6	211	5.54	14.75	0.38
9	203	5.67	15.32	0.39
12	196	6.18	15.37	0.41
15	173	6.73	15.12	0.46
LSD P.05	10	0.41	1.84	0.05

families on the basis of across-site performance may enhance performance under intermediate levels of water stress, and (3) a multiple selection index which includes characteristics expressed under moisture stress can be used to identify genotypes (families) that give better than average performance under moisture stress conditions without detriment to their performance under more favorable conditions or no-stress situations.

Disease Resistance

One of the major causes of yield instability in the maize crop is susceptibility to diseases. Development of a reliable polygenic resistance (field resistance/tolerance) against diseases is desirable because of its effects on yield stability. In CIMMYT's recurrent population improvement program, selection is exercised for ear and stalk rots (using artificial inoculation techniques) and for leaf blights and rusts (using reliable field inoculations). Results of international tests show that the level of resistance for these diseases has improved considerably in several materials.

CIMMYT also is involved in several collaborative research projects on diseases which cannot be handled in Mexico. One such collaborative research effort is for development of resistance against corn stunt, a major disease of maize in Latin America. Good progress has been made in developing agronomically superior materials having corn stunt resistance. Similar progress also has been made for resistance to downy mildew. Its regionally-assigned staff, working closely with national collaborators, carry the principal responsibility for CIMMYT's involvement in such research.

Insect Resistance

Susceptibility to insect attack is another important factor which limits yield. Successful insect mass-rearing facilities, and the development of techniques for the uniform application of larvae to the maize crop, have resulted in progress in developing resistance to fall armyworm in two CIMMYT pools and in two Advanced Unit populations. Similar progress is expected for sugar cane borer, Southwestern corn borer, and earworm resistance.

Improvement of Protein Quality

The advantages of high quality protein maize over normal maize are obvious. Simply, it provides better nutrition. For example, studies on nitrogen absorption and retention in children fed with diets based on non-fat milk and high quality protein maize performed at the Institute of Nutrition of Central America and Panamá in Guatemala indicated that the protein quality of this maize was approximately 90 percent that of milk.

In another series of experiments in Colombia and elsewhere, groups of weanling pigs were put on diets in which all protein was supplied by either normal or quality protein maize. The pigs receiving quality protein maize gained weight much faster, requiring only one-eighth as much feed per kilogram of body weight gained as their counterparts eating normal maize. The substitution of quality protein maize for normal maize in diets for weanling or growing pigs reduces the amount of protein supplements required to produce optimum performance in terms of weight gain. This is due to the improved balance of amino acids of the quality protein maize, especially lysine and tryptophan. It has been demonstrated that quality protein maize can be used as the only dietary source of protein during the finishing period for pigs. Due to the high cost of animal or soybean protein supplements, the use of quality protein maize offers considerable potential advantage.

However, certain detrimental effects associated with the original maize materials of high nutritional quality made them unacceptable to the farmer and consumer. The major defects had been soft chalky kernels with a dull appearance, greater vulnerability to diseases, such as ear rots, and to insect pests, higher moisture content at harvest, and, most important, reduced grain yields.

CIMMYT believed that the advantages which the extra protein quality provided merited the substantial effort required to overcome the associated disadvantages. The progress made there since 1971 in the development and improvement of normal-looking, hard-endosperm maize from the soft opaque-2 maize is illustrated in Figure 5. We now have materials which are equal to or superior to normal check materials under cultivation in Latin America, Africa, and Asia. The problems of reduced yield, vulnerability to ear rot and stored grain pests, and the dull and chalky

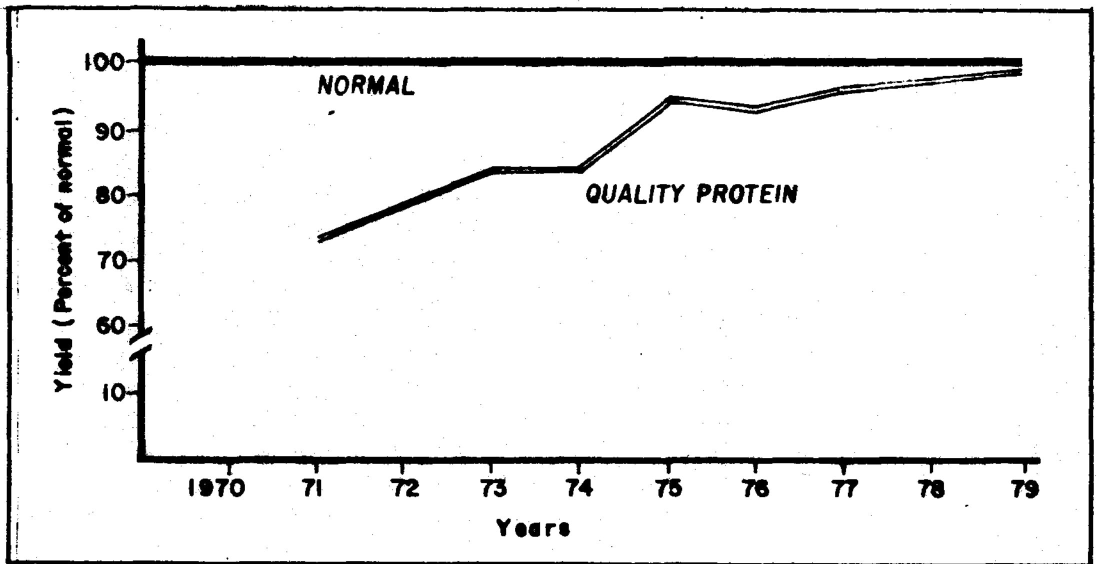

Figure 5. Grain yield of superior quality protein maize expressed as a percentage of normal maize check in different years across all test locations

appearance have been largely overcome. As I mentioned earlier, quality protein maize materials are in CIMMYT's Advanced Unit now and experimental varieties are being generated from them.

