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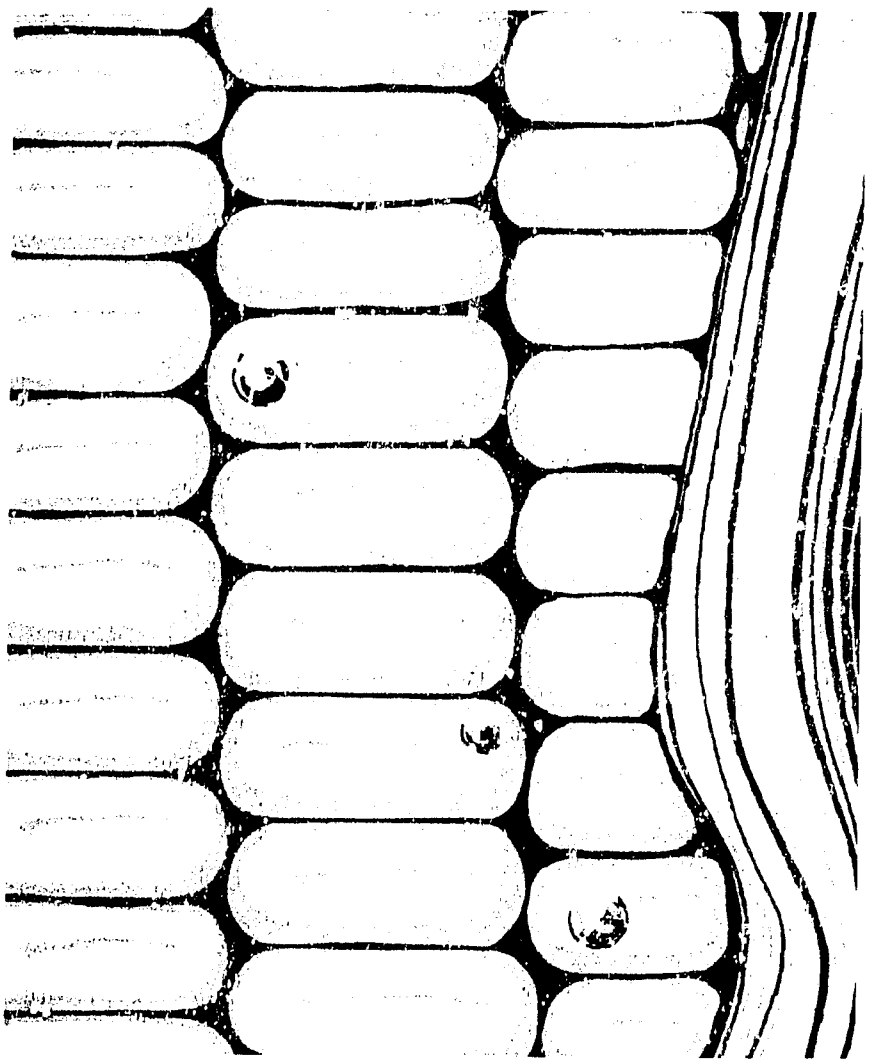
CIMMYT Report on Maize Improvement



1982-83

The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. It is one of 13 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 40 donor countries, international and regional organizations, and private foundations.

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Introduction

By the end of the two-year period covered in this report, the maize breeding and international testing scheme initiated by CIMMYT during the early 1970s had been in operation for about a decade. That is not a very long period in the life of a breeding program, but it has given the Maize Program sufficient time to make good progress toward some of its key objectives.

A primary concern of CIMMYT maize staff 10 years ago was to make available a wide array of broadly adapted, improved germplasm to breeders in developing countries. That goal has largely been accomplished through the development of gene pools and advanced populations, each of which is adapted to one of the Third World's approximately 15 *mega-environments* (globally dispersed areas characterized by relative uniformity in conditions, such as climate and length of growing season, that determine maize germplasm requirements). Progeny of the populations and experimental varieties developed from them have been distributed in hundreds of trials to scores of national programs, many of which have taken part in international maize testing, not only as recipients of the germplasm, but as participants in its improvement. National scientists are employing the products identified through the testing system by selecting them for adaptation to specific maize-growing environments and either releasing them directly as varieties or incorporating them into breeding programs.

Good progress has been made in improving the performance of the products now being delivered to maize breeders in developing countries. As indicated by the results of evaluations described in this report, the yields of most of the populations have been raised signficantly, and some improvement has been brought about in their adaptation to low-yielding environments. In addition, projects are underway at locations away from CIMMYT headquarters for development of disease-resistant materials that cannot be developed in Mexico.

Important achievements have also been registered in the development of quality protein maize (QPM). Notable progress has been made in overcoming the deficiencies of the original opaque-2 materials with which the Center initiated its work on this type of maize in the early 1970s, and as with the normal germplasm, a wide array of QPM types have been made available to national programs.

As the Maize Program's strategies for developing and delivering germplasm and other products began to take shape during the 1970s, so did its approaches to improving the capacity of national maize programs to make effective use of these products.

In a sense the development of those two functions—the creation of research products and support of research cooperators—followed parallel courses. For producing improved maize germplasm to meet the diverse requirements of the Third World, the most logical approach found was to organize the gene pools and populations on the basis of mega-environments. Likewise, it was decided that the greatest number of national programs could be strengthened in the shortest time through extensive regional programs, each of which would provide a range of services in numerous countries. To establish a separate project for each important maize-producing nation would have been no more practicable than developing improved maize varieties for every ecological niche in the Third World. Limited resources would not have permitted us to achieve either goal in a reasonable amount of time.

Because it is attempting to satisfy global needs for germplasm and research support, the Maize Program's resources must obviously be spread very thin. That circumstance does not necessarily imply slower progress in the development of global maize research and production than could be achieved through more concentrated investment in fewer countries. On the contrary, we are convinced that broadly adapted germplasm and fairly modest levels of support offered on a regional basis encourage efficient use of the research resources available in developing countries. The germplasm distributed by CIMMYT constitutes vital raw material for national breeding efforts, and the Center's regional programs provide a framework for germplasm exchange and other forms of cooperation whose end result is to multiply the benefits of investment in research. Of course, both of those strategies assume considerable commitment from national programs, which has been very much in evidence in the Maize Program's germplasm development efforts and in the activities of its regional networks.

Germplasm Bank

The main functions of the bank are to maintain landraces of maize and to supply useful germplasm to scientists at CIMMYT and elsewhere in the world for maize improvement or other research. At the end of 1983, the bank held in storage just over 10,200 accessions of maize and its wild relatives. During 1982-83 bank staff responded to requests for a number of those accessions, distributing a quarter of a million seeds in 1,155 samples to 29 countries. This germplasm was requested for numerous purposes, ranging from breeding and evaluation to very basic research.

Bank Accessions

Materials in the bank are referred to as accessions and assigned a CIMMYT accession number only after they have been successfully regenerated. About 94% of the accessions currently held are regenerations from the bank's original collections, and about 5% are groups formed during 1960-63 by recombining two or more collections of similar morphology and geographic distribution. The remaining 1% are composites formed on the basis of various traits or racial criteria. One or more of the collections considered typical of a group or composite are maintained as individual accessions; the other component collections have been discarded. The majority of the accessions are of *Zea mays* from Mexico and Brazil, although materials from some 55 other countries are included as well (Table 1). This germplasm is kept in two cold storage chambers, which have a combined volume of 244m^3 and are maintained at a temperature of 0° to 3°C, with an average relative humidity of 32%.

Regeneration of Accessions

During 1982 and 1983, as in previous years, bank staff devoted most of their time to regenerating and observing bank accessions. The longer the period between these regenerations the better, since the accessions are likely to undergo changes in their character and genetic composition as a result of genetic drift if they are regenerated too frequently. From time to time, however, it is necessary to regenerate the accessions because of the relatively low number of seeds kept in storage for meeting seed requests and the poor germination of seed that has been stored for a long period.

The results of germination tests indicate that in our present facilities seed of good quality can be kept viable for longer than 20 years. Thus, given the total number of accessions in the bank, approximately 500 of them must be regenerated each year in order for each accession to be regenerated once every 20 to 22 years. The Maize Program receives assistance in meeting its annual goal from the Pioneer Seed Company in the USA.

The accessions to be regenerated are chosen according to the age, quality, and viability of the seed. When possible, those selected are regenerated by growing 256 plants in 16 rows 5 m long. Bulk half-sib pollination is used, and selfing is avoided. In the process, some 125,000 hand-pollinations are done, and agronomic data are recorded. Approximately the best 10% of the materials are selected for further evaluation and crossing with appropriate gene pools in the breeding program. The best of those materials are then selected for introgression into the Maize Program's breeding materials.

Long-Term Plans

In 1983 we started regenerating some accessions for the second time. In most cases there was an obvious difference between percent germination and percent emergence in the field. This discrepancy underscores the need for more basic research on bank materials to find better ways of managing, maintaining, and evaluating the accessions. In fulfillment of its long-term commitment to the germplasm bank, the Maize Program is planning to increase its emphasis on some types of basic research (relating to the regeneration and evaluation procedure) and to markedly improve the bank's facilities.

Table 1. Sources of accessions in the maize germplasm bank

Country	Number of accessions
Afghanistan	19
Angola	6
Antigua	10
Argentina	93
Austria	7
British Virgin Islands	53
Bahama	1
Barbados	13
Bolivia	76
Brazil	2246
Chile	63
China	25
Costa Rica	387
Colombia	121
Congo	1
Cuba	171
Dominican Republic	99
Ecuador	368
Egypt	1
El Salvador	79
Ethiopia	29
French Guiana	9
Germany, West	6
Grenada	21
Guadeloupe	21
Guatemala	470
Guyana	13
Haiti	38
Honduras	118
India	2
Israel	4
Jamaica	9
Lebanon	7
Malawi	5
Mali	58
Martinique	2
Mexico	3489
Nepal	212
Nicaragua	73
Nigeria	1
Pakistan	2
Panama	152
Paraguay	99
Peru	196
Philippines	3
Puerto Rico	31
Saint Croix	13
Saint Lucia	7
Saint Vincent	16
Surinam	11
Tobago	19
Trinidad	40
United States	26
Uganda	4
Uruguay	836
Venezuela	270
Yemen	2
Total	10,153

Gene Pool Development and Improvement

Handling of gene pools is the main task of the backup unit within the Maize Program. Traditionally, this unit has served two purposes: (1) providing superior genotypes to the advanced unit, which is responsible for the improvement of advanced populations, and (2) maintaining useful genetic diversity, a vital precondition of success in the Program's germplasm improvement efforts.

Each gene pool is a broad-based germplasm complex formed through the genetic mixing of diverse varieties, varietal crosses, and hybrids having similar climatic adaptation, maturity, grain color, and grain texture. Currently, the Program maintains 33 gene pools: 9 for the tropical highlands, 12 for tropical lowlands, 8 for the subtropics, and 4 special gene pools for the temperate zone. An additional 13 quality protein maize (QPM) pools have been developed, 7 for the tropics and 6 for the subtropics. (Detailed descriptions of the normal pools are given in Appendix 1, and work on QPM materials is discussed in another section of this publication.)

Introduction Nurseries

Although most of the efforts of the backup unit go into the development and improvement of gene pools, it also attends to the more preliminary work of maintaining introduction nurseries. These nurseries are the means by which new germplasm is regularly incorporated into the gene pools to increase their genetic diversity.

The nursery entries, which are obtained from various sources around the world and also from the germplasm bank's regeneration plots, are planted at CIMMYT's experiment stations in Mexico. To avoid introducing any new diseases into the country, the introduction nurseries are planted in isolation, and plants showing disease symptoms are rogued. Each introduction occupies two rows 5 m long. Ten-row bulks of each pool are planted next to the introduction nursery.

The materials are evaluated for various characteristics, such as maturity, disease and insect pest reaction, height, grain color and texture, and yield potential. Promising materials are crossed and

Ear rot resistance is one of the main selection criteria in the improvement of CIMMYT's tropical and subtropical gene pools. Here Carlos De Leon demonstrates artificial infection of ear shoots with ear rot.

introgressed into the appropriate gene pools (Table 2). Superior progeny are harvested and planted the following season as female rows in the corresponding pools. This procedure prevents the introgression of untested materials into the pools and makes it possible to compare the F_1 progeny with the pool while they are being backcrossed. At harvest ears from selected F_1 progeny either of crosses between the pools and introductions, or of the backcrosses of the introductions to pools, are included in the pollinator for the next cycle of recombination.

Tropical and Subtropical Pools

The tropical and subtropical pools are improved by means of a modified half-sib method of selection. The 400 to 500 families that make up each pool (we have found this number to be both manageable and sufficient for maintaining genetic diversity) are planted in an isolated block in a ratio of two female rows to one male row. All families are represented in the female rows, and the pollinator rows are planted to a balanced seed mixture of selected families. Each family is planted in a 5-m row (with plants 33 cm apart), which is later thinned to leave 16 plants per family. All female rows and plants in pollinator rows that show undesirable traits before flowering are detasseled.

Most pools are grown at more than one of CIMMYT's experiment stations in Mexico. At each location superior families are selected by a multidisciplinary team of scientists, who take into account yield potential, height, maturity, uniformity, lodging, and reaction to diseases, insect pests, and other

Table 2. Origin of new germplasm added to tropical and subtropical gene pools, 1981-83

	Number of entries added to particular pools																				
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Africa																					
Burkina Faso	5	1	3	2		5	3	2	2	3		4	3	3			7	7	8	6	64
South Africa				1		6	2	2		4	2	3	1					2	7	7	35
Kenya																		2			2
Mozambique						1					1								1		4
The Americas																					
Nicaragua														1						1	
Dominican Rep.												4									4
Uruguay	12		6	3		10	5	11		4	3	11	19	8			23	39	40	42	236
Mexico	1		1	2	1	4	1	2	4	4		2		2	3	2	3	3	3	5	44
El Salvador						3															3
Panama										1		1							1	1	4
USA	3	10	13	14	6	11	8	18	1	12	6	18	9	10	11	25	8	12	20	34	249
Colombia	1	1	2	1	1	2	2	2	2	2	2	2		1	1			1			23
Brazil	1			2		2	1			2	1	2						2	5	4	22
Costa Rica						1	1	1	1	1		1						1		1	8
Honduras														1							1
Argentina																		1			1
Peru																		7	6	6	19
Asia																					
India	10	8	7	5	9	8	3	7	7	5	7	5	12	11	10	3	12	7	5	5	146
Indonesia	1	8		1	2	1							1	1	1		1	2	1		13
Philippines	3	6		1	5	2	1						3	2	1		2	3	1		31
Thailand	3	2	2	3	3	3	1	2	2		2		1	1	1	1	2	2	2	2	36
Pakistan	5	2	1	1	2	3		1	1	1		1	3	4		1	2	4	1	1	34
China	1	2	1	2		3	2	1	1	2	4	2	3	1			4	7	7	8	51
Nepal	3	1	4	1		4	4	1	3	4	7	4	2	1			7	7	7	7	67
Australia								3		1		2						1	2		9
Europe																					
Hungary	4	4	1	6	7	4							6	5			1	2	3	1	44
France	1	1	1	1	1	1							1	1			1		2	2	13
Switzerland	3	3	3		1								3						2		14
Germany, West																					
Yugoslavia					1								1	1		2		1			6
Total	57	42	45	46	39	74	34	53	24	46	37	63	68	54	28	34	73	111	124	133	1185

stresses at the appropriate stages of plant development. The best plants at each location are selected only among those families that have performed well across all locations. At harvest the best ears are chosen from the selected plants for each pool at each site.

The pools are subjected to pressures from various diseases occurring in Mexico. Table 3 lists some of the disease complexes found at the different locations where staff of the backup unit plant the gene pools and select for disease resistance. Pools that are highly susceptible to certain diseases are inoculated artificially for resistance screening.

Selection pressure in the pools is kept fairly mild to minimize the loss of attributes or genes that are needed for further advancement of the pools at a later stage. Approximately 30% of the families are selected in each cycle. Selection within families is practiced during plant development. Good plants in selected families are tagged, and at harvest two to four ears (from tagged plants when possible) are collected from each selected family. Those ears constitute the families for the next cycle of selection.

When the pools are considered to have adequate agronomic characteristics and resistances, either new advanced populations are extracted from them or superior fractions of the pools are merged into existing populations that are undergoing improvement and international testing (Table 4). The following sections describe the work done during 1982-83 to bring the tropical and subtropical pools up to that level of refinement.

Early maturity—In all four early tropical pools and the four early subtropical pools, approximately 1000 of the earliest silking plants are identified in the female rows. They are harvested soon after physiological maturity, and ears with good husk cover and the best rate of grain filling and drying are selected. Selection pressure for earliness is also applied by detasseling all male rows when approximately 70% of the female rows have silked, ensuring that late-flowering females do not receive pollen from late-flowering male plants. Since early maturing maize is generally more susceptible to stalk rots, greater emphasis has been placed recently on selecting plants with the "stay green" characteristic (that is, plants that remain green after the ear has already become dry), which tend to be less susceptible to these diseases.

Synchronization of pollen shed and silking—In all early pools, the male rows are planted at a density double that of the female rows. This has proven to be an efficient tool for improving synchronization of pollen

Table 3. Experiment sites and diseases for which selection for resistance is practiced

Site	Disease
Toluca 2640 masl 19°N latitude	Common rust (*Puccinia sorghi*) Ear rot (*Fusarium graminearum*) Stalk rot (*F. graminearum*)
El Batán 2249 masl 19°N latitude	Common rust (*Puccinia sorghi*) Ear rot (*Fusarium graminearum*) Stalk rot (*F. graminearum*)
Tlaltizapán 940 masl 19°N latitude	**Rainy season** (May-September) Ear rot (*F. moniliforme*) Stalk rot (*F. moniliforme*) Brown spot (*Physoderma maydis*) Maize dwarf mosaic virus Stunt disease **Off-season** (October-March) Ear rot (*F. moniliforme*) Stalk rot (*F. moniliforme*) Fine stripe virus Maize dwarf mosaic virus Stunt disease
Poza Rica 60 masl 21°N latitude	**Rainy season** (May-September) Ear rot (*F. moniliforme*) Stalk rot (*F. moniliforme*) Maydis leaf blight (*Helminthosporium maydis*) Polysora rust (*P. polysora*) Stunt disease Rayado fino virus **Off-season** (October-March) Turcicum leaf blight (*H. turcicum*) Maydis leaf blight (*H. maydis*) Tar spot (*Phyllachora maydis*) Stalk rot (*F. moniliforme*) Ear rot (*F. moniliforme*)

Table 4. Materials introduced from gene pools into advanced populations, 1981-83

Pool number	Population number	Number of families
26	24	27
25	27	41
26	28	44
33	33	24
22	36	29
34	45	33
32	47	30
30	48	50

shed and silking on the same plant. All plants in the male rows that are lodged, diseased, or otherwise undesirable and those showing poor synchronization are detasseled. At harvest ears are selected only from female rows observed to be superior during plant development. In addition to improving synchronization of flowering, this approach results in gradual improvement of the pools for performance under variable plant densities.

Fall armyworm resistance—Selection for resistance to fall armyworm (*Spodoptera frugiperda*) is being practiced in two late tropical pools (24 and 26). All plants in the male rows and half of the plants in the female rows are artificially infested at the seedling stage before thinning. Two to three weeks after infestation, the more susceptible of the two plants in each hill of the male rows is removed, a procedure that eliminates nearly 50% of the susceptible plants in those rows before they tassel. The noninfested half of all female rows is protected with insecticide and serves as a check for gauging the effect of infestation on the agronomic performance (that is, maturity, plant height, and yield) of the family. The plants that perform best in the selected families are identified at the flowering stage. At harvest ears showing desirable traits are selected from those selected plants. This guideline cannot always be followed, however. In many cases the ears produced by plants in the infested portion of the row do not develop to normal size, and yet the plants show a certain degree of tolerance to the damage caused by armyworm feeding.

Sugarcane borer resistance—Selection for resistance to this borer (*Diatraea saccharalis*) is being practiced in Pools 19 and 21, which are of intermediate maturity. Plants are artificially infested after thinning but before flowering. The infestation, evaluation, and selection procedures are similar to those followed for fall armyworm.

Table 5. Progress per cycle in the improvement of gene pools

Pool number	No. of cycles[b]	Yield	Progress per cycle (%)[a] Days to silk	Plant height	Disease resistance
15	11	3.26	-0.56	-0.90	-1.44
16	11	4.36	-0.28	-0.43	-1.67
17	11	5.65	-0.42	-0.12	-2.00
18	11	6.35	-0.57	-0.06	-2.15
20	15	1.16	-0.63	-0.77	-1.46
22	16	1.05	-0.42	-0.53	-1.43
23	15	0.23	-0.36	-1.02	-1.37
25	14	1.41	-0.39	-0.54	-3.02
29	11	0.09	-1.05	-0.63	-2.87
30	11	2.93	-0.66	0.06	-1.87
33	16	1.44	-0.67	-1.17	-2.27
34	16	4.24	-0.73	-1.14	-3.27

Note: Pools 15, 16, 17, 18, 22, 23, and 30 were inoculated with stalk rots and Pools 20, 25, 29, 33, and 34 with ear rots.

a The last cycles of selection were significantly different at the 0.05 level of probability in most cases, the exceptions being yield in Pools 23, 29, and 33; plant height in Pools 16, 17, 18, 20, 25, 29, and 30; and disease resistance in Pools 29 and 30.

b Does not indicate the number of cycles of selection for specific disease resistances under artificial inoculation.