B. Production Technology

Different maize-growing areas require appropriate varieties and cultural practices to maximize yields and minimize potential risks and losses; therefore, location-specific research is needed. Consequently, CIMMYT uses suitable locations in Mexico to train key workers from countries all over the world in the basic principles involved and the possible methods of approach to this problem.

This training focuses on the organization and execution of a production research program which can be implemented in the trainees' home countries. The importance of on-farm research at key locations is emphasized in order to obtain the necessary information on the value to the farmer of various materials and agronomic practices.

It is there, in the farmers' field, that appropriate materials, genuine fertilizer responses, economic rates of insecticides and herbicides, and appropriate plant densities can be identified. This is where the farmers, the extension staff, and the research staff meet and work together toward the common goal of increased production. This brings the farmer into the decision-making process, which is particularly important since it is he who decides which products of research are useful to him. He also can help determine, along with the research and extension staff, what further research should be carried out.

In addition to training key workers from various countries all over the world, CIMMYT, at the request of those countries, assigns staff in certain countries or regions important for maize production, in order to help organize such systems. The responsiblity of the CIMMYT staff is to help improve the maize production in the country or region of their assignment, in collaboration with local national programs.

This type of flow system ensures continuous improvement and acceptance of technology. Observation and research carried out with the involvement of the farmers quickly indicates the primary requirements and/or weakness of the system. As each weakness is corrected, another problem may be identified. As each link in the chain is tested and improved for strength, another link will be shown to be weak, and will require further strengthening.

C. Seed Industry

The best materials developed by researchers are only as good as the quality of seed planted by the farmer. Lack of proper seed production programs is a critical factor limiting maize production in most developing countries. Its importance in increasing maize production in

Latin America cannot be overemphasized. There must be a mechanism to supply good quality seed to the farmer.

In a few of the countries of Latin America, there are national and multinational seed companies marketing high quality seed; in these countries, seed supply and distribution should not be a constraint. However, in most Latin American countries, the farmers traditionally save their own seed and distribute it locally. However, most farmers cannot be expected to possess or exercise the management control that is possible on experimental stations which have uniform soil, fertility, irrigation, drainage, and insect and disease control. Good quality seed for the farmer begins with the production of good quality basic seed. This is a function of research and should be an integral part of the total agricultural production system.

Basic seed production includes both the maintenance of the purity and uniformity of varieties and the maintenance of inbred lines for hybrid production. Inadequate maintenance of parental stocks of hybrids and varieties will result in inferior performance, which is not compatible with increased maize production.

In order to produce good quality basic seed, it is essential to develop adequate experiment station facilities and management and satisfactory storage facilities. Such facilities could be organized on a regional basis within a country, where the appropriate material is increased and stored near the area where it will be used; this places less burden on the transport system.

Much of the work necessary to achieve increased maize production can and must be executed at a regional or local level. However, the whole system requires centralized organization, where appropriate analyses and conclusions can be made for the development and maintenance of an increasingly efficient program.

D. Government Policy

Ultimately, any program for increased maize production will succeed or fail depending on government policy. The task of improving maize production cannot rest solely with the farmer. For farmers to increase maize yields a host of factors must be in order. Appropriate technologies must be available to the farmers and must be acceptable to them. Critical inputs must be available and at appropriate prices. Markets must be in place to accomodate increased flows of product. Infrastructure must be strengthened so as to handle vastly increased demands for services. All of these things and more must be in place if farmers are to move forward with more intensive production practices and to attain the accompanying higher yields.

The farmer is interested in feeding himself and his family and in producing enough maize for his own needs. He also is interested in improving conditions for himself and his family, and he will grow excess maize if he can sell it at a profit. He will buy superior quality seeds and inputs and adopt practices to increase production if it is profitable for him.

This is largely, if not wholly, the responsibility of government. Grain prices are generally under government influence, as are the costs of the various inputs. Simple calculations can show the relative prices which would assure the farmer a satisfactory profit, provided that he follows suitable agronomic practices.

The availability of the input is not enough. The farmer must have a cash flow to be able to buy them. This will require the organization of a credit system which could be facilitated by government assistance.

Increased Maize Production Can Become a Reality

In conclusion, let me emphasize the fact that increased maize production in Latin America can become a reality. It is time for the countries of Latin America to pay close attention to all the links necessary for increased maize production and begin to strengthen each one. This task begins with the creation of an integrated research system with results that ultimately flow to the farmers' production fields. In this manner, sustained increases in maize production can be ensured for the future of Latin America.