Table 6. Results of an evaluation of cycles of selection in early maturing tropical pools, Poza Rica, summer and winter cycles, 1982

	Yield (kg/ha)[a]	Days to 50% silk	Plant height (cm)	Disease rating[b]
Pool 15				
C0	2698 b	65 a	172 a	3.8 a
C5	3728 a	65 a	157 b	3.7 a
C8	3687 a	64 a	157 b	3.3 b
C11	3668 a	61 b	155 b	3.2 b
C.V.(%)	14	2	5	6
Pool 16				
C0	2943 c	65 a	170 a	3.8 a
C5	3824 b	65 c	161 a	3.5 a
C8	4095 ab	64 a	162 a	3.1 b
C11	4354 a	63 b	162 a	3.1 b
C.V.(%)	8	1	5	7
Pool 17				
C0	2278 c	65 b	152 a	4.1 a
C5	3155 b	66 a	157 a	3.8 b
C8	3331 ab	64 c	147 b	3.6 b
C11	3695 a	62 d	150 ab	3.2 c
C.V.(%)	11	2	3	7
Pool 18				
C0	2301 c	64 a	146 a	3.8 a
C5	3741 b	65 a	149 a	3.4 ab
C8	3484 b	64 a	147 a	3.2 bc
C11	3908 a	61 b	147 a	2.9 c
C.V.(%)	8	2	5	7

Note: Values followed by different letters are significantly different at the 5% level of probability.

a At 15% moisture.

b Stalk rot rated on a scale of 1-5, with 1 = no fungus development and 5 = complete destruction of tissue.

Ear and stalk rot resistance— Tropical Pools 15, 16, 17, 18, 22, and 23 and subtropical Pool 30 are being improved primarily for stalk rot resistance and tropical Pools 20, and 25 as well as subtropical Pools 29, 33 and 34 for resistance to ear rot. With both diseases (caused by *Fusarium moniliforme*), one can expect progress to be slow since parental control of resistance is restricted to the female. Since the two diseases normally occur after flowering, selection of resistant plants in the male rows is impossible before or during pollen shed.

When the silks are fully expanded, plants are inoculated with ear rot by injecting 2 ml of inoculum (containing 500,000 spores/ml) with a syringe into the ear shoots. Inoculation with stalk rot is done when the tassels appear; wooden toothpicks on which the fungus has been grown are inserted into an opening made in the center of the first elongated internode with a hand-drill having a 3/32-inch bit. Only half of the plants in each family are inoculated. In screening for ear rot resistance, only relatively clean ears are selected from plants showing good agronomic traits, and in selecting for resistance to stalk rot, all ears are rejected that come from broken, rotten plants, show poorly filled tips, and/or have kernels that are not tight and compact, an indication that the stalk was infected.

In the summer and winter of 1982, different cycles of selection in several pools were evaluated to detect gains made through selection for stalk rot resistance and other agronomic characters. Results given in Table 5 for the early tropical Pools 15, 16, 17, and 18 (which, as mentioned previously, are being improved for stalk rot resistance) indicate that their yields increased by an average for all four pools of 4.91% per cycle. Pool 18 showed the maximum rate of gain per cycle (6.35%) and Pool 15 the lowest (3.26%). Even the lower rate of progress, though, is considered satisfactory for the system of improvement being used. As indicated by data given in Table 6, the last cycles of all four pools were higher yielding and earlier in maturity than the original cycles

Table 7. Results of an evaluation of cycles of selection in two intermediate and two late-maturing tropical pools, Poza Rica, summer and winter cycles, 1982

	Yield (kg/ha)[a]	Days to 50% silk	Plant height (cm)	Disease rating[b]
Pool 20 (interm.)				
C0	3748 b	74 a	190 a	32 a
C7	3593 b	70 a	169 a	26 a
C10	3909 a	68 b	166 a	32 a
C15	4398 a	67 b	168 a	25 b
C.V.(%)	13	1	4	31
Pool 22 (interm.)				
C0	4634 b	74 a	199 a	3.5 a
C7	4985 ab	70 ab	177 b	3.2 b
C12	4934 ab	71 ab	177 b	3.1 b
C16	5414 a	69 b	182 b	2.7 c
C.V.(%)	10	1	4	6
Pool 23 (late)				
C0	5065 a	74 a	202 a	3.4 a
C7	4701 a	71 b	182 b	3.4 a
C11	5010 a	70 b	169 c	2.9 b
C15	5242 a	70 b	171 bc	2.7 b
C.V.(%)	7	2	4	7
Pool 25 (late)				
C0	3462 b	74 a	200 a	26 a
C7	3347 b	73 ab	192 a	23 ab
C9	3666 ab	71 bc	183 a	22 ab
C14	4144 a	70 c	185 a	15 b
C.V.(%)	12	2	7	36

Note: Values followed by different letters are significantly different at the 5% level of probability.

a At 15% moisture.

b Stalk rot rated in Pools 22 and 23 on a scale of 1-5, with 1 = no fungus development and 5 = complete destruction of tissue. Percentage of rotten kernels per ear recorded for Pools 20 and 25.

Across all four pools evaluated, the gain in yield was accompanied by an average decrease per cycle of -0.46% in days to flowering and -0.35% in plant height (Table 5). As can be seen from the data in Table 7, however, plant height was reduced significantly only in Pool 15. The four pools registered significant improvement in stalk rot resistance as well. Reduction in disease rating per cycle averaged -1.82% for all four pools (Table 5), and the resistance of the last cycle of each pool was significantly better than that of the original (Table 6).

Results for tropical Pools 20 and 25 (in which selection for ear rot resistance was practiced) and Pools 22 and 23 (improved for resistance to stalk rot) show that the last cycles of selection were significantly better than the original ones in yield, with the exception of Pool 23, and were earlier in maturity (Table 7). Reduction in plant height was significant only in Pools 22 and 23. But in all four pools, significant progress was made in improving disease resistance; the average improvement per cycle for the four materials was -2.24% for ear rot and -1.40% for stalk rot (Table 5).

Among the subtropical Pools 29, 30, 33, and 34, only Pools 30 and 34 showed significant gains in yield

(Table 8). All four, however, were earlier in maturity, while plant height in Pools 33 and 34 was lower in the last cycles than in the original ones. For all four materials, the average progress per cycle was 2.18% for yield, -0.78% for reducing time to maturity, and -0.72% for plant height reduction (Table 5). Pool 30, which had been inoculated with stalk rot, showed small progress per cycle in improvement of resistance. In the other three subtropical pools, all inoculated with ear rot, the disease rating was decreased by an average of -2.92% per cycle.

Resistance to turcicum leaf blight and common rust—The Program's eight subtropical gene pools show reasonable levels of resistance to leaf blight (*Helminthosporium turcicum*) and common rust (*Puccinia sorghi*) as well as to ear and stalk rots. To increase their levels of resistance to the foliar diseases, the pools are artificially infected and screened in disease nurseries. Selection for turcicum leaf blight is done in a nursery planted during November at the Poza Rica station, where conditions for the disease are optimum. Plants are inoculated at four-day intervals alternately with ground turcicum-infected leaves and 5-ml doses of inoculum (adjusted to 70,000 spores/ml), which are produced in the laboratory and placed on the whorl of three- to four-week-old plants. In April-May the common rust nursery, consisting of half-sib recombination blocks, is planted at the El Batán station. When plants reach the knee-high stage, all are artificially infected with 5 ml of inoculum (adjusted to 70,000 spores/ml), which is prepared from uredospores collected the previous year. During both seasons in which the disease nurseries are being grown, the subtropical pools are also planted at the Tlaltizapán station to maintain their wide adaptation and to select for other agronomic characters.

Table 8. Results of an evaluation of cycles of selection in two early and two intermediate-maturity subtropical pools, Tlaltizapán, summer and winter cycles, 1982

	Yield (kg/ha)[a]	Days to 50% silk	Plant height (cm)	Disease rating[b]
Pool 29 (early)				
C0	3083 a	69 a	158 a	19 a
C5	3120 a	63 ab	154 a	20 a
C8	3097 a	63 ab	157 a	19 a
C11	3114 a	61 b	147 a	13 a
C.V.(%)	13	2	10	15
Pool 30 (early)				
C0	2399 b	69 b	148 a	3.4 a
C5	2817 a	64 b	154 a	3.3 a
C8	2886 a	65 b	140 a	3.1 ab
C11	3173 a	64 b	149 a	2.7 b
C.V.(%)	9	3	8	10
Pool 33 (interm.)				
C1	3156 a	75 a	198 a	22 a
C7	3904 a	71 ab	175 b	20 a
C10	4131 a	69 ab	176 b	19 a
C16	3883 a	67 b	161 b	14 a
C.V.(%)	12	2	5	34
Pool 34 (interm.)				
C1	2877 b	77 a	202 a	21 a
C7	4055 ab	73 ab	178 ab	18 ab
C10	4114 ab	71 ab	169 b	14 ab
C16	4827 a	68 b	165 b	10 b
C.V.(%)	16	2	6	59

Notes: Values followed by different letters are significantly different at the 5% level of probability.

a At 15% moisture.

b Stalk rot rated in Pool 30 on a scale of 1-5, with 1 = no fungus development and 5 = complete destruction of tissue. Percentage of rotten kernels per ears recorded for Pools 29, 33, and 34.

Table 9. Incidence of turcicum leaf blight in eight subtropical pools, Poza Rica, summer cycle, 1984

Pool number	Cycle of selection: Initial	Interm.	Latest	Pool LSD (5%) = 0.398
27	3.63	3.13	3.11	3.29
28	3.36	3.37	3.55	3.43
29	3.98	3.95	3.48	3.80
30	3.52	3.23	3.11	3.29
31	2.48	2.31	2.11	2.30
32	2.07	2.08	1.91	2.02
33	3.12	2.84	2.75	2.90
34	2.90	2.56	2.24	2.57
Cycles	3.13	2.93	2.78	

LSD (5%) = 0.184

LSD (5%) among means for cycles of same pool = 0.522

Note: Disease incidence was rated on a scale of 1 to 5, with 1 = resistant and 5 = susceptible.

in the winter of 1983, the various cycles of selection in the subtropical pools were evaluated for turcicum blight resistance at Poza Rica. The trials had a split-plot design, with pools as main plots and cycles of selection as subplots. The results of this evaluation (given in Table 9) indicate that, with the exception of Pool 34, no significant gain in turcicum resistance was made between the initial and latest cycle of selection. There was, however, a significant difference in susceptibility between early and intermediate-maturity pools, the early ones being more susceptible. A preliminary evaluation of the subtropical pools for resistance to common rust showed that some progress had been made between the original and advanced cycles of both the early and intermediate pools (Figure 1).

The failure to improve turcicum resistance significantly over various cycles of selection in a given pool has resulted from the way in which the materials are handled. The disease-resistant selections made at Poza Rica are recombined with those made at Tlaltizapán, where selection is carried out mainly for desirable agronomic characters in a disease-free environment. This same approach is followed in selection for resistance to common rust, and a critical evaluation of cycles of selection would probably show, as with turcicum, that no significant progress in resistance has been achieved.

Tar spot resistance—This foliar disease (caused mainly by *Phyllachora maydis*) creates considerable problems at the Poza Rica station in Mexico and has also been reported recently in other countries, where it is raising some concern among maize growers. Several highly resistant families have been identified in the population Selección Precoz QPM. This character has now been incorporated into all tropical pools, and families selected at the BC_2 stage have been added as components of the male bulks. In addition, studies are being conducted on the inheritance of resistance to the disease.

Temperate Pools

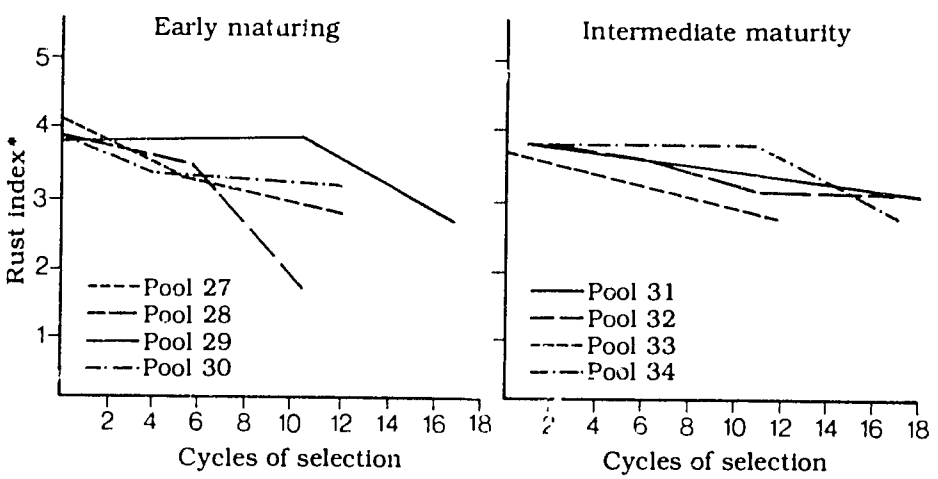
Most maize materials cultivated in the USA and Europe have a narrow genetic base, which limits the possibilities for further improvement and could make the materials highly vulnerable to new problems. Under cooperative arrangements with maize researchers working in the temperate zone, the Maize Program has developed four temperate gene pools that can be used by those researchers to broaden the genetic base of their germplasm and avert problems arising from its lack of variability.

All four temperate pools (see the descriptions in Appendix 1) are handled by means of a shuttle breeding system. Selected entries are recombined in a winter nursery planted during November at Tlaltizapán. Seed of selected families is sent to various countries for planting in May either as modified ear-to-row half-sib recombination blocks or as bulks of the selected families. Cooperators make plant-to-plant crosses or self-pollinate desirable plants. To maintain the broad adaptation of the pools, half-sib recombination blocks are also planted at El Batán and Tlaltizapán. At El Batán all plants in the female and male rows are artificially infected with common rust. After selected families are harvested at the various locations, seed is sent back to Mexico to be planted in a crossing block during the winter at Tlaltizapán for recombination of the selections made at all locations.

What follows is a brief summary of details on recent work with the four temperate pools:

- Pool 39 is for the southern temperate region and consists of approximately 40% tropical highland, 40% temperate, and 20% subtropical germplasm. Until 1980 it had only been recombined and selected at El Batán and Tlaltizapán. During the summer of 1982 and 1983, seed of families and/or their bulks were sent for selection to cooperators in California, Texas, Mississippi, and Tennessee, among other locations.
- Pool 40 is for the intermediate temperate region and is made up mainly of germplasm from Europe. Sets of selected families and/or their bulks were distributed to cooperators in Minnesota, Kansas, New York, southern France, and other locations for recombination, selection, and utilization.

Figure 1. Common rust (*Puccinia sorghi*) infection in cycles of selection in subtropical pools, El Batán, 1982



* 1 = no disease and 5 = very heavy infection.

- Pool 41 is for the northern temperate region and is composed mainly of germplasm from the US Corn Belt and of several materials from Asia. Sets of selected families and/or their bulks were distributed to collaborators in France and other countries for recombination, selection, utilization.
- Pool 42, also for the northern temperate region, was developed by putting together entries from the highlands of Mexico and South America and adding to them some US and Asian germplasm. During the summer of 1982 and 1983, selected families and/or their bulks were sent to cooperators in France, the Netherlands, Switzerland, West Germany, and other countries for recombination, selection, and utilization.

Good progress has been made in selection for earliness, standability, cold tolerance, and other desirable agronomic characters. Some of the pools are already being used by cooperators as sources of tropical and subtropical germplasm for transfer into temperate materials.

Highland Pools

During the late 1970s and early 1980s, eight gene pools (differing in time to maturity, grain type, and grain color) were developed for the Andean highlands. These materials were formed by intercrossing the main germplasm components for a particular grain type with other donor entries (For a detailed account of the establishment of these pools, see *CIMMYT Report on Maize Improvement, 1980-81*, pages 81-82).

A shuttle breeding system for the Andean pools—Initially, selection pressure was fairly moderate to allow genetic recombination among the entries. Currently, the pools are being improved by means of modified half-sib recurrent selection within a shuttle breeding system in which the Maize Program cooperates with Ecuador's National Institute of Agricultural and Livestock Research (INIAP). With this system, one cycle of multilocational crossing and selection is completed each year.

Families of all highland pools are planted around the end of March at the Maize Program's two highland stations in Mexico (El Batán and Toluca) and harvested in September. At El Batán a half row of each half-sib family is artificially infested with earworms, *Heliothis zeae*, and at Toluca a half row of the same families is inoculated with ear rot (*Fusarium graminearum*). These two pests are major problems of maize in the Andean highlands.

Seed of all pools is harvested in Mexico during September-November and sent to the Santa Catalina Experiment Station in Ecuador for immediate planting. Selections made in one country are recombined with those of the other each year to take advantage of two different growing seasons, one in the northern and the other in the southern hemisphere.

Each year the male composite is made up of a balanced mixture of seed from the male selections made at El Batán and Santa Catalina. That was not the case, however, for the 1982-83 plantings at Santa Catalina, since the crop grown at El Batán had been damaged by hail. Instead, for the plantings in Ecuador, we used only the selections made at Santa Catalina for the male composite and the selections made at El Batán as the female. Then, in 1983 at El Batán and Toluca, we planted the balanced male composite consisting of selections from Santa Catalina, El Batán, and Toluca.

In each cycle no fewer than 400 half-sib families from each gene pool were evaluated. By 1983 Pools 1, 2, and 4 had undergone three cycles of improvement, Pools 3 and 6 four cycles, and Pools 7 and 8 one cycle.

Maturity time of Andean pools—In Pools 1 to 4 and 6, this characteristic varied somewhat between 1982 and 1983 at Santa Catalina (Table 10), where the experimental plots differ in topography and elevation (2650 to 2850 m). In 1983 the mean number of days to flower for Pools 5, 7, and 8 was lower than in 1982. Pool 5 flowered earlier perhaps because it was planted in a plot at a lower elevation than in 1982. The earlier flowering of Pools 7 and 8, on the average, probably resulted from incorporation of CIMMYT selections (largely flint and dent grain types). Pool 2 remained intermediate in

Table 10. Plant characteristics of the Andean highland gene pools, Santa Catalina, Ecuador, 1982-83

Pool number	Days to flower 1982	Days to flower 1983	Plant height (cm) 1982	Plant height (cm) 1983	Ear height (cm) 1982	Ear height (cm) 1983	Ear proliferation (%)[a] 1982	Ear proliferation (%)[a] 1983	Tillering (%)[b], 1983
1	88.9	90.7	206.6	196.7	111.4	103.9	29.4	29.6	12.7
2	101.3	103.1	218.1	243.9	122.4	135.0	7.5		9.4
3	89.0	91.3	197.3	179.8	104.9	93.0	30.6	15.1	5.8
4	108.2	108.2	238.5	241.5	139.8	137.1	12.5	7.5	2.1
5	94.2	87.8	197.6	222.8	105.0	123.0	15.6	21.5	10.4
6	85.6	88.6	198.4	193.5	102.3	101.9	18.8	15.1	4.3
7	105.7	101.5	199.4	214.5	113.6	120.3	5.9	11.3	3.5
8	109.4	102.3	262.9	194.1	124.5	108.0	6.3	14.3	4.5

a Percentage of the average number of plants showing ear proliferation in a row of 16 plants.
b Percentage of the average number of plants tillering in a row of 16 plants.

maturity. With the exceptions of Pools 2 and 5, all the pools approached the maturity times for which we are aiming, 90 days to flowering for early materials and 110 days for late ones.

Undesirable traits in Andean pools—Ear proliferation, considered an undesirable characteristic in these pools, was observed in all of the materials. It has varied in frequency from year to year at Santa Catalina but seems most pronounced in the early pools, which contain a greater share of the Mexican highland germplasm than do the other materials.

The early pools also exhibit a greater tendency toward tillering. Selection against this trait and ear proliferation is being practiced in every cycle of selection. The main selection criteria, though, in all pools (both among and within families) are grain and plant characters. Thus, at flowering plants in the male rows that show foliar disease symptoms, undesirable tassel characters, excessive plant height, and tillering are rogued. Then, at harvest visual selection is practiced among and within families.

Experimental varieties for the Andean region—In 1981 the full-sib progeny of Populations 1, 3, and 4 (developed from Andean gene pools) were tested at El Batán. On the basis of the trial results, experimental varieties (Batán 8101, 8103, and 8104) were formed during the 1981-82 season at Santa Catalina and during 1982-83 underwent preliminary testing. The same full-sib progeny trials that had been grown at El Batán were conducted at Santa Catalina as well. Then in 1982 at El Batán, all full-sib families of the three populations were planted to regenerate progeny for a new cycle of improvement. But these plantings were lost as a result of a hail storm shortly before flowering, so the progeny were regenerated at the Santa Catalina station during 1982-83. In 1983 the second cycle of full-sib progeny trials was conducted at El Batán, and in 1983-84 the same trials were planted, each at two or three locations in the Andean region.

In cooperation with INIAP at Santa Catalina, a new population, Amarillo Duro Tardio, was developed to meet the need of Ecuadorian farmers for widely adapted, yellow flint material. The population was formed on the basis of the results of a full-sib progeny trial from the following materials: INIAP 176, INIAP 178, INIAP 176 x Pool 4B, ICAV 507, and MB 517 x ICAV 507. In 1983-84 an experimental variety (ADT 81) developed from this population was tested by INIAP.

Cooperative testing of Andean materials—In cooperation with INIAP, some of the gene pools, plus experimental varieties from Populations 1, 3, and 4 (developed from the Andean gene pools), were tested in Ecuador during the 1982-83 growing seasons. The trials had a randomized complete block design with four replications and a plant density of 50,000 plants/ha. In all trials the yields of both the pools and experimental varieties generally matched or exceeded that of the local check. Other results for the eight Andean pools are discussed below.

- Pool 1, in a trial conducted during 1982-83, showed a high percentage of root and stalk lodging. During that same cycle, however, floury grain segregates from Population 1 x INIAP 153 were evaluated in female rows and could contribute the greater stalk strength of the local materials to Pool 1.
- Pool 2, in a 1983-84 trial, had the highest ear rot rating of all the materials tested. During the previous season, 500 selected male plants had been inoculated with fusarium ear rot (50,000 spores per plant) and 50 ears from resistant plants selected at harvest for incorporation into the pool during 1983-84.
- Pool 3, a yellow floury material evaluated in 1982-83 and 1983-84 trials, showed some segregation of white grains and *morocho* type kernels, which have a hard, crystalline layer surrounding a more or less soft endosperm. Tillering was considerably reduced in 1983 from the previous year. Grain size was small, on the average. Selection was practiced for stalk strength, larger leaf size, and good husk cover
- Pool 4, evaluated in 1983-84, showed good standability, the desired range of maturity, and a good grain type. Selection for a more cylindrical type ear would be desirable, since conical *chillo* (an Ecuadorian race of maize) type ears seem to predominate in the pool. The male rows of the pool were inoculated with ear rot.
- Pool 5, tested in 1983-84, showed some segregation of various grain types (*morocho*, flint, dent). Some families having the *morocho* type tended to be intermediate in maturity. Selected plants in male rows were evaluated for ear rot resistance.
- Pool 6 was considerably improved for plant type but in some families showed segregation of flint and dent grains. The male rows had been inoculated with ear rot in 1982-83.
- Pools 7 and 8 showed good yield potential in 1983-84 trials.

A new pool for African highlands—During the 1982-83 cycle, improvement of Pool 9 was begun. This is a late-maturing, white dent pool with characteristics fitting the requirements of highland areas in Africa. The main components of the pool are SR-52, Kitale Synthetic II, Ecuador 573, Tuxpeño, Pools 11 to 14 (highland pools developed by the program in 1973), Montana Race, B 71, and Guatemalan *criollos* 4, 34, 48, and 89. One drawback of the pool is its susceptibility to foliar diseases, particularly turcicum leaf blight, which is a serious problem in the African highlands. Selection is being practiced for resistance to this disease and for late maturity, appropriate kernel type, and high yield potential. The pool is planted in November-December, when turcicum leaf blight is present, and harvested in April. Two cycles of improvement have been completed at Poza Rica.

Population Improvement

Once they have reached a certain stage of refinement, the gene pools, as explained in the preceding section, are used to form new advanced populations or, more likely, their superior fraction is merged into existing populations. That work and the tasks of further improving the populations and extracting experimental varieties from them are carried out by the advanced unit, which is currently handling 22 normal maize populations. (Detailed descriptions of those populations are given in Appendix 2, and work with QPM materials is discussed in another section of this publication.)

The populations, like the gene pools, are classified according to zone of adaptation and other distinguishing characteristics. Even so, this section describing work on the populations is divided, not by the materials' zones of adaptation (tropical, subtropical, etc.), as was the case with the pools, but more by procedures carried out by the advanced unit, such as population improvement and formation of experimental varieties.

A substantial part of this work is conducted outside Mexico. Scientists in numerous countries around the world test progenies of the populations and send the results back to Center headquarters, where they are used in the continued improvement of the materials and in the formation of experimental varieties. Other population improvement activities, particularly the development of resistance to diseases that do not commonly occur in Mexico, are coordinated by the Program's regional staff in cooperation with national and international maize researchers.

Improvement Activities in Mexico

In improving the populations, staff of the advanced unit employ a modified, full-sib, recurrent selection scheme that involves international testing. One cycle of improvement is completed in four seasons over two years (see Figure 2 in section on international testing), one season longer than would be required with normal full-sib recurrent selection. Additional seasons are necessary because the Program's international trials are grown both north and south of the equator. Since the main growing season occurs at different times in the two hemispheres, it takes two seasons for all the trials to be grown and the data collected. A summary of population improvement activities carried out in Mexico during 1982-83 is given in Table 11.

The steps in a cycle of improvement—For each cycle, 250 full-sib families are regenerated in Mexico between October and April. International Progeny Testing Trials (IPTTs) made up of these families are then dispatched to test sites in the northern hemisphere. During the following season, while the trials are being grown at locations in the

Table 11. Maize population improvement activities, 1982-83

Population number	Emphasis in selection	Location	Breeding procedures 1982A	1982B	1983A	1983B	Cycles of selection completed
21	Fall armyworm res.	Poza Rica	Self	Bulk sib	Rec. full sib	IPTT	5
22	Downy mildew res.	Farm Suwan	Rec. full sib	IPTT	Self	Bulk-sib	5
23	Better seed type	Poza Rica	Rec. full sib	IPTT	—	—	-
24	Fall armyworm res.	Poza Rica	Rec. full sib	IPTT	Self	Bulk sib	5
25	Better seed type	Poza Rica	—	—	Self	Bulk sib	-
26	Ear rot res.	Poza Rica	Self	Bulk sib	Rec. full-sib	IPTT	5
27	Sugarcane borer res.	Poza Rica	Rec. full sib	IPTT	Self	Bulk sib	5
28	Downy mildew res.	Farm Suwan	Self	Bulk sib	Rec. full sib	IPPT	5
29	Reduced plant height	Poza Rica	Within-fam. sib	Bulk sib	Rec. full sib	IPTT	5
30	Better seed type	Poza Rica	Self	Bulk sib	Rec. full sib	IPTT	2
31	Downy mildew res.	Farm Suwan	Self	Bulk sib	Rec. full sib	IPTT	2
32	Res. to leaf diseases	Poza Rica	Rec. full sib	IPTT	Self	Bulk sib	4
33	Ear rot res.	Tlaltizapán	Rec. full sib	IPTT	Self	Bulk sib	2
34	Better seed type	Tlaltizapán	Self	Bulk sib	Rec. full sib	IPTT	5
35	Standability	Poza Rica	Rec. full sib	IPTT	Self	—	-
36	Reduced plant height	Poza Rica	Within-fam. sib	Bulk sib	Rec. full sib	IPTT	5
42	Better seed type	Tlaltizapán	Self	Bulk sib	Rec. full sib	IPTT	4
43	Streak res.	Ibadan	Rec. full sib	IPTT	Within fam. sib	Bulk sib	5
44	Reduced plant height	Tlaltizapán	Rec. full sib	IPTT	Self	Bulk sib	4
45	Reduced plant height	Tlaltizapán	Rec. full sib	IPTT	Self	Bulk sib	2
46	Stalk rot res.	Tlaltizapán	Self	Bulk sib	Rec. full sib	IPTT	1
47	S.W. corn borer res.	Tlaltizapán	Rec. full sib	IPTT	Self	Bulk sib	2
48	Stalk rot res.	Tlaltizapán/ Turkey	Rec. full sib	IPTT	Self	Bulk sib	4
49	Increased yield without increased height or maturity	Poza Rica	Self	Bulk sib	Rec. full sib	IPTT	1

southern hemisphere, each group of 250 families is planted in 11-m rows (32 plants per row) in a breeding nursery at one of the Maize Program's stations in Mexico. Approximately 50% of the plants are selfed in each family. Then, based on data received from international test sites, a certain number of families are selected, and among them selections are made for a single major trait that is deficient in the population (in 1983 selection pressure among families was greater than it had been previously, 50 families compared to about 80 in the past). At harvest two to three ears are chosen from each selected family. Every S_1 ear is identified with its full-sib parental family and planted ear-to-row the next season.

The better S_1 families are identified among the selected full-sib families, and approximately 50% of the plants within the S_1 families are selected and bulk pollinated. These selections are based, as in the preceding season, on a single major trait. At harvest two or three half-sib ears are selected from S_1s of each selected full-sib family.

During the following season, seeds from the half-sib ears are planted ear-to-row, giving 32 plants. Superior half-sib families in each full-sib family are identified to ensure that the two half-sib families involved in a cross come from different full-sib families, and reciprocal plant-to-plant crosses are made among them.

Germplasm introgression—From time to time, germplasm from the gene pools is introgressed into the populations during the course of an improvement cycle. While the progeny trials are being grown in the southern hemisphere, approximately 50 half-sib families of the corresponding gene pool are planted alongside the full-sib families of the population. During that and subsequent seasons, the families of the pool are handled in the same manner as those of the population. No crosses are made between the two groups of families. During the season when plant-to-plant crosses are made, about 220 full-sib families are selected from the population and another 30 from the gene pool to make up the 250 full-sib families of the population. The families from the gene pools that are equal or superior in performance to the population mean are used along with the families selected from the population in the next cycle of selection.

Insect resistance—Selected populations were improved for insect resistance under artificial infestation: Populations 21 (Tuxpeño-1) and 24 (Antigua-Veracruz 181), both lowland tropical materials, for resistance to fall armyworm (*Spodoptera frugiperda*); Population 27 (Amarillo Cristalino-1), also adapted to tropical lowlands, for resistance to sugarcane borer (*Diatraea saccharalis*); and the subtropical Population 47 (Templado Blanco Dentado-2) for resistance to southwestern corn borer (*D. grandiosella*).

The populations were artificially infested, using larvae mixed with corn grits, at the selfing, bulk-sibbing, and progeny regeneration stages. At the latter stage, duplicate plantings were infested. Visual ratings for insect damage were made at various growth stages. Families and plants showing less damage were used in pollinations. At harvest ears were selected from plants showing greater insect resistance, as well as from parts of the row that had been protected from insect attack.

Disease resistance—At the Maize Program's stations in Mexico, resistance to ear and stalk rots and leaf diseases is being improved under artificial infection.

The lowland tropical Population 26 (Mezcla Amarilla) and the subtropical Population 33 (Amarillo Subtropical) were improved during 1982-83 for resistance to ear rots. In the selfing and bulk-sibbing generations, half of the pollinated ears were inoculated approximately one week after pollination with spore suspensions containing a mixture of *Fusarium* spp. and *Diplodia* spp. Relatively clean ears were selected at harvest from the ones that had been inoculated; additional ears were selected from the uninoculated section of the row to give a total of three selected ears per row.

The temperate Populations 46 (Templado Amarillo Cristalino) and 48 (Compuesto de Hungría) were improved for stalk rot resistance. During the selfing generation at Tlaltizapán, about one week after pollination, the first extended internode of half of the plants pollinated was inoculated by means of toothpicks laden with stalk rot fungi (*Fusarium* spp. and *Gibberella* spp.). Stalks were split at harvest to assess disease damage, and ears were retained only from the more resistant plants. This same procedure was carried out with Population 46 during the bulk-sibbing stage at Tlaltizapán. Meanwhile, three sets of each S_1 ear of Population 48 were being grown by Turkey's national maize program, one set at each of three locations under high natural infection with stalk rot. Bulk sibbing was done at only one site, but data from all three sites were used in selecting the S_1 families and half-sib ears. These were returned to Mexico to be used in developing the new set of 250 full-sib families.

Turcicum leaf blight (*Helminthosporium turcicum*) and common rust (*Puccinia sorghi*) pose a serious threat to subtropical, white maize populations grown in midaltitude regions of Africa or during winter in many other parts of the world. Efforts were made to improve resistance to those diseases in Populations 34 (Blanco Subtropical), 42 (ETO-Illinois), 44 (AED-Tuxpeño), and 47 (Templado Blanco Dentado-2). Those populations were grown during summer at El Batán, where they were artificially inoculated with turcicum leaf blight, and in winter at Poza Rica, where they were inoculated with both leaf diseases. Selection for resistance to those diseases required adjustments in the planting, pollination, and harvest of the materials to keep them in step with the various operations involved in international testing.

Selection for resistance to turcicum leaf blight was also practiced at Poza Rica in Population 32 (ETO Blanco). Because of the temperate germplasm contained in this population, it is particularly susceptible to leaf diseases.

Development of Streak Resistance in Nigeria

Improvement of resistance to some major tropical diseases cannot be carried out effectively at CIMMYT's research stations in Mexico. For that reason, a significant portion of the Maize Program's work on improvement of disease resistance in populations, as mentioned previously, takes place in other countries under cooperative arrangements with national and international organizations. For example, to improve resistance to maize streak virus, a disease found only in Africa, Program staff are working at the International Institute of Tropical Agriculture (IITA) and in various African countries.

Several approaches are being taken in this work, including recurrent selection in a population, conversion of experimental varieties, and improvement of various pools. Although there are separate sections in this report for each of those types of activities, all are described here in a single section to give readers a complete picture of the Program's total effort to develop streak resistance. The regional maize specialists carrying out this work are also engaged in a number of other activities (described on pages 58-59), such as training and consultation with national scientists.

Population 43 (La Posta)—During 1982, 250 full-sib families from this population were tested for yield, along with six local checks, in Costa Rica, Ivory Coast, Nicaragua, Nigeria, Thailand, and Zimbabwe. The trials had a 16 x 16 simple lattice design. The 10 best full-sib families at each site were selected for the formation of experimental varieties; the yields of selected families are listed in Table 12. For some sites two varieties were formed, one based on visual selection by the trial cooperators and the other according to data on yield and other agronomic characters. Another variety was formed on the basis of across-site data. All of these varieties were developed from remnant seed at IITA and sent to CIMMYT for distribution by the international testing program during 1984.

Two approaches were adopted for development of streak resistance in Population 43. The first was to capitalize on the variability for streak resistance that has already been detected in the population, as described in the *CIMMYT Report on Maize Improvement 1980-81*. For that purpose, 250 full-sib families that were distributed during 1982 in an International Progeny Testing Trial (IPTT) were screened during the same season for streak resistance at IITA. Twelve families with a very high level of streak resistance were identified, and the resistant plants were selfed. Plants in 48 additional families were found to have intermediate to moderate resistance and were selfed.

In the following season, the progenies of those plants were screened for streak resistance. Resistant progenies were either selfed or included in plant-to-plant crosses within each progeny. In families that showed no streak resistance, those same types of pollinations were made in nurseries that were protected from streak. Based on the results of the IPTTs, 78 families were selected for the next cycle of population improvement. In 29 of those families, plants with various levels of streak resistance had been identified.

The progenies of both the resistant and nonresistant plants represented their original families in the half-sib recombination of the selected families. The half-sib families so generated were planted in streak and nonstreak nurseries during the 1983 dry season (November to April). In both those nurseries full-sib families were generated by means of reciprocal plant-to-plant crosses for international testing during 1984. Whenever possible, streak-resistant plants were used for the generation of full-sibs.

The second approach was to incorporate streak resistance into Population 43 through backcrossing. IITA's population TZSR-W-1 served as the streak-resistant donor, and a bulk of the families selected from

Table 12. Grain yield in IPTT 43 (La Posta), 1982

	Honduras (Catacamas)	Ivory Coast (Ferke)	Nicaragua (St. Rosa)	Nigeria (Ikenne)	Thailand (Suwan)	Zimbabwe (Gwebe)	Mean
				t/ha			
Selected families	7.87	9.64	6.25	7.09	8.56	9.15	7.45
Population	6.63	7.83	4.89	5.12	6.62	6.67	6.29
Best check	5.51	9.31	5.40	5.44	7.25	12.35	7.54
C.V. (%)	13.7	11.7	17.3	16.6	11.8	13.1	

Population 43 was used as the recurrent parent. Full-sib families were generated from streak-resistant plants in the $BC_2(F_2)$ generation. Twenty of those families were among the 250 full-sibs distributed for international testing in 1984.

Conversion of experimental varieties—Another approach being taken to meet the urgent need in Africa for streak-resistant germplasm is to convert experimental varieties from several other populations besides La Posta to streak resistance through backcrossing. This project has included EVs developed from nine populations in CIMMYT's international maize testing program. In 1983 EVs from three other populations, two from CIMMYT and one from IITA, were added to the program. The parent materials of all the varieties now included in the program are Populations 21, 22, 28, 29, 30, 31, 35, 43, 44, 49, and 62 as well as TZB, an IITA population that is adapted to the lowland tropics, is late maturing, and has white flint grains.

The varieties are being converted to streak resistance by means of a modified backcross procedure, in which the most recent promising EV from each population is used as the recurrent parent. In 1983 five of the conversions were included in the streak-resistant variety trials EVT-LSR(W) and EVT-LSR(Y), which were distributed from IITA to African national programs.

Those five varieties, particularly Poza Rica 7822-SR BC_2, Poza Rica 7843-SR BC_2, and Across 7728-SR BC_2, showed much promise, comparing favorably in yield and other agronomic characters with national program checks and with other streak-resistant experimental varieties. In trials conducted in Nigeria, with and without streak pressure, susceptible recurrent parents were included for comparison with the resistant conversions. Under heavy and uniform streak pressure, the streak-resistant conversions were decidedly superior in yield and other agronomic characters to their recurrent parents (Table 13). The results of the trials grown without streak pressure (Table 14) suggest that resistance was gained at no cost in yield potential.

Other breeding populations—In addition to improving La Posta and incorporating streak resistance into EVs, CIMMYT's maize breeders at IITA had primary responsibility during 1982-83 for Pool 16, TZESR-W, and early and late-maturing, white-grain backup pools. Pool 16, an early maturing, white dent back-up pool developed by CIMMYT, has performed well in the regional trials of the Semi-Arid Food Grains Research and Development Project (SAFGRAD). It was therefore decided to improve this pool for streak resistance at IITA and to subject it to full-sib recurrent selection for yield and other agronomic characters in cooperation with African national programs.

Table 13. Comparison of streak-resistant conversions and nonstreak-resistant counterparts in EVT-LSR (W) and (Y) under artificial streak pressure at Ibadan, Nigeria, 1983

Trial and variety	Grain yield (kg/ha)	Days to silk	Plant height (cm)	Ear height (cm)	Streak rating (1-5)
EVT-LSR(W)					
Poza Rica 7822	901	63	132	74	5.0
Poza Rica 7822-SR BC_2	7040	56	215	113	2.3
Across 7729	1087	62	140	72	5.0
Across 7729-SR BC_2	7050	54	212	107	2.3
Poza Rica 7843	1502	60	165	80	5.0
Poza Rica-SR BC_2	7400	55	242	128	2.5
EVT-LSR(Y)					
Across 7728	857	61	113	76	4.8
Across 7728-SR BC_2	6743	55	234	133	2.3
Tocumen (1) 7835	1435	58	120	54	3.5
Tocumen (1) 7835-SR BC_2	5118	50	206	103	1.3

Table 14. Comparison of streak-resistant conversions with normal counterparts of three late-maturing, white-grain varieties under negligible streak incidence at Ikenne, Ilorin, and Samaru (Nigeria), 1983

Variety	Grain yield (kg/ha)	Yield Index[a]	Days to silk	Plant height (cm)b	Ear height (cm)[b]
Poza Rica 7822	6572	100	56	229	116
Poza Rica 7822-SR BC_2	6601	100	56	226	119
Across 7729	5811	100	55	218	109
Across 7729-SR BC_2	6495	112	55	220	110
Poza Rica 7843	6964	100	58	238	134
Poza Rica 7843-SR BC_2	6638	95	56	243	129

a Nonresistant variety = 100.
b Data from Ilorin and Samaru only.

During 1982 full-sib families from Pool 16 were tested at Kamboinse in Burkina Faso and at Gusau and Ikenne in Nigeria. Based on data collected and observations made at those locations, 84 families were selected and recombined twice in 1983. During recombination, selection for kernel texture and uniform plant type was emphasized.

A short-term goal achieved in the work on Pool 16 was the development of a streak-resistant EV from the pool through backcrossing. Upon completion of the BC_4 generation in 1983, this streak conversion, which has very good resistance, was entered in a preliminary variety trial in Nigeria. Moreover, 80 full-sib families were generated within this conversion for testing in an IPTT during 1984, along with 170 families from Pool 16 itself.

In 1982 full-sib families of TZESR-W, an early maturing, white flint, streak-resistant population that is being improved through full-sib recurrent selection, were evaluated at five locations in four countries: Cameroon, Nigeria, Tanzania, and Zaire. Site-specific and across-site EVs were formed during 1983 for future testing. On the basis of data from Gusau and Ikenne in Nigeria and Mayo Galke in Cameroon, 63 full-sib families were selected for recombination in the first season of 1983. Another recombination was done in the second season, during which selection for reduced plant height, stalk quality, and earliness was emphasized. In the third season, 250 full-sibs were generated for the IPTT to be distributed in 1984.

Two broad-based, streak-resistant, white back-up pools, one late and the other early maturing, were formed by crossing streak-resistant sources with materials from CIMMYT, IITA, and African and Asian national programs. After thorough mixing, these pools will be improved by means of half-sib family selection for streak resistance and agronomic characters.

Development of DM Resistance in Asia

Downy mildew (DM), caused by *Peronosclerospora sorghi*, is another disease that does not occur at CIMMYT's stations in Mexico and for which, therefore, the Maize Program is developing resistance at a site outside the country. This research, begun in 1981, is being conducted in cooperation with Thailand's Kasetsart University under the coordination of CIMMYT's Asian Regional Maize Program, with headquarters in Bangkok.

Resistance to downy mildew, which is a major problem in Asia but also occurs in parts of Africa and Latin America, is being improved in three advanced materials: Populations 22 (Mezcla Tropical Blanca), 28 (Amarillo Dentado), and 31 (Amarillo Cristalino-2). These materials are being handled by staff of the University's National Maize and Sorghum Program within CIMMYT's system of international progeny testing, recycling of the best progeny for improvement, and formation of experimental varieties. The populations have already shown good agronomic adaptation in the Asian region, and satisfactory progress is being made in their improvement. It is anticipated that within one or or two additional cycles they will generate varieties with good agronomic characters, high and stable yields, and DM resistance.

Special Projects

The Maize Program has for many years contained a research section that explores new ideas or investigates new techniques. In the past a number of special projects have involved the testing of hypotheses, many of which have a physiological basis, by setting up selection experiments in which single characters of interest have been selected. These have been regarded as special projects whose results may not be known for several years, and which may, or may not, provide useful germplasm to the main breeding program. A number of these projects, especially the ones relating to selections that have led to higher harvest index, and hence higher efficiency in the use of available dry matter, have been the subject of previous reports. Others, such as selection for drought tolerance and earliness, are ongoing projects that involve repeated cycles of selection followed by evaluation. There were extensive staff changes in the period reviewed, and no evaluations of these projects were carried out.

Selection for drought tolerance—In many maize-growing environments in the tropics, drought of varying severity occurs as a random event in the growing cycle of the crop. It is thought that in marginal areas drought of sufficient severity to cause a 40% yield reduction may occur with a frequency of two years out of five. In the remaining three years, rainfall is adequate, or drought occurs at a time when grain yield is little affected. If the frequency of drought increases, farmers normally will change crops to more drought-tolerant species, such as sorghum and millet.

Drought severity is amplified when the crop is grown on soils low in organic matter or on coarse-textured soils with low water-holding capacity. When drought coincides with the pollination period, the decline in grain yield can be severe. Another important time is during crop establishment, when the rains have begun but are sporadic and a prolonged break in rainfall can lead to considerable stand reduction. In many areas the effects of drought early in the growing season are minimized by altering planting date or by using early maturing varieties. But since those strategies normally exact a cost in grain yield, the Maize Program opted for a recurrent selection program that exploits other mechanisms of drought tolerance. The project was initiated in 1976 with the population Tuxpeño Drought, which is a white dent lowland tropical material that has the capacity to produce a good yield across a wide range of conditions in many parts of the tropics.

Selection has been carried out at Tlaltizapan in the rain-free winter cycle. The soil on the station is a heavy clay vertisol overlying a calcareous parent material at a depth of 1.5 to 2.0 m. Lateral movement of water across the limestone pan occasionally occurs. Because temperatures during the December-January period are quite low (the average is approximately 18°C), evapotranspiration is low, and stress takes a long time to develop, even when no irrigation water is applied after planting. Selection is carried out under three irrigation regimes: no stress (normal irrigation), medium stress (irrigation until two weeks prior to silking, then no more water applied), and severe stress (irrigation at planting, then no more water applied). In general, grain yields under the three regimes are, respectively, 6, 4 and 1.5 t/ha. Growth stages that are stressed are the grainfill period in the medium stress condition and the flowering and grainfill periods under the severe stress treatment.

Full-sib recurrent selection has been used as the method of population improvement. In each cycle of selection (that is, C5 and C6 in 1982-83), 250 full-sib families were evaluated with six checks in two replications per moisture stress treatment in a 16 x 16 simple lattice design. Plot size was a single row 2.5 m in length, grown at a target density of 53,000 plants/ha. Three weeks prior to anthesis, relative leaf and stem extension rates (RLE) were determined by measuring the height of the tip of the youngest visible leaf in the whorl of four plants per plot in the irrigated and severely stressed treatments. The measurement was repeated one week later on the same plants. A second determination of RLE was made at the same time, using a different leaf, and the two estimates averaged. Inherent differences in elongation rate between families are taken into account in the RLE calculation.

Counts of plants anthesed and silked were taken in each plot each day during the flowering period, and the interval between 50% anthesis and 50% silking (ASI) was calculated. Canopy temperatures were measured near flowering time on two occasions, using an infrared thermometer. Approximately five weeks after flowering, each plot was scored for the rate of lower leaf death under severe, medium, and no drought stress. At harvest grain was dried at 80°C for 72 hours before being hand-shelled and weighed.

Correlations among these various characters associated with performance under drought have been reported previously in a CIMMYT technical bulletin entitled *Breeding and Selection for Drought Resistance in Tropical Maize* by K.S. Fischer, E.C. Johnson, and G.O. Edmeades. Selection was based on a consideration of all characters, although no formal selection index was used during the cycles under review. As with previous cycles, families were selected to maintain yield under irrigation while increasing yield under drought stress. At the same time, families showing high RLE, small ASI, low canopy temperatures, and prolonged leaf life under drought stress were included. Care was taken that selected families did not flower either later or earlier in the no stress treatment than in the bulk of the population. Selection thus favored families that could either tolerate low soil water potentials or that could send roots down to wetter regions of the soil.

While the families were being tested under drought at Tlaltizapán, they were also grown at Poza Rica for within-family improvement of plant type. Plants were selected under irrigation on the basis of height, small ASI, leaf angle, and disease resistance. Then, plant-to-plant crosses were made between selected plants within a family. At harvest the 50 to 60 families selected on the basis of performance under the stress levels at Tlaltizapán were harvested and sown for recombination in Poza Rica during the summer cycle. Recombination consisted of making reciprocal full-sib families in all combinations among the selected families, and these new full-sib families were tested at Tlaltizapán in the following cycle.

A yield trial, conducted after three cycles of selection, showed (see previously cited report by Fischer et al.) that grain yield had increased under stress by about 9% per cycle, while the yield and flowering dates under irrigation remained unchanged. The changes due to selection (reduced barrenness, hence higher harvest index) reflected a better water status of the plants and/or an improved capability of the flowering process to withstand internal water deficits. Further evaluation of this population is planned in 1983-84.

Selection for early maturity— Earlier maturing maize varieties are in constant demand in tropical and subtropical areas, since they provide a wider range of technological choices to farmers. For example, planting date of earlier varieties under rainfed conditions becomes less critical, and a wider range of other crops can be planted before or after the maize crop. Early maturing varieties may also provide food at a time when no other is available, and thus shorten the "hunger period" between major food harvests.

The sacrifice in yield per unit area (although not per unit time taken for the crop to mature) has long been recognized as a major problem in the development of early maturing varieties. Two alternative solutions to this problem were examined, beginning in 1975. The first involved the collection and compositing of a range of early maturing germplasm from lowland tropical sites in Indonesia, Pakistan, and Central America. These composites were selected for yield at Poza Rica, Tlaltizapán, and Obregón, while maintaining their early maturity. The second approach was to form a composite of elite genotypes of intermediate and late maturity (for details, see *CIMMYT Report on Maize Improvement 1978-79*), which was

named Compuesto Selección Precoz (CSP). This composite has been selected in a modified half-sib recurrent scheme for earliness, while attempting to maintain yield per hectare and thereby increase yield per day.

Selection was commenced in 1976 in all composites. It became clear by 1979 that the composites based on early landraces per se had limited variability for yield and generally poor agronomic type and were susceptible to a number of diseases. By that time CSP was almost as early to 50% silking, though it was later to mature because of a longer grainfill period, which appeared to be associated with its higher yield. From those observations it was concluded that more rapid progress could be made in obtaining high-yielding, early maturing germplasm with a good level of disease resistance by selecting within elite, intermediate-maturing germplasm rather than by selecting for yield among very early landraces. As a consequence, all composites other than CSP were shelved.

In the period under review, four cycles (C9 through C12) of selection for earliness were completed in CSP at each of the two locations, Poza Rica and Tlaltizapán. Five hundred half-sib families were planted in a structure of two female rows to one male row, where the male was composed of a balanced bulk of the superior fraction of selected families. Females were planted at 44,000 plants/ha in a single 5-m row per family, and the males were planted at twice that density. Males were selected for good synchronization of pollen shedding and silking, moderate height, and good lodging resistance. Undesirable plants in male rows were detasseled prior to anthesis, where possible. One thousand early silking plants in female rows were tagged with their silking date. When 70% of all female plants had silked, the male rows were completely detasseled, thus forcing the late-maturing plants to become barren. Harvest was conducted as early as possible, so that good dry ears from plants whose foliage was still green could be identified. At each of the two selection sites, approximately 250 ears were selected to serve as females in the next cycle. Ears from superior plants within elite families were chosen from the 250 selected to make up the male composite.

Evaluations made previously indicate that it has been possible to select early flowering types without reducing grain yield, provided that selection pressure for earliness is not too severe. Yield trials have indicated that days to silk have been reduced by about one day per cycle (1.3%) in the winter season and by the same relative amount in the summer. Grain yield in CSP has apparently not been reduced by selection for earliness.

A further evaluation of changes due to selection in this population is planned for 1984-85, as well as an investigation of the genetic control of earliness in this material.

Development of Experimental Varieties

Experimental varieties (EVs) are developed either on the basis of data from particular sites where progeny tests have been conducted (these are termed *site-specific* varieties) or according to data from all progeny test sites (*across-site* varieties). Each population has the potential to produce seven experimental varieties: six site specific and one across site. The former are designated by the name of the site at which the IPTT was conducted, along with four digits, the first two being the year of the test and the last two the number of the population (for example, Pirsabak 7930). For the development of site-specific varieties, 6 to 10 superior families are selected according to visual observations and/or on the basis of IPTT data. An EV designated Pirsabak (1) 7930, for example, would differ from Pirsabak 7930 in that the selection of families for its development was based on visual observations, whereas selection for the latter was based on test data. Data from all sites at which a population was tested are used to select the 6 to 10 families from which an across-site variety (such as Across 8022) is developed.

For the formation of EVs, selected families are planted in 11-m rows and diallel crosses made among them. At harvest ears from each family, products of crosses with other families, are saved and shelled in bulk. An equal quantity of seed is taken from each family bulk and mixed to form the F_1 bulk. This is planted during the next season in approximately 100 rows 5 m long, giving a total of 1500 plants. About 300 plants are selected at flowering and their pollen bulked to pollinate all plants except the ones that are severely damaged by disease, lodged, or judged to be off-types. At harvest all desirable ears are saved and shelled in bulk to provide seed for Experimental Variety Trials (EVTs) and Elite Variety Trials (ELVTs). Trial design and results are covered in the section on international testing, beginning on page 30.

In the process of improving the populations, full-sib or S_1 families may be identified that are superior in particular major traits, and EVs can be developed specifically for those traits. The traits currently emphasized in the Maize Program include resistance to various diseases and insect pests, better seed type, reduced plant height and maturity, and improved husk cover. Nine experimental varieties were developed for those traits during the 1983A season at Tlaltizapán, using the full-sib or S_1 families. Specific traits were heavily emphasized in the selection of those families, though their performance in the IPTTs was also taken into account in the final selection of families that would be included in the varieties. Those varieties were advanced to the F_2 generation at Tlaltizapán during the 1983B season.

Populations Added or Discarded

Depending upon the needs of national maize programs, some populations are temporarily or permanently withdrawn from international testing and, when possible, replaced with more useful germplasm, generally from the gene pools. Superior half-sib families are extracted from the pools and handled in a combined S_1, half-sib,

or full-sib selection scheme for a few generations to reduce the frequency of undesirable recessive genes as well as to increase uniformity of plant and seed attributes.

(Mix. 1 x Colima group 1) x ETO, a late, white flint population, was withdrawn from international testing during 1980-81. Work was begun in the 1982A season to replace it with the superior fraction of Pool 23 (Tropical Late White Flint). The resulting new material, Population 25 (Blanco Cristalino-3) should be ready for international testing in 1984.

Work was also begun during the 1983A season at Poza Rica to replace Population 23 (Blanco Cristalino-1) with a higher yielding, tropical, white flint material of intermediate maturity. The new version of the population is based on the superior fraction of Pool 19 (Tropical Intermediate White Flint). It is being improved by means of the system ordinarily used for population improvement and will be evaluated in an IPTT for the first time during 1985.

The subtropical Populations 42 (ETO-Illinois), 44 (AED-Tuxpeño), and 48 (Compuesto de Hungria), which had been withdrawn from international testing during 1980-81, were brought back into the population improvement program in 1982-83. It was felt that the first two populations would be very useful for midaltitude maize-growing areas of Africa and for regions of the world where maize is grown during the winter season if their resistance to turcicum leaf blight and common rust were improved. Population 42 also needed improvement in uniformity of kernel color and texture. The reason for resuming work on Population 48 was that, with better resistance to stalk rot, it might be useful in Turkey or other countries having similar growing conditions. These three populations were improved for the traits in which they are deficient and were evaluated in IPTTs during 1982-83.

Population 35 (Antigua x República Dominicana), a yellow dent material of intermediate maturity, was withdrawn from the population improvement program. The consensus among Program staff at headquarters and in the regional programs was that demand for this population among national maize scientists around the world was not sufficient to warrant continued improvement of it.

Progress in Population Improvement

Periodically, the Maize Program monitors the progress of its efforts to improve the mean performance and stability of the populations. The purpose of these evaluations is to ensure that national programs can profit from the germplasm they acquire from the Program for use as source materials in the development of improved varieties and hybrids. During 1982-83 three "cycles of selection" trials were conducted to measure the rate and amount of population improvement, and two variety trials were carried out to determine if that improvement was leading to better varieties. Since the trials were multilocational, it was also possible to monitor changes in the stability of the materials' performance.

During the period covered by this report, the advanced unit (under the direction of Shivaji Pandey, center) conducted a major evaluation of the progress being achieved in population improvement and of the performance of varieties being developed from the populations.

Trial design and data collection—All five trials had a split-plot design. In the trials evaluating various cycles of selection, populations were the main plots and cycles of selection the subplots. In the variety trials, populations were again the main plots and years in which the varieties were developed the subplots. The trials had four replications and were grown at different locations, using fresh seed of each entry. The plots consisted of four rows 5 m long, with 0.75-m spacing between rows; data were recorded only for the two central rows.

The trials were overplanted and thinned to a uniform stand of about 53,000 plants/ha. All planting and harvesting were done by hand. Grain yield was calculated on the basis of ear weights adjusted to 85% shelling and 15% moisture. The number of days by which 50% of the plants had silks was recorded for each plot. Plant and ear height were measured in centimeters as the distance between the base of the plant and, for the former, the point where tassel branching began and, for the latter, the base of the node bearing the upper ear. Ear aspect was rated on a scale of one to five (with one indicating good and five poor) based on uniformity of ear size, kernel rows, kernel texture and color, and damage by ear rots and ear insects. The number of ears per plant was calculated by dividing the total number of ears harvested by the number of plants in a plot. Progress per cycle was calculated according to the following equation:

$$\left[\frac{\text{Perf. of last cycle}}{\text{Perf. of initial cycle}} - 1\right] \times \frac{1}{\text{No. of cycles}} \times 100$$

Statistical analyses were performed using the methods for a split-plot experiment, and LSD values for comparisons among treatments were calculated at the 5% level of probability. Stability analysis was conducted for grain yield, days to silk, and plant height according to the Eberhart and Russell linear regression model. Sums of squares resulting from entry x environment interactions were partitioned into individual entry regressions (b) on environmental means (of all entries in each environment) and mean square deviations (s^2d) from regressions.

Late-maturing lowland tropical populations—Three cycles of selection (C0, C2, and C4 or C5) in Populations 21 (Tuxpeño-1), 22 (Mezcla Tropical Blanca), 24

Table 15. Mean performance of eight late-maturing tropical maize populations evaluated over six locations for three cycles of full-sib selection

Cycles of selection	Yield (kg/ha)	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Ear aspect (1-5)	Ears per plant
Population 21						
CO	5975	65.6	212	112	3.8	0.96
C2	6041	65.3	208	110	3.8	0.97
C5	6335	66.4	220	114	3.4	0.96
Mean	6117	65.8	213	112	3.7	0.96
Population 22						
CO	6090	67.6	226	127	3.7	0.94
C2	6502	66.1	226	124	3.7	0.95
C4	6548	65.3	220	119	3.5	0.97
Mean	6380	66.3	224	123	3.6	0.95
Population 24						
CO	5682	66.8	226	127	3.5	0.96
C2	5327	67.3	214	117	3.8	0.94
C5	5763	66.0	214	117	3.5	0.96
Mean	5590	66.7	218	120	3.6	0.95
Population 27						
CO	5267	67.5	226	120	3.6	0.94
C2	5275	66.9	232	123	3.8	0.94
C5	5751	65.7	220	117	3.4	1.00
Mean	5431	66.7	226	120	3.6	0.96
Population 28						
CO	6021	67.5	238	133	3.5	0.99
C2	6028	66.0	226	126	3.6	0.96
C4	6386	65.1	220	115	3.6	1.04
Mean	6145	66.2	228	125	3.6	1.00
Population 29						
CO	6201	66.7	224	120	3.7	0.93
C2	6009	66.3	220	122	3.9	0.92
C5	6213	64.5	207	111	3.6	0.95
Mean	6141	65.8	217	118	3.7	0.93
Population 36						
CO	5706	66.1	234	136	4.1	0.93
C2	5570	65.8	232	131	3.9	0.98
C5	6248	63.2	213	114	3.4	0.99
Mean	5842	65.1	226	127	3.8	0.96
Population 43						
CO	6124	69.6	248	146	3.6	0.91
C2	6262	69.0	244	142	3.6	0.96
C4	6578	67.0	233	130	3.4	0.98
Mean	6322	68.6	241	139	3.5	0.95
LSD (5%) between pops.	230	0.7	4	4	0.2	0.02
LSD (5%) within pops.	314	0.8	6	5	0.2	0.04

(Antigua-Veracruz 181), 27 (Amarillo Cristalino-1), 28 (Amarillo Dentado), 29 (Tuxpeño Caribe), 36 (Cogollero), and 43 (La Posta) were evaluated in six environments: Poza Rica (summer and winter), Cali (Colombia), Ciudad Obregón (Mexico), Cuyuta (Guatemala), and Las Acacias (Honduras).

Table 16. Progress per cycle through full-sib selection for six traits in eight late-maturing tropical maize populations

Population number	Yield	Days to silk	Plant height	Ear height	Ear aspect	Ears per plant
			Percent			
21	1.20	0.27	0.75	0.35	-2.10	0
22	1.88	-0.85	-0.66	-1.57	-1.35	-0.79
24	0.28	-0.23	-1.06	-1.57	0	0
27	1.83	-0.53	-0.53	-0.50	-1.11	1.27
28	1.53	-0.88	-1.89	-3.38	0.71	1.26
29	0.03	-0.65	-1.51	-1.50	-0.54	0.43
36	1.89	-0.87	-1.79	-3.23	-3.41	1.29
43	1.85	-0.93	-1.51	-2.73	-1.38	1.92

Table 17. Eberhart and Russell's stability parameters for various traits of eight tropical maize populations after two and four or five cycles of full-sib selection

Population number	Cycles of selection	Yield b	Yield $s^2d \times 10^4$	Days to silk b	Days to silk s^2d	Plant ht. b	Plant ht. s^2d
21	C0	1.00	2.64	0.99	0	0.94	9.65
	C2	1.01	0	0.98	0	0.94	57.81*
	C5	0.99	10.82	1.02	0	1.02	0
22	C0	1.05	0	1.02	0	0.97	0
	C2	1.12	1.83	0.99	0.05	0.94	0
	C4	1.06	4.15	0.97	0	0.94	23.42
24	C0	1.08	0	1.01	0	0.97	11.90
	C2	0.93	0	0.99	1.26*	0.93	0.11
	C5	1.02	0.96	0.99	0.53	0.85	0
27	C0	0.78	35.66**	1.05	3.85**	1.03	29.73
	C2	0.99	32.72**	1.02	0	0.97	0
	C5	0.86	22.29**	0.99	0	0.95	0
28	C0	1.04	0	1.00	0	0.99	0
	C2	1.11	0	0.97	0.34	1.14	11.59
	C4	0.92	34.23**	0.96	0	1.17	20.88
29	C0	1.10	1.33	0.96	0	0.92	0
	C2	0.93	0	0.96	0	0.95	34.23
	C5	0.91	17.95*	0.96	0.25	0.90	16.99
36	C0	1.14	11.34	0.98	0	1.06	88.52**
	C2	0.89	36.16**	0.99	1.19**	1.20	6.18
	C5	0.92	2.53	0.94	0	1.02	66.28**
43	C0	1.11	11.00	1.08	0	1.12	114.02**
	C2	1.06	10.33	1.07	0	1.12	56.12*
	C5	0.97	3.21	1.06	0	0.96	0
LSD (5%) cycles in a pop.		0.29		0.66		0.26	

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Data on the performance of each population and cycle, averaged over environments, is given in Table 15. Population 22 was the highest yielding, giving 6380 kg/ha, and Population 27 the lowest, with 5431 kg/ha. Population 36 was intermediate in yield and significantly different from other materials. Population 43 was latest maturing (68.6 days to silk) and Population 36 earliest (65.1 days to silk). The plant and ear heights of Population 43 were significantly greater than those of the other materials, while Population 21 had the lowest. Only the latter was significantly better than Population 36 in ear aspect. The other materials neither differed among themselves nor from those two populations in ear aspect. Population 28 had the highest average number of ears per plant (1.00), significantly more than the other populations, and Population 29 the fewest (0.93).

Percentages of progress per cycle for six traits are given in Table 16. In improvement of yield and ear aspect, the greatest progress per cycle was achieved with Population 36. Population 43 showed the most improvement per cycle in ears per plant and the largest decrease in days to silk. The greatest reduction per cycle in plant and ear heights was brought about in Population 28. No progress was made in improving the yield of Population 29, the ears per plant of Population 21, and the ear aspect and ears per plant of Population 24. Progress per cycle across all eight populations for yield, days to silk, plant height, ear height, ear aspect, and ears per plant averaged 1.31, -0.59, -1.06, -1.77, -1.15, and 0.87%, respectively. The ranges in improvement for those traits were 0.03 to 1.89, -0.93 to 0.27, -1.89 to 0.75, -3.38 to 0.35, -3.41 to 0.71, and 0 to 1.92%, respectively.

Eberhart and Russell's stability parameters of the original and two other cycles of selection for yield, days to silk, and plant height are given in Table 17. For most populations and cycles, the b values were generally close to 1.0 and the

s^2d values mostly not significant. Although the b values of the cycles did not differ significantly within any of the populations, the last cycles of selection had lower b values than cycle 0 for all three traits in six of the populations. Those values were accompanied by higher yields, lower numbers of days to silk, and reduced plant height. The b values for cycles of selection in each population, though differences between them were not significant, did indicate a decreasing trend over cycles of selection. That trend suggests that, as a result of selection, the populations are tending to become better adapted to low-yielding environments characterized by high stress. The later cycles of selection also performed better than cycle 0 in high-yielding and medium environments.

Lowland tropical populations of intermediate maturity—Three cycles (C0, C1 or C2, and C4 or C5) of Populations 23 (Blanco Cristalino-1), 26 (Mezcla Amarilla), 32 (ETO Blanco), and 35 (Antigua x República Dominicana) were evaluated at the following locations: Ciudad Obregón (Mexico), Las Acacias (Honduras), Cuyuta (Guatemala), Farm Suwan (Thailand), Cali (Colombia), and Poza Rica (Mexico, summer and winter). In all four populations, yield and number of ears per plant increased, while plant and ear height decreased (Table 18). Ear aspect was improved in Populations 26 and 35 but did not change in Populations 23 and 32. Days to silk increased slightly in Population 35 but decreased in the other populations. The greatest improvement in yield and number of ears per plant was achieved with Population 32. Progress per cycle across the four populations for yield, days to silk, plant height, ear height, ear aspect, and ears per plant averaged 2.05, -0.30, -0.45, -0.84, -1.25, and 1.20% respectively. The ranges in improvement for those traits were 0.71 to 3.22, -0.95 to 0.17, -0.58 to -0.35, -1.30 to -0.27, -2.50 to 0, and 0.42 to 2.27%, respectively (Table 19).

Eberhart and Russell's stability parameters for yield, days to silk, and plant height in the original and two subsequent cycles are given in Table 20. As in the trial of late-maturing materials discussed above, b values were generally close to 1.0. Moreover, although the b values of the cycles did not differ significantly from one another in any of the populations, the intermediate cycles of selection consistently had lower b values than the original and later cycles.

Table 18. Mean performance of four intermediate-maturity tropical maize populations evaluated over seven locations for three cycles of selection

Cycles of selection	Yield (kg/ha)	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Ear aspect (1-5)	Ears per plant
Population 23						
C0	5106	64.1	211	113	3.2	0.91
C2	5636	61.8	201	103	2.7	0.98
C5	5288	63.4	206	108	3.2	0.97
Mean	5343	63.1	206	108	3.0	0.95
Population 26						
C0	4968	62.9	208	108	3.2	0.96
C2	4638	62.2	197	93	3.2	0.96
C5	5403	59.9	202	101	2.8	0.98
Mean	5003	61.6	202	101	3.1	0.97
Population 32						
C0	4842	64.4	212	108	3.2	0.88
C1	5035	64.5	210	111	3.4	0.92
C4	5465	63.9	209	104	3.2	0.96
Mean	5114	64.3	210	108	3.3	0.92
Population 35						
C0	4659	58.8	192	94	3.0	0.95
C1	4539	59.3	183	87	2.9	0.92
C4	5128	59.2	189	93	2.7	0.98
Mean	4775	59.1	188	92	2.9	0.95
LSD (5%) between pop.	204	0.5	3	3	0.2	0.02
LSD (5%) within pop.	284	0.7	5	5	0.2	0.04

Table 19. Progress per cycle through full-sib selection for six traits in four tropical maize populations of intermediate maturity

Population number	Yield	Days to silk	Plant height	Ear height	Ear aspect	Ears per plant
			Percent			
23	0.71	-0.22	-0.47	-0.88	0	1.32
26	1.75	-0.95	-0.58	-1.30	-2.50	0.42
32	3.22	-0.19	-0.35	-0.93	0	2.27
35	2.52	0.17	-0.39	-0.27	-2.50	0.79

Subtropical populations—Three cycles of selection (C0, C1 or C2, and C4 or C5) in Populations 34 (Blanco Subtropical), 42 (ETO-Illinois), 44 (AED-Tuxpeño), 45 (Amarillo Bajío), and 48 (Compuesto de Hungría) were evaluated in three environments: Tlaltizapán (Mexico, summer and winter) and Ciudad Obregón (Mexico). Yield was increased in four of the populations, showing a slight decrease only in Population 48 (Table 21). The greatest amount of progress was made with that population, however, in reducing maturity and height. Improvement in plant and ear height and in ear aspect was brought about in all five populations. The greatest degree of progress in yield occurred in Population 34, although the time to maturity of this population also increased slightly. Progress per cycle across the five populations for yield, days to silk, plant height, ear height, ear aspect, and ears per plant averaged 1.47, -1.02, -1.97, -3.51, -3.78, and -0.37%, respectively. The ranges in improvement of those traits were -1.19 to 3.68, -1.90 to 0.17, -2.86 to -0.58, -5.96 to -1.88, -5.88 to -1.56, and -1.57 to 0.74%, respectively (Table 22). Stability analyses were not performed for this trial because there were too few locations.

Site-specific varieties—Varieties developed on the basis of data collected at Poza Rica for cycle 0 and the most recent cycle of selection in ten populations were evaluated in four environments: Poza Rica (summer and winter) and Tlaltizapán (summer and winter). The test materials were Populations 21, 22, 24, 26, 27, 28, 32, 35, 36, and 43 (see descriptions in Appendix 2).

In all ten populations, the varieties derived from the latter cycles of selection were higher yielding, earlier, and less barren than those from cycle 0. They were also significantly shorter, with the exception of varieties from Populations 21 and 43, and had better ear aspect, except those from Populations 22 (Tables 23 and 24).

Analyses of yield stability suggested that the more recently developed varieties were better adapted to low-yielding environments than those from cycle 0. For eight of the populations, varieties derived from the more recent cycle had lower b values than those from cycle 0 (Table 25). Standard deviations from regression were significant only for three varieties, all of which were developed in the first cycle of improvement of three populations. Stability parameters for maturity and plant height indicated that the varieties were generally stable in those traits across the four environments.

Across varieties—Varieties of this type, developed from the same cycles of selection in the same 10 populations discussed in the preceding section, were evaluated in the same environments for progress in improvement. Varieties developed from the more recent cycles of selection were higher yielding and less barren than those from cycle 0 in all 10 populations. They were also shorter, with the exception of those from Population 21 (Tuxpeño-1), and earlier, except in the case of materials from Populations 21 and 35 (Antigua x República Dominicana) and had better ear aspect, though not the varieties from Population 24 (Antigua Veracruz-181) (Tables 26 and 27).

Analyses of yield stability indicated that the across varieties derived from the more recent cycles were better adapted to low-yielding environments than those from cycle 0 (Table 28). Regression values for the cycle 0 varieties averaged 1.11 across the ten populations, compared to 0.89 for varieties from the more recent cycles of selection. For nine of the populations, the more recent varieties had lower b values than those developed earlier. Deviations from regression were significant only in the case of varieties from Populations 21 and 26 (Mezcla Amarilla) and for Across 7936 and 7442.

Regressions and deviations from regression for maturity and plant height indicate that the varieties were generally stable in those traits across the four environments.

Table 20. Eberhart and Russell's parameters for various traits of four tropical maize populations of intermediate maturity

Population number	Cycles of selection	Yield b	Yield $s^2d \times 10^4$	Days to silk b	Days to silk s^2d	Plant ht. b	Plant ht. s^2d
23	C0	1.10	0	1.04	0.23	1.00	26.53
	C2	0.89	0	0.99	0	0.96	0
	C5	1.06	0	1.01	0	0.99	0
26	C0	1.14	0.48	1.01	0.10	1.01	0
	C2	0.95	14.16*	0.98	0	1.02	14.06
	C5	1.09	5.71	0.97	0.67	0.95	20.68
32	C0	1.06	19.19**	0.97	0.68	1.02	12.25
	C1	1.03	19.02**	1.01	0	0.94	0
	C4	1.09	15.81	0.98	0.64	0.94	0
35	C0	0.87	11.39*	0.99	0.11	1.06	0
	C1	0.79	1.45	1.03	0.48	1.09	50.25*
	C4	0.93	1.64	1.02	0.54	1.02	28.39
LSD (5%) cycles in a pop.		0.27		0.07		0.19	

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Comparison of reference entries and EVs—Reference entries are included in the EVTs so that the EVs can be compared with varieties derived from other cycles of the same population or from different populations. The same reference entries, generally the more stable varieties that have been developed by the Maize Program, are used in the trials over a period of several years.

A comparison was made between the experimental varieties and reference entries evaluated in various EVTs during 1982. All the reference entries were across varieties. The across variety test entries, developed after one additional cycle of selection in six populations and after two additional cycles in another, yielded between 95 and 115% of the yield of the appropriate reference entries, with an average of 102%. The EVs were also earlier and shorter (Table 29).

A similar comparison was made of entries in EVTs conducted during 1983. Again, only across varieties were compared, and there was a difference of two cycles of selection between the reference entries and the EVs. The EVs were superior in yield, which ranged from 101 to 112% and averaged 107% of the yield of the reference entries. There were no differences in maturity and height between the EVs and appropriate reference entries (Table 29).

Summary of trials—The population improvement scheme employed by the Maize Program has proven to be effective in raising the yield of most of the populations. Selection has simultaneously reduced height and maturity, brought about a greater reduction in ear than in plant height, and decreased barrenness and ear aspect. Stability analyses indicate that the populations have also been improved slightly for adaptation to low-yielding environments while good performance in high-yielding and medium environments has been maintained.

Experimental varieties developed from the more recent cycles of selection in the populations are higher yielding, earlier, and shorter than those from the original cycles. The former are also more prolific and better in ear aspect. Stability analyses indicate, moreover, that those varieties are better adapted to low-yielding environments than ones from the original cycles and also perform better in high-yielding and medium environments.

Table 21. Mean performance of five subtropical maize populations evaluated over three locations for three cycles of selection

Cycles of selection	Yield (kg/ha)	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Ear aspect (1-5)	Ears per plant
Population 34						
C0	6155	68.7	215	115	3.4	1.14
C2	7412	72.1	225	129	3.7	1.19
C5	7289	69.3	196	101	3.0	1.05
Mean	6952	70.0	212	115	3.3	1.13
Population 42						
C0	7238	70.2	215	117	4.1	1.13
C2	7555	70.4	223	118	3.7	1.05
C4	8014	69.7	210	106	3.0	1.06
Mean	7602	70.1	216	114	3.6	1.08
Population 44						
C0	7118	76.2	233	135	3.2	1.01
C2	8165	74.0	227	128	3.0	1.03
C4	7490	71.5	212	114	3.0	1.04
Mean	7591	73.9	224	126	3.1	1.03
Population 45						
C0	6556	66.7	206	103	3.4	1.02
C1	6563	65.3	197	101	3.3	1.02
C2	6670	64.5	196	96	3.0	1.02
Mean	6596	65.5	200	100	3.2	1.02
Population 48						
C0	4792	64.3	192	88	3.1	0.99
C2	5631	63.3	194	97	2.8	0.98
C4	4563	59.4	170	67	2.8	1.01
Mean	4995	62.4	186	84	2.9	0.99
LSD (5%) between pops.	360	0.8	5	5	0.2	0.04
LSD (5%) within pops.	502	1.3	8	7	0.3	0.66

Table 22. Progress per cycle through full-sib selection for six traits in five subtropical populations

Population number	Yield	Days to silk	Plant height	Ear height	Ear Aspect	Ears per Plant
			Percent			
34	3.68	0.17	-1.76	-2.43	-2.35	-1.57
42	2.68	-0.17	-0.58	-1.88	-6.70	-1.54
44	1.30	-1.54	-2.25	-3.88	-1.56	0.74
45	0.86	-1.64	-2.42	-3.39	-5.88	0
48	-1.19	-1.90	-2.86	-5.96	-2.41	0.50

Table 23. Performance of 20 site-specific varieties developed during cycle 0 and the last available cycle of selection, means for four locations

Varieties (Poza Rica)	Yield (kg/ha	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Ear aspect (1-5)	Ears per plant
7421	5069	77.8	181	91	2.7	0.90
8121	5196	77.6	186*	94*	2.5	0.92
Mean	5132	77.7	183	93	2.6	0.91
7422	5231	78.1	198	108	2.8	0.86
8022	5604	76.4*	187*	95*	2.9	0.90
Mean	5418	77.2	193	101	2.8	0.88
7424	4739	78.1	194	107	2.9	0.91
8024	5243*	77.9	194	101*	2.7	0.93
Mean	4991	78.0	194	104	2.8	0.92
7426	4535	75.6	178	86	3.2	0.94
7926	4838	71.9*	172*	82	2.4*	0.98
Mean	4687	73.8	175	84	2.8	0.96
7427	4477	78.6	204	107	2.7	0.89
8027	4961*	76.1*	190*	97*	2.3*	0.96
Mean	4719	77.4	197	102	2.5	0.92
7428	4675	79.0	202	109	3.1	0.90
8128	5237*	75.4*	190*	97*	2.9	0.93
Mean	4956	77.2	196	103	3.0	0.92
7532	4516	78.8	187	98	3.1	0.87
8032	4952	76.0*	176*	85*	2.6*	0.94
Mean	4734	77.4	181	92	2.8	0.91
7535	4521	73.6	169	80	2.9	0.93
8035	4614	71.4*	164*	74*	2.9	0.95
Mean	4567	72.6	166	77	2.9	0.94
7436	4665	78.4	211	121	3.1	0.92
7936	5306*	74.6*	177*	91*	2.5*	0.93
Mean	4986	76.6	194	106	2.8	0.92
7443	4681	80.9	205	112	3.5	0.85
8043	5359*	80.6	210*	119*	2.4*	0.90
Mean	5020	80.8	208	115	2.9	0.88
LSD (5%) between pops.	376	0.7	5	4	0.2	0.04
LSD (5%) within pops.	440	0.8	5	5	0.3	0.04

* Significant at the 0.05 level of probability.

Table 24. Percentage change in varieties developed from later cycles of selection compared to those developed from cycle 0 of 10 tropical maize populations

Varieties (Poza Rica	No. of cycles	Yield	Days to silk	Plant height	Ear height	Ear aspect	Ears per plant
				Percent			
7421 vs. 8121	4	2.50	-0.25	2.76	3.29	-7.40	2.22
7422 vs. 8022	4	7.13	-2.17	-5.55	-12.03	3.57	4.65
7424 vs. 8024	4	10.63	-0.25	0	-5.60	-6.89	2.19
7426 vs. 7926	3	6.68	-4.89	-3.37	-4.65	-25.00	4.25
7427 vs. 8027	4	10.81	-3.18	-6.86	-9.34	-14.81	7.86
7428 vs. 8128	4	12.02	-4.55	-5.94	-11.00	-6.45	3.33
7532 vs. 8032	3	9.65	-3.55	-5.88	-13.26	-16.12	8.04
7535 vs. 8035	3	2.05	-2.98	-2.95	-7.50	0	2.15
7436 vs. 7936	3	13.74	-4.84	-16.11	-24.79	-19.35	1.08
7443 vs. 8043	4	14.48	-0.37	2.43	6.25	-31.42	5.88

Note: The percentages were derived as follows:

$$\left[\frac{\text{Performance of latest variety}}{\text{Performance of first variety}} - 1\right] \times 100$$

Table 25. Eberhart and Russell's stability parameters for varieties developed from cycle 0 and later cycles of selection in 10 tropical maize populations.

Varieties (Poza Rica)	Yield b	Yield $s^2d \times 10^5$	Days to Silk b	Days to Silk s^2d	Plant ht. b	Plant ht. s^2d
7421	0.73	4.64**	0.99	0	0.89	6.35
8121	1.42*	0	0.95	0	0.74	0
7422	1.19	0.16	0.99	0	1.10	6.86
8022	1.09	0.56*	1.02	0	0.89	9.61
7424	0.90	0	1.04	0	0.93	11.30
8024	0.87	0	1.08	0	0.97	0
7426	1.26	3.69*	0.99	0	1.02	0
7926	0.95	0	0.93	0	1.02	7.17
7427	0.76	0.24	1.02	0.15	1.01	0
8027	0.64	0.60*	0.98	0	1.21	0
7428	1.18	0	0.97	0.06	0.85	136.59**
8128	0.94	0.68*	0.96	0	0.84	0
7532	1.14	0	0.96	0.47	1.18	160.78**
8032	1.02	0	0.96	0.03	1.21	34.89**
7535	0.70	0	0.97	0	1.18	0
8035	0.69	1.73*	0.92	0.45	1.13	4.81
7436	0.92*	0.44	1.02	0	0.84	35.76*
7936	0.98	0	0.97	0	1.13	14.88
7443	1.43	6.00**	1.16	0.37	0.90	486.79**
8043	1.15	0.59	1.09	0	0.93	16.78
LSD within pops.	0.65		0.05		0.62	

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.

Table 26. Performance of 20 across varieties developed during cycle 0 and the last available cycle of selection, means for four locations

Across varieties	Yield (kg/ha)	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Ear aspect (1-5)	Ears per plant
7421	4969	76.4	179	85	2.8	0.85
8121	5451*	77.8*	193*	100*	2.7	0.90*
Mean	5210	77.1	186	93	2.7	0.88
7422	5437	78.2	198	105	3.0	0.88
8022	5665	76.0*	187*	93*	2.8	0.94*
Mean	5551	77.1	193	99	2.9	0.91
7424	4767	77.9	183	103	2.7	0.93
8024	5209*	77.2*	182	97	2.8	0.94
Mean	4988	77.6	182	100	2.7	0.94
7426	4504	74.2	184	90	3.4	0.91
7926	4608	68.9*	164*	77	3.0*	0.97*
Mean	4556	71.5	174	84	3.2	0.94
7427	4690	78.9	213	115	2.7	0.86
8027	5454*	77.6*	192*	99*	2.4*	0.97*
Mean	5072	78.2	203	107	2.6	0.91
7428	5097	78.2	207	115	2.9	0.91
8128	5530*	75.8*	200	102*	2.8	0.95
Mean	5313	77.0	204	108	2.8	0.93
7532	4207	79.1	211	112	2.8	0.75
8032	5318*	77.1*	181*	88*	2.7	0.91*
Mean	4763	78.1	196	100	2.7	0.83
7535	4489	70.5	177	83	3.0	0.90
8035	5027*	71.7*	173	79*	2.8	0.96*
Mean	4758	71.1	175	81	2.9	0.93
7436	4828	77.6	211	124	3.3	0.91
7936	5492*	73.6*	185*	96*	2.5*	0.96*
Mean	5160	75.6	198	110	2.9	0.93
7443	5505	81.7	223	127	3.5	0.84
8043	5563	80.9*	213*	116*	2.5*	0.85
Mean	5534	81.3	218	122	3.0	0.85
LSD (5%) between pops.	433	0.7	8	4	0.2	0.04
LSD (5%) within pops.	425	0.7	8	4	0.3	0.05

* Significant at the 0.05 level of probability.

Table 27. Percentage change in across varieties developed from cycles of selection, compared to those developed from cycle 0 of 10 tropical maize populations

Across varieties	No. of cycles	Yield	Days to silk	Plant height	Ear height	Ear aspect	Ears per plant
				Percent			
7421 vs. 8121	4	9.70	1.83	7.82	17.64	-3.57	5.88
7422 vs. 8022	4	4.19	-2.81	-5.55	-11.42	-6.66	6.81
7424 vs. 8024	4	9.27	-0.89	-0.54	-5.82	3.70	1.07
7426 vs. 7926	3	2.30	-7.14	-10.86	-14.44	-11.76	6.59
7427 vs. 8027	4	16.28	-1.64	-9.85	-13.91	-11.11	12.79
7428 vs. 8128	4	8.49	-3.06	-3.38	-11.30	-3.44	4.39
7532 vs. 8032	3	26.40	-2.52	-14.21	-21.42	-3.57	21.33
7535 vs. 8035	3	11.98	1.70	-2.25	-4.81	-6.66	6.66
7436 vs. 7936	3	13.75	-5.15	-12.32	-22.58	-24.24	5.49
7443 vs. 8043	4	1.05	-0.97	-4.48	-8.66	-28.57	1.19

Note: The percentages were derived as follows:

$$\left[\frac{\text{Performance of latest}}{\text{Performance of first variety}} - 1\right] \times 100$$

Table 28. Eberhart and Russell's stability parameters for across varieties developed from cycle 0 and later cycles of selection in 10 tropical maize populations

Across varieties	Yield b	Yield $s^2b \times 10^5$	Days to silk b	Days to silk s^2d	Plant ht. b	Plant ht. s^2d
7421	1.04	4.25*	0.95	0.07	0.77	32.8
8121	1.18	3.26*	1.00	0	0.95	18.0
7422	0.94	0.19	1.02	0	1.00	0
8022	0.82	0	1.04	0	1.04	10.5
7424	0.88	0	1.07	0	1.43	164.3*
8024	0.85	0	1.04	0.24	1.49	0
7426	1.36	5.46**	1.00	0	0.96	34.6
7926	0.81	10.67**	0.79	0.43	1.03	110.5*
7427	0.94	2.49	1.03	0	0.93	38.6
8027	0.83	0.79	1.05	0	0.98	0
7428	1.42	0.31	1.04	0	0.91	164.8*
8128	0.81	0	1.02	0	1.02	0
7532	1.38	1.62	0.92	0.42	1.56	545.3**
8032	0.97	0.34	0.99	0	0.78	16.0
7535	0.78	1.09	0.91	0.31	1.08	0
8035	0.73	0	0.94	0	1.11	0
7436	0.94	0	0.99	0.75	0.78	0
7936	0.66	3.67*	0.95	0	0.82	0
7443	1.43	3.79*	1.09	0.74	0.65	65.9
8043	1.25	2.16	1.11	0	0.72	46.2
LDS (5%) within pops.	0.92		0.05		0.69	

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.

Table 29. Comparison of experimental varieties with appropriate reference entries in EVTS conducted during 1982 and 1983

No. of locations	Experimental Varieties (EVs) Name (Across)	Yield (kg/ha)	Plant ht. (cm)	Days to silk	Reference Entries (RE) Name (Across)	Yield (kg/ha)	Plant ht. (cm)	Days to silk	(EV/RE) X 100 Yield	Plant ht.	Days to silk
1982 Trial											
28	8022	5593	205	59	7622	5739	207	59	97	98	100
28	7926	4502	182	54	7726	3916	187	56	115	98	96
23	7928	4580	211	58	7728	4644	215	59	99	98	99
28	7929	5531	205	59	7729	5433	206	60	102	99	98
10	7934	6271	188	62	7734	6624	192	62	95	98	99
15	8045	6115	191	62	7845	5766	195	63	106	98	94
15	7948	4649	182	58	7748	4665	184	58	100	98	99
1983 Trial											
23	8027	4525	209	55	7627	4048	214	55	112	98	100
23	8128	4726	213	54	7728	4427	209	55	107	102	99
19	8035	4643	188	53	7635	4601	186	52	101	101	102

International Testing

The Maize Program's international testing network serves as a link between the Advanced Unit and CIMMYT's clients in national maize research organizations around the world. It is the principal means by which national scientists become involved in maize breeding conducted at the Center and receive germplasm generated through that work.

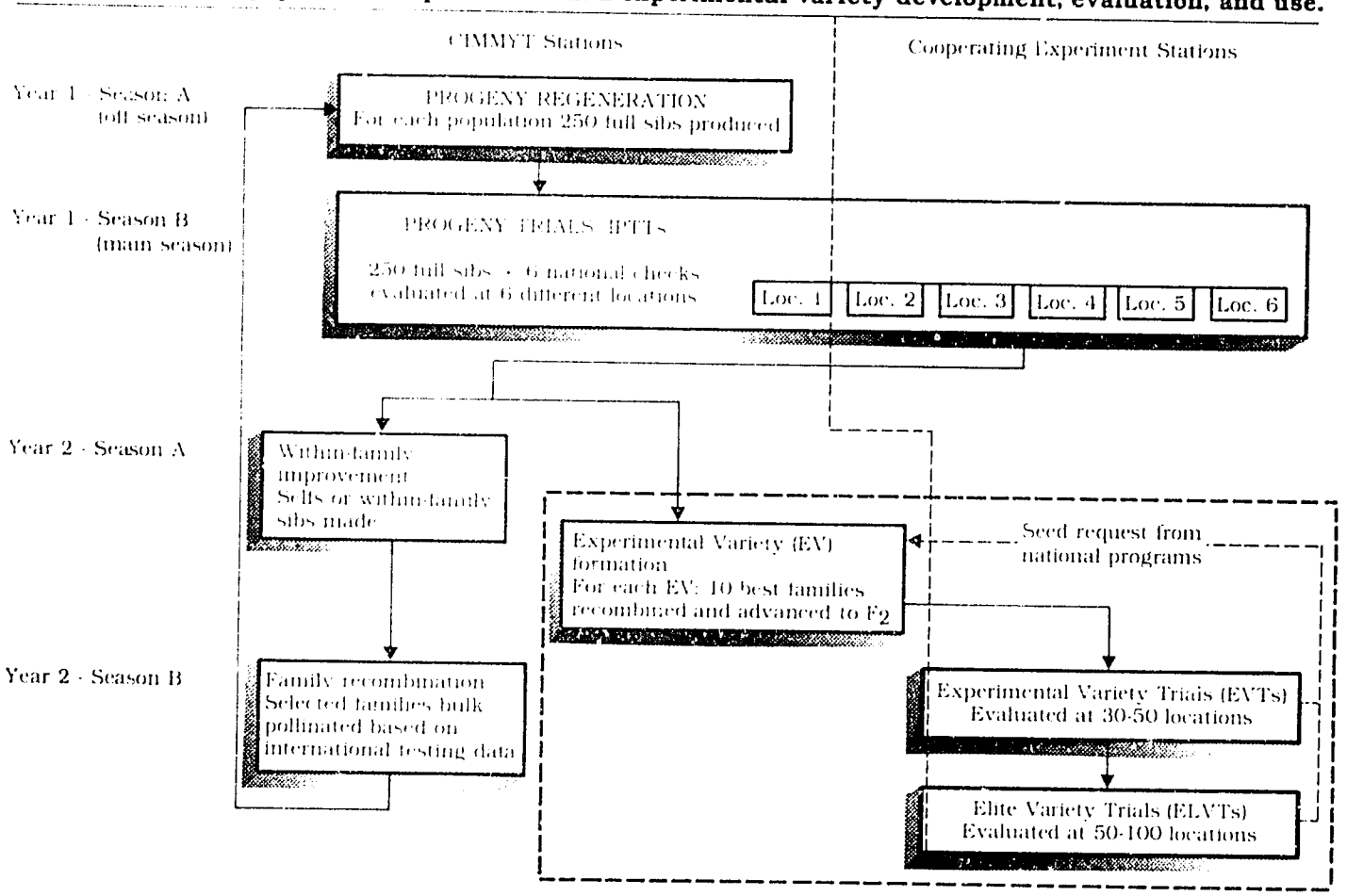
Structure of the Testing Network

Germplasm improved by the Maize Program undergoes three stages of international testing: (1) evaluation of full-sib families in International Progeny Testing Trials (IPTTs), (2) testing of newly formed varieties in Experimental Variety Trials (EVTs), and (3) further evaluation of the most promising varieties in Elite Variety Trials (ELVTs). The steps in population improvement and international testing are shown in Figure 2, and the relation between gene pools, populations, and the corresponding variety trials is indicated in Table 30.

IPTTs—As indicated in a preceding section of this report, international testing is an integral part of the Program's population improvement scheme. In the course of the two-year improvement cycle, 250 full-sib families of each population are tested in IPTTs at up to six locations around the world (one of them a CIMMYT station in Mexico). Test sites are chosen that represent the environment in which a given population is intended to be employed. Since each of the 32 populations is tested every other year, about 15 are evaluated in a given year.

The experimental design of the trials is a 16 x 16 lattice with two replications. Cooperators compare the 250 families with six local checks (the best locally available hybrids or varieties) on the basis of grain yield and a number of other agronomic traits. They send the results to CIMMYT for analysis of data from specific sites and combined analysis across test locations.

Figure 2. Steps in population improvement and experimental variety development, evaluation, and use.



In 1982 a total of 66 IPTTs developed from 12 normal populations were sent to cooperators in 26 countries (Table 31). Data were received for 50 of those trials (76%). During 1983, 94 IPTTs from 11 normal (including three highland) populations and four quality protein maize (QPM) populations were distributed to 31 countries. Results were returned for 86% of the total number of trials sent.

The results, as mentioned in the section on population improvement, are used for two purposes. First, on the basis of across-site data, the best 25 to 30% of the families are chosen from each population and retained for within-family improvement, recombination, and regeneration of new progeny for the next cycle of improvement. The second use of progeny trial data is for the development of experimental varieties (EVs). Most EVs are generated from the 10 best families at a given test location; they are also generated from the 10 best families across sites. In the formation of those varieties, the selected families are crossed in all possible combinations and advanced to the F_2 stage by bulk pollination.

Most experimental varieties are identified by test site, year, and population, indicating where and when the progeny that form the variety were tested. The variety Iboperenda 8321, for example, was generated from the ten best families in a progeny trial of Population 21 grown at Iboperenda, Bolivia, during 1983. Varieties developed from the best 10 families across all test sites receive names like Across 8321.

EVTs—In these trials EVs (grouped according to climatic adaptation, maturity, and grain color and type) are evaluated at 30 to 50 locations

Table 30. Relationship between gene pools, populations, and variety trials in CIMMYT's normal maize improvement program

Climatic adaptation	Grain color	Type	Pools	Populations	EVT	ELVT
Tropical, late maturing	White	Flint	23	25	12	18A
		Dent	24	21, 22[a], 29, 43[b]		
	Yellow	Flint	25	27	13	
		Dent	26	24, 28[a], 36		
Tropical, early and intermediate maturity	Yellow	Flint	17 21	31[a] 26	14A	18B
		Dent	18, 22			
	White	Flint	15 19	30 23, 32	14B	
		Dent	16 20	49		
Subtropical, early and intermediate maturity	Yellow	Flint	29 33	46 33	16A	20
		Dent	30 34	48 45		
	White	Flint	31 27	34	16B	
		Dent	32 28	42, 44, 47		

[a] At Farm Suwan (Thailand) for improvement of downy mildew resistance.
[b] At IITA (Nigeria) for improvement of streak resistance.

by cooperators in national research programs, who compare them with two local checks and two reference entries (the latter are CIMMYT materials with which trial entries are compared over several years of testing). The trials have a randomized complete block design with four replications and are grown in four-row plots of approximately 16 m^2. They are overplanted by 33% and thinned to the desired plant density, which is determined by trial cooperators. In 1982-83 a total of 193 new experimental varieties were tested in 17 different EVTs.

ELVTs—The EVs that perform best across all the EVT locations are assembled into ELVTs, which are widely distributed, upon request, to national programs throughout the developing world and carried out in much the same way as the EVTs. In 1982-83 a total of 25 new elite EVs were evaluated in three different ELVTs. These trials and the EVTs totaled 560 and were distributed to 72 countries in 1982; during the following year 733 EVTs and ELVTs were sent to 68 countries (Table 31).

Quality of the Trial Data

The current international maize testing system has grown and improved in precision considerably since its inception in the early 1970s. Likewise, the national programs involved in this system have become ever more adept at developing their own breeding materials and in using germplasm from CIMMYT more effectively to meet farmers' variety requirements. The continued development of those programs is vital to the success of the Center's maize improvement work, which depends to a large degree on evaluation of full-sib families by national cooperators. The more skill and precision they bring to the work of compiling data on the yield and agronomic traits of this material, the greater will be the Program's progress in improving the populations.

To determine the quality of yield data generated from the 1983 IPTTs, the trials were analyzed on the basis of coefficients of variation (CVs) and the relative efficiency (RE) of the lattice design, compared to that of a randomized complete block design. The CV is not, of course, a very precise indicator of trial quality, but it can give some idea of the amount of variability in a trial. CVs of 10% or less are considered excellent, 11 to 20% good, and 21 to 25% acceptable. An RE of 100 indicates that the statistical value of the lattice design is the same as that of a randomized complete block design and values higher than 100 that the lattice design is more efficient. An RE of 125 indicates that the lattice design offers a significant benefit. Of the 69 sets of 1983 IPTT data, 49 were good or excellent, judging from the CVs, and 13 were acceptable. At eight of the test locations, the lattice design was of significant benefit (Table 32).

Table 31. Distribution of international maize trials in 1982 and 1983

Region	IPTTs 1982	IPTTs 1983	EVTs and ELVTs 1982	EVTs and ELVTs 1983
South America	16	26	75	94
Mexico, Central America, and the Caribbean	17	34	162	181
Africa	13	18	187	240
Asia	20	16	122	205
Other			14	13
Total no. of trials sent	66	94	560	733
Total no. of countries participating	26	31	72	68

Table 32. Distribution of coefficients of variation (CV) and relative efficicencies (RE) of the lattice design for grain yield of the 1983 International Progeny Testing Trials

RE (%)	CV (%) 6-10	11-15	16-20	21-25	26-30	31-35	Over 35	Total
Less than 100	—	—	—	—	—	—	—	0
100-115	8	19	15	8	2	1	1	54
116-125	—	2	1	2	2	—	—	7
126-150	2	—	1	—	—	1	—	4
151-175	—	1	—	2	—	—	—	3
176-200	—	—	—	—	—	—	—	0
Over 200	—	—	—	1	—	—	—	1
Total	10	22	17	13	4	2	1	69

Performance of Experimental Varieties

Another basis for judging the quality of the international trials is the average yields achieved. As shown in Figure 3, average yields of 5 t/ha or greater were reported for 55 of the 1983 IPTTs (86%). Such high yields are an indication, not only of the high quality of the germplasm, but also of the excellent trial management provided by national cooperators.

The performance of the germplasm is also judged by comparison with reference entries and local checks. The former are elite varieties that have given high and stable yields and shown wide adaptation in previous trials. Comparing new EVs with those varieties is an important means of monitoring the progress of population improvement. The EVs are compared with local checks (which are provided by trial cooperators and are the best materials available locally) to get an indication of their possible usefulness to national programs and of their range of adaptation.

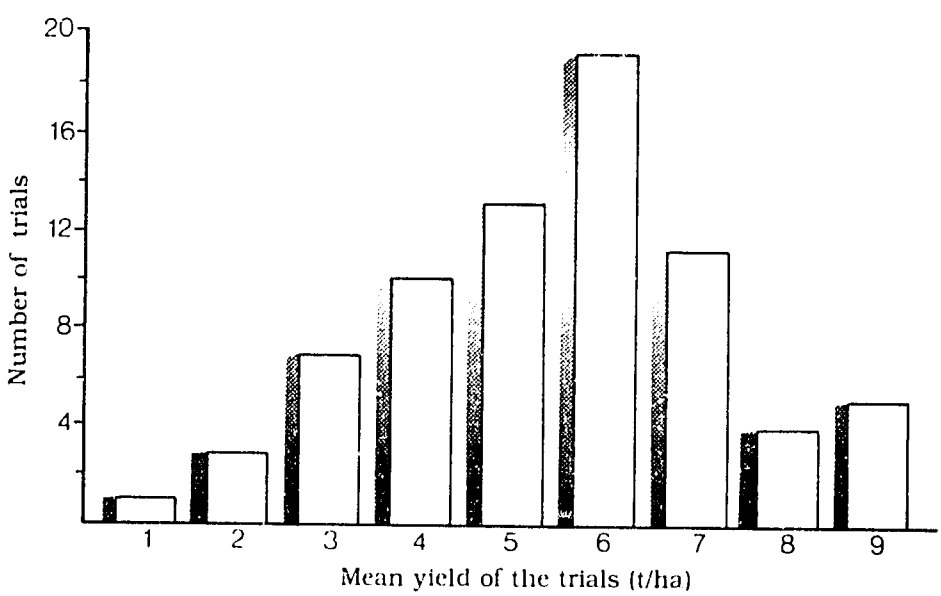
Among tropical, late-maturing, white dent varieties, Across 8121, Gandajika 8022, Ferke 8129, Ilonga 8043, and Santa Rosa 8073 were top performers at a number of locations in Asia, South America, and Africa. The best yellow dent materials in the tropical, late group were Los Baños 8027, Guarare (1) 8128, and Los Baños (1) 8136. Of the tropical, early to intermediate-maturity varieties, Suwan 8126, Islamabad (1) 8131, Across 8035, Ilonga 8032, and Across 8149 gave high and stable yields across several locations. The subtropical varieties Guaira 8045 and Tlaltizapán 8134 consistently yielded more than the local checks at many test locations. Most of the varieties mentioned here were also earlier in maturity and had shorter plant height than the best checks at several locations.

Many elite varieties tested during 1983 in ELVTs were superior in yield to the local checks and in most cases were shorter in plant height and a few days earlier in days to flower.

Table 33 summarizes the performance of new EVs and elite varieties, by comparison with the reference entries, in various EVTs and ELVTs conducted during 1983 over a wide range of environments. In general, more varieties giving higher yields than the reference entries were found among the tropical materials of all maturity classes (tested in EVTs 12, 13, 14A, and 14B and ELVTs 18A and 18B) than among the QPM and subtropical varieties (tested in EVTs 15A, 15B, 16A, and 16B and ELVT 20).

Overall summaries of variety yields and trial CVs during 1983 are given in the form of histograms in Figures 4 and 5, respectively. As shown in Figure 4 the greatest percentage of trial sites for all 11 trial types falls into the yield category of 3 to 6 t/ha. EVTs 12, 15B, and 16B and ELVT 18A and 20 (which contain tropical full-season, subtropical QPM, and subtropical normal maize) are particularly noteworthy, since mean yields were 6 t/ha or greater at more than 20% of the sites at which these trials were conducted. Good grain yields in the trials can be attributed to a combination of factors, including favorable weather, the high yield potential of the test materials, and careful trial management by cooperators in national programs.

Figure 3. Histogram of the mean yields of the 1983 International Progreny Trials.



Use of CIMMYT Germplasm

Germplasm developed and distributed by the Maize Program is used in both the public and private sectors for two purposes: (1) maize research and (2) maize production. The following sections describe how and to what extent the germplasm has been used for those purposes in recent years. Such information is not always easy to obtain, and the Maize Program has not expended too much effort in trying to do so. As a result, this account is far from complete.

Maize research—National maize programs develop new populations from CIMMYT materials and introgress them into existing populations and germplasm complexes, which are improved according to various selection schemes and serve as sources of

new varieties and lines. Germplasm from the Center is also employed in various types of theoretical studies. The latter use is expected to increase as national breeding programs develop greater interest and expertise in that type of work and as better plant types and sources of resistance (to diseases, insect pests, etc.) are developed by CIMMYT through primary-trait improvement in various maize populations.

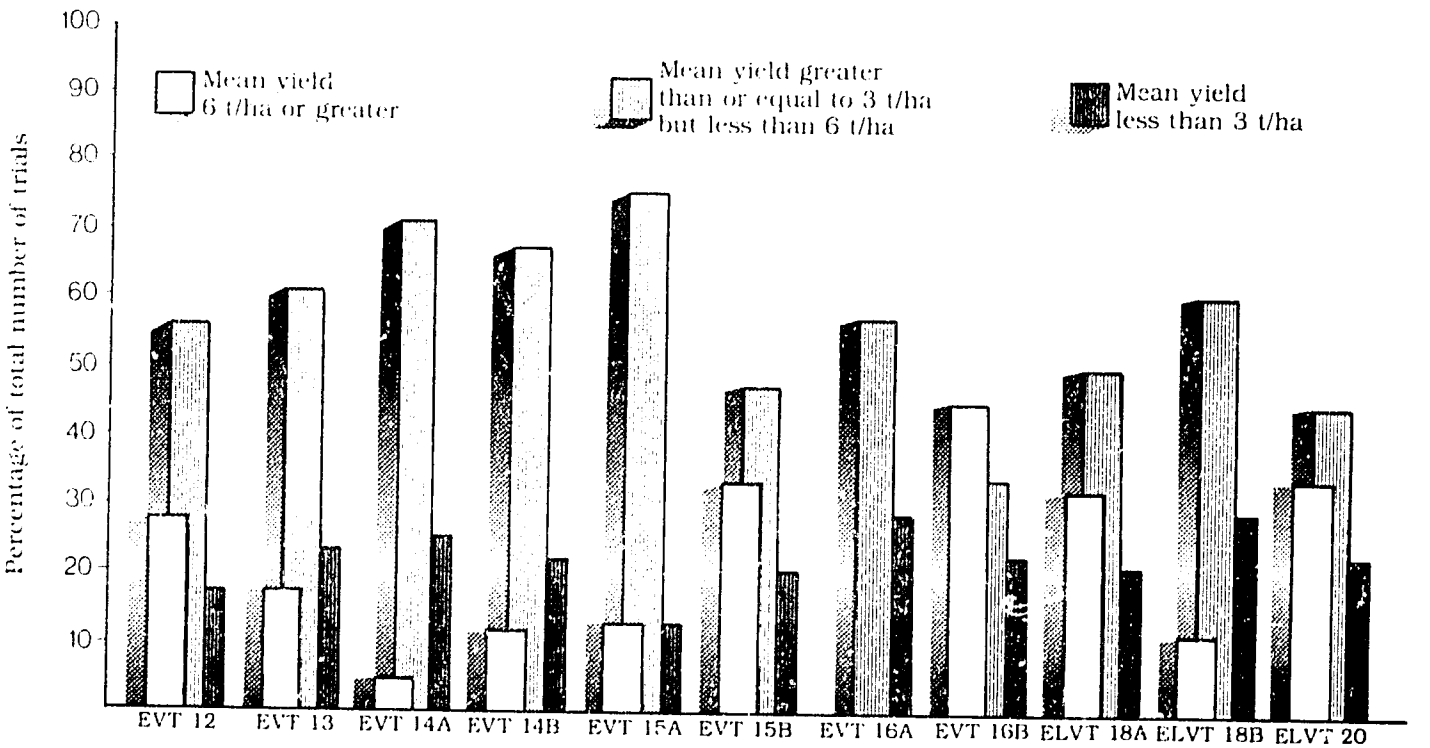
Though it is difficult to document germplasm use in national programs, we can safely say that practically all national maize programs around the world, including many in developing countries, are employing materials from the Center in their germplasm enhancement work.

Maize production—CIMMYT populations and experimental varieties, as well as materials that have not undergone international testing, have been released as such, or after a few cycles of improvement, by a number of national programs. National

Table 33. Comparison of experimental varieties (EVs) with reference entries (REs) from the same population, 1983 trials

Trial	No. of locations	Pop. number and name	No. of EVs with yield higher than REs	No. of EVs with yields lower than REs
12	42	22 Mezcla Tropical Blanca	0	1
		29 Tuxpeño Caribe	3	0
13	46	27 Amarillo Cristalino-1	3	1
		28 Amarillo Dentado	9	1
14A	38	26 Mezcla Amarilla	2	0
		35 Antigua-Rep. Dominicana	1	1
14B	35	30 Blanco Cristalino-2	3	1
15A	29	40 White QPM	1	4
15B	11	41 Templado Amarillo QMP	1	5
16A	19	45 Amarillo Bajio	0	1
16B	20	34 Blanco Subtropical	0	6
18A	61	28 Amarillo Dentado	1	0
		29 Tuxpeño Caribe	1	0
18B	42	26 Mezcla Amarilla	1	0
		30 Blanco Cristalino-2	2	0
20	19	34 Blanco Subtropical	0	1
		48 Compuesto de Hungría	0	2

Figure 4. Histogram of three yield classes for 11 international variety trials grown in 1983.



researchers have also used full-sib families of various populations to develop hybrids. In some cases the heterotic counterparts of those families have been germplasm developed and improved by national breeding programs.

To get from the IPTT stage to the point of releasing cultivars based on a population generally takes up to five years. Families need to be selected based on the results of progeny tests; varieties have to be formed and tested in experiment station and on-farm trials to satisfy the requirements of varietal release committees; and adequate quantities of seed have to be produced for release to farmers.

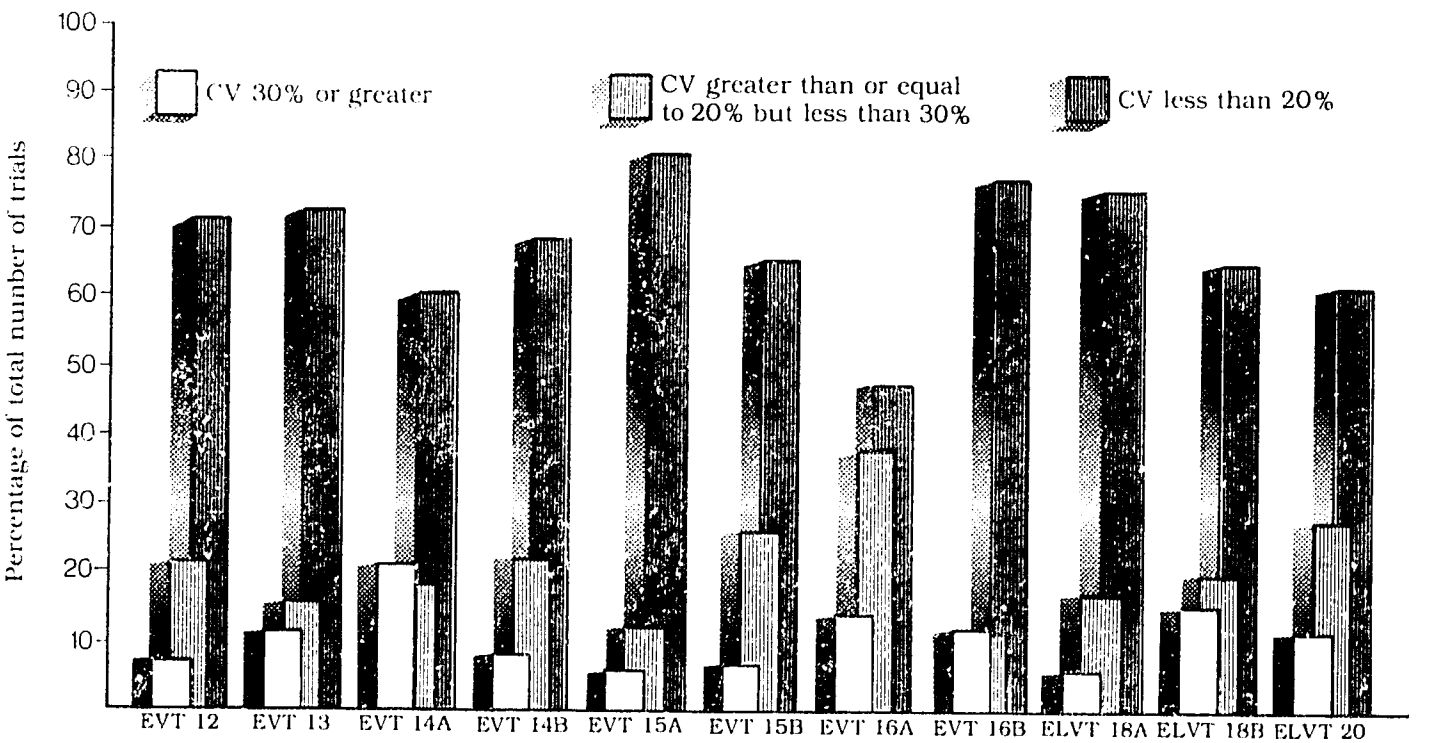
To date 35 national programs around the world have released 131 materials that include CIMMYT maize germplasm (see Appendix 3 for a list of the materials released). About 83% of them have been varieties and the remainder hybrids. Population bulks have been released 78% of the time as varieties, and 22% of the time they have contributed to released hybrids. Experimental varieties have been released 95% of the time as varieties, and all families released have contributed to the formation of hybrids.

Based on the results of IPTTs conducted through 1979, the Center's Maize Program has developed 533 experimental varieties. Of that total 42 have been released as such in 21 developing countries. In 29% of those cases, the variety was released in the same country where the corresponding IPTT was conducted. Nineteen percent of the releases were across varieties and 81% site specific. But since the ratio of site-specific to across varieties is about 4.5 to 1, it would appear that the two types have been released in equal proportions.

Of the approximately 70 million hectares of maize grown in developing countries, it is estimated that some 3 million (4.3%) are planted to varieties based on CIMMYT germplasm. The contribution to yield made by that germplasm is estimated to be about 600,000 t annually, worth nearly US$100 million at current international prices.

Thus, the benefits accruing to national research and production from germplasm distributed through the international testing network have been fairly substantial. Another way in which national scientists have profitted from their participation in the network, one which may be of even greater long-term importance, is that they have gained broader contact with their colleagues in other countries. Exchange of information among national cooperators has made them more fully aware of the problems they have in common and has enabled them to help one another in working toward solutions to those problems. One indication of closer cooperation among national scientists is that they are currently releasing EVs developed with the help of colleagues almost 2.5 times as often as those based entirely on their own IPTT data.

Figure 5. Histogram of three classes of CVs for 11 international variety trials grown in 1983.



Quality Protein Maize Improvement

The protein in maize is deficient in two essential amino acids, lysine and tryptophan. During 1970 the Maize Program initiated a research project, with financial assistance from the United Nations Development Programme (UNDP), to lessen that deficiency and thus improve the quality of protein in maize. Several factors have contributed to the overall success of the project, the most important being the research strategy and methodology employed and the efficiency of the Center's protein quality laboratory in carrying out a huge volume of chemical analyses in a timely fashion. The interdisciplinary work of participants in this research has been exemplary. They have also shown great flexibility in periodically revising their objectives and methods according to changing circumstances.

Early Work With Opaque-2 Maize

The first efforts of this research were directed toward developing materials with the opaque-2 gene, which improved protein quality but also caused maize grain to become soft and chalky. This gene was introduced into a wide array of germplasm, and some soft-grain opaque-2 composites were formed and handled using intrapopulation improvement schemes.

By 1972 Program scientists had accumulated a considerable amount of information about problems that could arise with those materials under commercial production in farmers' fields. At about the same time, similar drawbacks were observed by staff of other organizations deeply involved in work with the opaque-2 gene. The problems were serious enough to prompt researchers and funding agencies to reconsider whether this research merited further investment of time and resources. By the following year, however, CIMMYT had accumulated substantial experimental evidence that it could overcome the major problems and develop quality protein maize (QPM) that would give acceptable yields and possess other desirable agronomic traits. After a period of some uncertainty about the future of work on QPM, the Center received assurances of further support for this research. Since then the project has been reviewed periodically, with favorable results, and has continued to enjoy the financial backing of UNDP.

The first hopes for success were based on two research developments: (1) the formation of QPM donor stocks possessing kernels with the characteristics of normal grain and (2) the discovery that those characteristics are genetically controlled and can be manipulated in germplasm containing the opaque-2 gene. These developments led the project to a turning point in 1973, when a major shift was made in the type of germplasm developed, from soft- to hard-endosperm types.

The methodology employed to develop hard-endosperm opaque-2 maize dealt with two genetic systems, one involving the opaque-2 gene and the other genetic modifiers of the opaque-2 locus. This approach required the use of two approaches in QPM development: one for converting normal maize to hard-endosperm opaque-2 types and another for the development of QPM gene pools. Over time numerous adjustments were made in both programs to achieve breeding objectives more quickly and efficiently.

The conversion program was an attempt to obtain QPM versions of most of the Maize Program's pools and populations through backcross-cum-recurrent selection. Because of the complexity of the problems involved and the need to select simultaneously for several desirable attributes, while at the same time maintaining protein quality, each material in the conversion program had to be handled in a family structure. This scheme was modified in several ways to make the QPM versions of each material as similar to the recurrent parent as possible. In addition, care had to be taken not to permit dilution of the genetic modifiers that had been accumulated through tedious visual selection of modified kernels at each stage. Through this approach practically all the germplasm being worked actively in the Maize Program was converted to QPM. Most of the QPM versions of the different materials had no more than two to four backcrosses with the recurrent parent.

The idea behind the second approach, development of QPM pools, was that, by working broad-based gene complexes in a homozygous opaque-2 background, researchers could make more rapid progress in accumulating genetic modifiers, while maintaining adequate genetic variability for subsequent selection. The use of a half-sib breeding method made it possible to develop large pools and generate new recombinations every cycle and permitted selection for several traits.

Through this dual approach, the Maize Program developed QPM germplasm that was adapted to some of the major maize-growing environments and that had satisfactory kernel characteristics, with a high frequency of genetic modifiers. Progress was somewhat slower than it might have been with other approaches, but the result has been more useful end products, a wide array of QPM germplasm that can be employed in various ways as open-pollinated varieties and can serve as source germplasm for the development of QPM hybrids.

Consolidation of QPM Germplasm

By the early 1980s, a substantial amount of QPM germplasm had been developed, and researchers next considered how to further improve the material in a systematic way. They carefully examined and reorganized it into 13 pools (7 tropical and 6 subtropical) and 10 advanced populations (6 tropical and

4 subtropical), which are described in Appendices 1 and 2, respectively. The relationship between the pools and populations is shown in Table 34.

The merging and reorganization of QPM germplasm facilitates its handling in the following ways:

- QPM pools and populations will be handled uniformly in a homozygous opaque-2 background, accelerating the accumulation of genetic modifiers.
- As with the Maize Program's normal materials, it will be possible to extract families from backup QPM gene pools and introgress them into the corresponding populations.
- The Program's collection of QPM germplasm will be reduced by at least 20% without sacrificing any major types of maize needed around the world.
- At least seven new populations are now undergoing international progeny testing. This permits more systematic improvement of the materials through multilocational evaluation, broadens their adaptation (they had not previously been improved outside Mexico), allows selection of stable modifiers that may interact differently with different environments, and leads to fuller participation by national programs in the selection and use of QPM germplasm.
- Greater emphasis will be placed on early and late-maturing materials, which in our experience with international testing appear to be in greater demand among national scientists.

Table 34. QPM gene pools and corresponding populations

No. of pool	Name	No. of population	Name
15 QPM	Tropical Early White Flint QPM		—
17 QPM	Tropical Early Yellow Flint QPM	61	Early Yellow Flint QPM
18 QPM	Tropical Early Yellow Dent QPM	—	
23 QPM	Tropical Late White Flint QPM	62[a]	White Flint QPM
24 QPM	Tropical Late White Dent QPM	63, 64	Blanco Dentado-1 and Blanco Dentado-2 QPM
25 QPM	Tropical Late Yellow Flint QPM	65[a]	Yellow Flint QPM
26 QPM	Tropical Late Yellow Dent QPM	66	Yellow Dent QPM
27 QPM	Subtropical Early White Flint QPM	—	
29 QPM	Subtropical Early Yellow Flint QPM	—	
31 QPM	Subtropical Intermediate White	67	Templado Blanco

Improving QPM Gene Pools and Populations

Establishment of this new set of pools and populations was begun in 1982. New QPM materials (the early maturing pools, for example, which are being formed for the first time) will have to undergo genetic mixing for a few cycles, the exact number depending on the quantity of the material involved. In the already existing pools, new materials will be introgressed either as bulks or as families.

It is envisaged that most of the QPM pools will be handled in a half-sib mating system, with an inbreeding phase at least once every three years for improving the resistance of the materials to inbreeding stress and for eliminating deleterious genes. By the end of 1983, two cycles of half-sib selection had been completed in the newly formed early maturing pools, with emphasis on earliness and other important agronomic characters. No data are available yet showing progress in those pools nor in the intermediate-maturity Pools 31 and 32 QPM.

Additional cycles of selection were also completed in four tropical and two subtropical pools. During the 1982A season, Pools 23 and 24 QPM, both tropical materials, were handled in a half-sib system: S_1s

QPM populations, after they have undergone several cycles of genetic mixing and refinement, will be handled in a full-sib recurrent selection scheme with multilocational progeny testing. The three populations that are now included in the international testing network will remain there but with new numbers. In 1982 those materials were subjected to within-family improvement. Selfs were made in each of 250 full-sibs, and an average of three to four of these selfs were saved from roughly 40% of the full-sib families, based on progeny performance data. The selfs from selected families were recombined, and then during 1983A the half-sib ears saved from each population were used to generate a new set of full-sibs.

New QPM populations will enter the international progeny testing system at varying times following a few cycles of recombination and improvement in kernel characteristics. Two new populations, 63 and 68, were added to the IPTT system during 1983, though the latter was tested only in Mexico. In the former, full-sib families were generated for the first time. Populations 64, 66, and 70 will be improved through full-sib family selection in Mexico and will probably be ready for testing in IPTTs by 1984. Population 61 will be improved in Mexico for earliness and endosperm characteristics over at least the next two years before undergoing progeny testing.

Once all the QPM populations are included in the IPTT system, they will be divided into two groups, with one undergoing progeny testing during odd years and the other in even years. As with the pools, some populations will be artificially infected with ear rots.

On the basis of data received from various countries, a number of experimental varieties were formed from QPM populations. Table 35 gives data on the mean performance of the 10 families constituting those varieties, compared to that of the base population. Before being evaluated in EVTs, the varieties will be advanced to the F_2 stage by sib mating.

Table 35. Mean grain yield and other agronomic traits of families used in the formation of experimental varieties on the basis of 1983 data

Experimental variety	Grain yield (kg/ha) Pop. mean	Mean of selected fam.	Check mean	% difference between mean of families and: Pop. mean	Check mean	Days to flower Pop. mean	Mean of selected fam.	Plant ht. (cm) Pop. mean	Mean of selected fam.
Population 62									
Los Baños 8362	4900	6038	4712	23.2	28.1	53	53	189	187
Palmira 8362	4212	5609	5293	33.2	5.9	65	65	198	205
Kindia 8362	1483	1853	3957	24.9	53.2	62	61	130	135
Poza Rica 8362	6348	7390	6498	16.4	13.7	56	57	200	201
Population 63									
La Máquina (1) 8363	5359	6326	4546	18.0	39.1	50	53	212	222
La Máquina 8363	5359	6294	4546	17.4	38.4	50	52	212	220
San Jerónimo (1) 8363	7935	9365	7911	18.0	18.4	62	64	245	250
Las Acacias (1) 8363	6206	7613	5822	22.7	30.8	52	52	244	238
Poza Rica 8363	6654	7925	7124	19.1	11.2	57	56	204	212
Alajuela 8363	6234	7279	5456	16.8	33.4	66	65	198	201
Suwan 8363	5251	7005	5737	33.4	22.1	50	49	204	214
Across 8363	6277	7098	6099	13.1	16.3	56	57	—	—
Population 65									
Poza Rica 8365	5554	6630	5608	19.4	18.2	57	57	197	201
Vallecito 8365	5844	7098	5172	21.4	37.2	61	61	154	155
Palmira 8365	4154	5733	5048	38.0	13.6	66	64	241	244
La Molina 8365	2653	4523	1708	70.5	164.8	72	73	146	184
Guarare 8365	2347	3182	1615	35.6	97.0	—	—	161	173
Ilonga 8365	3054	4078	3020	33.5	35.0	59	59	176	191
Across 8365	4117	4713	3830	14.5	23.0	64	64	180	183
Population 69									
Tlaltizapán 8369	3118	3793	3199	—	—	58	57	197	203

Protein Quality and Biochemical Analysis

Most of the pools and populations formed during the reorganization of QPM germplasm were analyzed for protein, tryptophan, and lysine content in the whole grain. Results for the populations are given in Table 36. In most of those materials the percentage of protein was 9% or above. The proportion of tryptophan in protein ranged from 0.9 to 1.1% and that of lysine from 3.8 to 4.5%. Most of the QPM materials appear to have good protein quality, and it has been maintained over cycles of selection.

Cycles 0, 4, 8, and 10 of the white o_2 b.u. pool were analyzed for content of protein, tryptophan, lysine, and various protein fractions in the endosperm. C10 had greater protein content than the original cycle, though there was a slight decline in the values for lysine, tryptophan, and quality index (Table 37). Protein fractions I (albumins and globulins) and II (zein) also showed slight reductions in the advanced cycles, but fraction III (zeinlike) registered a gradual increase over cycles. Fraction IV (glutelinlike) remained almost unchanged, while fraction V (glutelins) showed a slight reduction.

Protein fractionation was performed on three samples each of three versions of Tuxpeño germplasm: normal, soft opaque-2, and hard endosperm opaque-2. The percentage of fraction I in hard-endosperm Tuxpeño was somewhat lower than in the soft version, but in both those materials, it was greater than in the normal version (Table 38). Fraction II was drastically reduced in the soft- and hard-endosperm versions from that in the normal, and so was fraction III. The latter tended to increase, however, with selection for hard endosperm. In both the soft- and hard-endosperm versions, fractions IV and V were greater than in normal Tuxpeño, though selection for hard endosperm tended to reduce this fraction.

Developing Early Maturing Germplasm

Increased emphasis is being given to the development of early maturing QPM materials, since this work has lagged behind that with intermediate- and late-maturing germplasm. Most of the early material will be formed from QPM versions of existing early materials and from intermediate-maturity QPM germplasm that is already available in the Maize Program.

The early maturing, tropical Pools 15, 17, and 18 QPM and subtropical Pools 27 and 29 QPM were all developed in 1982 from the QPM versions of various materials. The source materials constituting those pools were recombined in a half-sib system, during which process some selection among and within families was practiced for earliness. Afterwards, during two cycles of selection, at least 30% of the late-maturing plants were eliminated, and selection was also practiced for

Table 36. Protein, tryptophan, and lysine in the whole grain of QPM populations

Population number	Percent protein	Percent tryptophan in protein	Percent lysine in protein	Quality index
61	9.2	0.98	4.2	3.8
62	9.9	0.92	3.9	4.4
63	9.1	0.97	4.3	4.3
64	9.6	1.00	3.8	4.3
65	9.2	0.96	4.2	4.4
66	9.3	1.01	4.3	4.3
67	9.9	1.04	3.9	4.8
68	9.5	1.01	4.0	4.3
69	10.0	0.98	4.2	4.4
70	9.3	1.10	4.3	4.7

Table 37. Endosperm analyses for different cycles of selection in the white o_2 b.u. pool

Cycles	Percent protein	Percent tryptophan in protein	Percent lysine in protein	Quality index	Protein fractions I	II	III	IV	V
C0	7.4	0.89	3.39	3.2	15.8	12.8	20.9	15.6	36.0
C4	8.1	0.79	3.02	3.0	12.6	9.6	25.3	16.7	35.8
C8	8.6	0.78	2.86	2.8	12.9	9.6	26.0	17.2	34.2
C10	8.2	0.80	3.04	2.9	12.3	10.6	27.8	16.2	33.2

yield and kernel characteristics. Male rows are being detasseled in each pool as soon as it has reached 70% silking to prevent late-maturing families and late plants within families from being pollinated. The early maturing Population 61 was improved for kernel characteristics and other traits through full-sib family selection without multilocational progeny testing. It appears that further improvement will have to be made in this material before it is evaluated in IPTT 61.

Improvement of Highland Germplasm

The two highland Pools 1 and 2 QPM were formed in 1979 and further recombined during 1980 and 1981. During the period reported here, two cycles of selection were completed, using a modified ear-to-row half-sib system. Selection is being practiced for large floury kernels, ear rot resistance, and reduced interval between pollen shedding and silking.

In the QPM versions of Pools 3 and 4, S_1s were developed during 1981, and selected plants in selected families were recombined during 1982. Among the selected ears, selection was practiced for larger, yellow floury kernels. The selected kernels were planted on an ear-to-row basis in 1983; full-sibs were made at pollination time; and yellow, floury ears were selected.

Pools 5 and 6 QPM were handled in a full-sib recurrent selection scheme during 1982-83, without replicated progeny trials. In the improvement of these pools, emphasis is being placed on kernel modification, ear rot resistance, and yield.

In a highland modified opaque-2 composite, selfs were made during 1982 and recombined during 1983 in a half-sib recombination block. Another material, Mezcla Amarilla P.B. x Lin. Ill. H.E.o2, is being improved through full-sib recurrent selection, without replicated progeny evaluation. This material appears to be fairly resistant to leaf blight (*Helminthosporium turcicum*) and rust (*Puccinia sorghi*) and has single-stalk plants. Kernel modification is also good but requires further improvement.

Summary of Data From International Trials

During 1982 EVT 15A and one special QPM trial of subtropical materials (QPMT-11B) were distributed to 45 and 47 locations, respectively. The former consisted of 15 entries, and the latter of 11 entries, each with 3 checks and 2 reference entries. In EVT 15A most entries yielded as well as or better than the normal reference entry. Yields of entries in QPMT-11B were 84 to 98% of that of the normal reference check, the best entries being La Platina 7941, Across 7941, and Pool 34 QPM (Table 39).

Table 38. Protein fractionation of normal, soft opaque, and hard-endosperm opaque-2 version of Tuxpeño-1

Fraction	Tuxpeño Normal	Tuxpeño Soft Opaque-2	Tuxpeño H.E. o2
		Percent	
I Albumins + Globulins	6.2	20.6	15.5
II Zein	39.2	8.1	10.4
III Zein-like	19.7	10.7	16.2
IV Glutelin-like	13.6	18.5	21.4
V Glutelins	22.4	42.5	36.6

Table 39. Results of QPMT-11B 1982 (means across 27 locations)

Entry	Grain yield (kg/ha)	Percentage of normal reference entry yield
Piracicaba 7941	4022	91
La Platina 7941	4234	96
Across 7941	4342	98
ETO x Illinois QPM (check)	3956	90
Pool 31 QPM (check)	3715	84
Pool 34 QPM (check)	4261	97
Across 7741 (reference entry)	4051	92
Across 7845 (normal reference entry)	4415	100

In 1983 EVTs 15A and 15B were distributed to 67 and 45 locations, respectively. The first consisted of 13 entries and the second of 7, each including 3 checks and 2 reference entries. Data from 25 locations indicate that several QPM entries in EVT 15A yielded as well as the CIMMYT reference entry (Table 40). The best of those entries gave yields that were 95 to 97% of the yield obtained from the best local check. The top entries were from Population 40 (now designated Population 62, White Flint QPM); yields of varieties from Population 39 (now Population 65, Yellow Flint QPM) were 8 to 10% less than those of materials from Population 40. In EVT 15B two varieties (Tlaltizapán 8141 and Across 8141) yielded about the same as the normal reference entry across the eight locations for which data have been received (Table 40).

Table 40. Results of EVT 15A and 15B, 1983

Entry	Grain yield (kg/ha)	Percentage of normal reference entry yield	Percentage of yield of best check
EVT 15A (means, 25 locations)			
San Jerónimo 8039	4015	97	85
Pichilingue 8039	4048	98	85
Across 8039	4077	98	86
San Jerónimo 8140	4523	109	95
San Jerónimo (1) 8141	4548	110	96
Poza Rica 8140	4546	110	96
Los Baños 8140	4394	106	92
Across 8140 (reference entry)	4443	107	94
Across 7940 (reference entry)	4626	112	97
Across 7726 (normal reference entry)	4145	100	87
Local check	4576	110	96
Local check	4754	115	100
EVT 15B (means, 8 locations)			
Tlaltizapán 8141	5195	105	
Islamabad 8141	4553	92	
Antalya 8141	4684	94	
Antalya (1) 8141	4711	95	
Across 8141	4978	100	
La Platina 7941	4704	95	
Pool 34 QPM	4606	93	
Across 7941 (reference entry)	4809	97	
Across 7845 (normal reference entry)	4967	100	

Exploratory Research

The germplasm development and improvement discussed in preceding sections are within the mainstream of QPM work. Apart from that research, there are two exploratory projects, one involving selection for high oil content and the other identification of a simply inherited system of modifying genes.

Selection for high oil content was continued during 1982-83 in two QPM populations, White Dent QPM and Temperate x Tropical QPM. In the former, four cycles were completed in a full-sib recurrent selection scheme without progeny testing. Families selected for high oil content were analyzed for protein quality. At pollination approximately 20% of the families, those having the best oil content and protein quality, were recombined through plant-to-plant crosses among families. The same procedure was followed with the other population.

Both materials have shown a steady increase in oil content, which in the seventh cycle was 5.6% for Temperate x Tropical QPM and 5.9% for White Dent QPM, compared to 4.0 and 4.4%, respectively, in the original cycle, an increase of 1.6 and 1.5%. The effect of this increase on yield and other agronomic traits will be determined in special trials conducted during 1984. It appears already that the advanced cycles of selection for high oil content in both populations are shorter and earlier than the original ones. Protein quality, meanwhile, has remained much the same (compare Tables 41 and 37).

Table 41. Protein content and quality and oil content of high-oil QPM materials

	Percent Protein	Percent tryptophan in protein	Percent lysine in protein	Quality index	Percent oil
White Dent QPM (HO)C6	9.4	1.06	4.2	5.1	6.4
Temperate x Tropical Dent QPM (HO)C6	9.5	1.13	4.3	4.8	5.6

In the other special project, lines from Pools 23, 24, 25, and 26 QPM are being employed. Because of their reduced vigor and inability to withstand inbreeding, lines from each pool had to be intercrossed separately. The intercrossed materials will undergo further inbreeding, after which new lines will be extracted.

Progress in Overcoming Problems With QPM

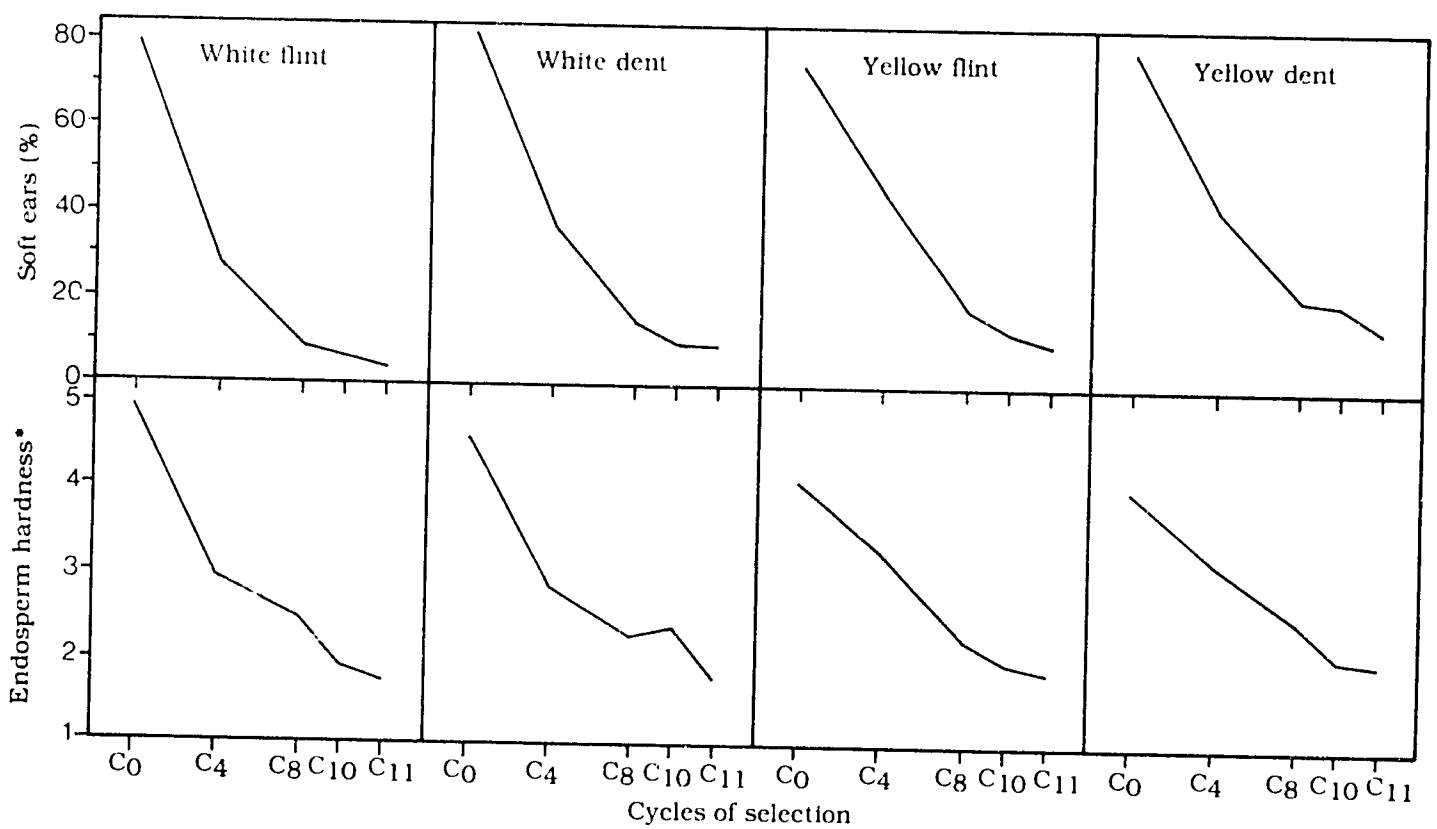
The current and future usefulness of germplasm coming out of the QPM program depends very much upon advances in solving problems that proved to be a stumbling block to acceptance of early opaque-2 materials. Marked progress has been achieved in overcoming the principal drawbacks of those materials, as discussed in the following sections.

Kernel modification—Intense selection pressure for kernel modification has been applied in all QPM materials and at all levels, without sacrificing improved protein quality. As a result, those materials are becoming more and more like normal maize in their kernel characteristics. The degree of modification that has been brought about is indicated in Figure 6. Class 5 type kernels have completely disappeared in the more advanced cycles, and there has been a corresponding increase in the frequency of modified kernels belonging to classes 1 and 2. The proportion of class 3 kernels appears to have remained unchanged. Though much progress has been made in kernel modification, there is still considerable genetic variation for this trait, and additional cycles of selection are needed to produce more normal-looking kernels.

Grain yield—The grain yields of QPM materials have continued to show an upward trend as a result of several approaches, including selection for kernel modification and higher kernel weight, discarding ears that have open spaces between kernel rows, and various intrapopulation improvement schemes (involving full-sib, half-sib, and S_1 selection). Data from EVTs, summarized above, suggest that some entries yield as much as normal maize. Yield gains have also been registered in some of the QPM pools being handled in Mexico, along with improvements in other desirable agronomic attributes.

Scientists in several countries report that QPM varieties are performing on a par with materials already under cultivation. In a Central American regional trial conducted during 1983, for example, a QPM

Figure 6. Kernel modification in tropical QPM pools over cycles of selection.



* Endosperm hardness rated on a scale of 1-5 in which 5 = unmodified kernels and 1 = normal-looking kernels.

variety being prepared for release in Guatemala under the name Nutricta yielded similarly to commonly grown hybrids and experimental varieties (Table 42). In China Tuxpeño-1 H.E.o2 has given yields comparable to those of its normal counterpart Tuxpeño-1. The results of national variety trials in Mexico indicate that three QPM materials (La Posta QPM, Obregón 7740, and Tuxpeño-1 QPM) perform about as well as H507, H510, and H524, all of which, however, yielded less than Poza Rica 7822 (Table 43).

Ear rot resistance—QPM materials are gradually becoming more resistant to this disease partly because of improvements in kernel phenotype and better drying of the more advanced materials. Another change in the QPM germplasm that has contributed substantially to resistance is a reduction in the frequency of undesirable genes responsible for pericarp splitting, which leads to secondary infection by ear rots. Visual selection against ear rots has been practiced in all QPM pools and populations under natural infection, though in some of those materials (Pools 25, 26, 33, and 34 QPM and Populations 62 and 65), selections have been made under artificial infection. Work carried out at IPTT locations where there is a high incidence of ear rots has also been extremely helpful in improving resistance. Data from EVTs 15A and 15B show little or no difference in response to ear rots between the QPM entries and normal checks, although incidence of the disease was slightly higher in QPM materials at locations where the disease is severe (Table 44).

Table 42. Performance of Nutricta in a Central American regional trial, 1983

Variety	Yield (kg/ha)	Percentage of check yield
ICTA-B1 (normal)	5235	98
Nutricta	5298	98
CENTA H5 (check)	5397	100
Diamantes 8643	5248	97
Tocumen 7428	5095	94
La Máquina 7727	4780	88
ICTA HB-83	6189	114
CENTA HE 20	6008	111

Use of QPM Germplasm

Progress in the development of QPM germplasm with acceptable kernel characteristics and good agronomic traits has caused a renewal of interest in this material among breeders in the private and public sectors. The germplasm is now being used as a source of various types of materials:

1. Germplasm that can undergo further improvement in adaptation and other agronomic characteristics in diverse environments around the world
2. QPM donor stocks for conversion of normal populations and inbred lines
3. Site-specific and across-site experimental varieties formed on the basis of IPTT data
4. Inbred lines for the formation of synthetics and hybrids
5. Combinations that can be used in a hybrid program and germplasm for developing divergent populations representing different heterotic groups

Table 43. Mean yields in a variety trial conducted at 27 sites in Mexico

Variety	Yield (t/ha)
Poza Rica 7822	5.2
H507	4.7
H510	4.4
V-524 (Tuxpeñite)	4.3
La Posta QPM	4.4
Obregón 7740 QPM	4.4
Tuxpeño-1 QPM	4.2

In the near future, the greatest opportunities for use of QPM germplasm lie in the development of populations, experimental varieties, and synthetics. This is the approach being taken by most of the breeding programs whose QPM work is discussed below.

Guatemalan scientists, for example, have extensively tested some locally developed QPM varieties and CIMMYT QPM populations and varieties at experiment stations and in farmers' fields. In the course of these evaluations, a QPM variety (Nutricta) consisting of Tuxpeño germplasm has shown much promise and will be released to farmers soon. Currently this variety is undergoing further improvement for uniformity, husk cover, and yield potential. Germplasm that has done well in Guatemala also seems to be performing well in Honduras, where it is being multiplied for testing in national trials.

Researchers in other Central American and Caribbean countries (including Costa Rica, Panama, and the Dominican Republic) have demonstrated interest in the development of QPM hybrids. They are now extracting inbred lines from QPM pools and populations and have received some S_1 lines from CIMMYT populations. Brazil also has a fairly ambitious QPM hybrid program and has acquired practically all of the Center's QPM germplasm for combining ability studies and derivation of inbred lines for hybrids.

In Venezuela, where flint is preferred to dent maize for the preparation of *arepas*, an EV from Population 62 (Across 7740) has shown superior yielding ability and kernel characteristics. Enough seed of that variety has been produced to cover some 800 ha. More recent selections from the same population should be even better in kernel phenotype and have a harder flinty texture. Milling tests are being conducted to determine the suitability of the material for preparing *arepas*.

Two varieties, Tuxpeño opaque-2 and Chiquisaca 7741, have performed reasonably well in Bolivia and are being produced on a small scale primarily for use as swine feed. Meanwhile, the country's maize scientists continue evaluating new QPM germplasm to find superior materials that are better suited to growing conditions there.

Several uses of QPM both for human food and animal feed are being explored in Mexico, whose maize researchers are conducting national trials to evaluate CIMMYT's and their own QPM materials. Some highland materials of this type are already being used in the state of Michoacan, where farmers are growing them on a small scale. A few lowland tropical materials, such as Poza Rica 8140 and Tuxpeño-1 QPM, have also been increased for swine feeding trials. In addition, one of the country's largest bread companies has shown an interest in QPM and performed tests of QPM materials in farmers' fields.

Heightened interest in QPM is by no means limited to Latin America. The national maize program of Senegal, for example, has found Obregon 7740 and a temperate, white QPM pool to be promising and are subjecting them to further testing. Seed of these materials is being produced on a small scale.

The country that probably has the greatest potential for QPM, however, is China. After evaluating a wide array of germplasm, Chinese scientists have concluded that the population Tuxpeño QPM yields as much as its normal counterpart Tuxpeño-1, which is currently grown on about 250,000 ha in southern China. They have designated the QPM material Tuxpeño 102 and from the 1-kg shipment received in 1983 have rapidly multiplied seed in Guangxi province. CIMMYT staff visiting the country have brought back encouraging reports about this material, particularly its potential as livestock feed. Swine feeding trials have clearly demonstrated that pigs fed QPM are larger and have better appetites than those fed normal maize. Other possibilities for QPM have arisen in northern China, where inbred lines are being extracted from CIMMYT's tropical and subtropical QPM germplasm. The line 079, developed from Yellow H.E. o2, is being used in an experimental hybrid.

The Outlook for QPM

The development of a wide range of new QPM germplasm products coincides with the greater interest in this material that has been stimulated by the Maize Program's progress in eliminating the deficiencies of the original opaque-2 maize. The addition of new populations to the international progeny testing system will offer maize researchers many more options in choosing materials for their own QPM programs. Their testing of the germplasm will also facilitate the accumulation of stable modifiers and improve the adaptation of the populations, which have not previously undergone multilocational evaluation.

The QPM program at CIMMYT will continue trying to monitor and meet the changing needs of those scientists. Some interest has been expressed in hard-endosperm QPM germplasm for temperate regions. In response the program will convert four special temperate pools into hard-endosperm opaque-2 types, using two or more subtropical QPM pools and populations as donor stocks. The conversion process has already begun, and suitable QPM versions of the temperate pools should be available within two or three years.

Over the past few years, several developing countries have become increasingly involved in work on normal and QPM hybrids. QPM hybrids offer several advantages, including better maintenance of seed purity, more stable modifiers, further improvement of traits in which QPM has been deficient, and reduced dependence on laboratory analysis. CIMMYT can assist in the development of those materials in a number of ways: by generating information on the combining ability of QPM pools and populations, suggesting procedures for inbred line development, and offering germplasm products having different levels of homozygosity/heterozygosity that can be used in the formation of QPM hybrids. Some efforts have already been made to determine the combining ability and heterotic patterns of various QPM materials, and the results will be summarized and documented for use by maize researchers.

As new materials and methods are employed in QPM work, we hope that the interest of national scientists in this maize will continue to grow and that greater funding will be made available to programs that are promoting commercial use of QPM germplasm.

Table 44. Ear rot data from EVTs 15A and 15B, 1982 and 1983

Entry	Ear rot (%)
EVT 15A, 1983 (22 locations)	
Poza Rica 8140	15.2
San Jerónimo (1) 8140	2.8
Across 7940 QPM (reference entry)	13.5
Across 7926 (normal ref. entry)	15.1
Normal check	13.1
EVT 15B, 1983 (7 locations)	
Tlaltizapán 8141	1.5
Across 8141	1.4
La Platina 7941	2.3
Across 8045 (normal ref. entry)	2.7
Normal check	1.2
EVT 15A, 1982 (6 locations)*	
Across 8039	28.3
Across 7740 QPM (reference entry)	22.0
Across 7940	28.2
Across 7926 (normal ref. entry)	24.2
Normal check	18.6
EVT 15A, 1983 (8 locations)*	
Poza Rica 8140	34.9
San Jerónimo (1) 8140	33.3
Across 7940 QPM (reference entry)	33.0
Across 7926 (normal ref. entry)	27.6
Normal check	34.6

* Incidence of ear rots was high at these locations.

Wide Crosses

The goal of the wide-cross program for maize is to introduce variation for traits in which the germplasm base is currently lacking variation or not showing an acceptable response to selection. A wide cross with maize, as defined by the program, is one that involves other (alien) genera and produces F_1 hybrids. Those hybrids should have the chromosome complement of both parents, be self-sterile (a normal characteristic in combinations of two sets of genetic information that are not very closely related), and should possess a phenotype that is at least intermediate between the two parental phenotypes. The intermediate phenotype demonstrates that at least some of the alien genes can express when put together with the maize chromosomes. Attempts are then made to achieve successive generations, using techniques such as backcrossing, to obtain maize plants into which some beneficial genetic material has been incorporated from the alien genera.

During 1982-83 research continued on the hybridization of maize with sorghum, *Tripsacum*, and millet. The aim of this research is first to determine the feasibility of intergeneric hybrids involving those species. The cytology of the hybrids and subsequent generations is then studied to determine the best method of transferring genes from the alien genera to maize.

Maize x Sorghum and Maize x Millet

More than 16,000 crosses were made between maize and sorghum in 1982-83. But in spite of the large number of crosses and the fact that stimulation was almost 5%, we were unable to produce any evidence of hybridization between the two crops. Efforts were made to hybridize over 100 different sorghum parents with maize (primarily from two broadly based CIMMYT gene pools), and over 130 plants were derived through embryo culture. All the recovered plants, however, were determined cytologically to be of maize origin.

It was determined finally that with the currently available techniques the probability of sexually hybridizing maize and sorghum and recovering a hybrid plant is less than one in three million. Hence, further attempts to make such a hybrid at CIMMYT have ceased.

Over 2000 crosses were made between maize and millet following a report that millet pollen would germinate on maize silks (Reger and James 1982). But the results were very similar to those obtained from the efforts to hybridize maize and sorghum, so this line of research has also been discontinued at the Center.

Maize x *Tripsacum*

Attempts to hybridize maize and *Tripsacum* continued during 1982-83. Our intention was to compare the results of such crosses with those obtained from the maize-by-sorghum and maize-by-millet crosses. We also hoped to repeat the isolation of "classical" and "nonclassical" hybrids between maize and *Tripsacum* (James 1979a, 1979b, 1981; CIMMYT 1981, 1985). In addition, efforts were made to increase the number of *Tripsacum* parents in F_1 combinations with maize.

Tripsacum is a highly variable genus, having a wide tolerance to various soil and climatic conditions, together with sources of resistance to most common diseases and insect pests of maize. As such, it is of considerable interest to the wide-cross program as a source of genetic variation for desired traits not present in maize or for which little progress is being made within the existing germplasm base.

Experimental hybridization of maize and *Tripsacum* is by no means new; see, for example, Mangelsdorf and Reeves (1931, 1939), Randolf (1950), Forquharson (1957), Anand and Leng (1964), Chaganti (1965), Galinat (1961, 1971), Petro et al. (1971), De Wet et al. (1972a, 1972b), and James (1979).

The results of work on the hybridization of maize and *Tripsacum* in 1982-83 represent a considerable improvement over the Maize Program's previous attempts. Success rates for hybrid isolation during that period averaged between seven and nine percent. In the 1982A cycle, for example, 142 hybrids between maize and *Tripsacum* were isolated from only 2008 crosses, whereas previously only 36 hybrids had been isolated from 32,000 crosses between the two species (James 1981). We were unable, however, to isolate (and hence confirm reports of) nonclassical hybrids between maize and *Tripsacum*.

At the end of 1981, we were maintaining only three different *Tripsacum* parents in combination with maize as F_1 hybrids. As of the end of 1983, we now have 129 living F_1 hybrids involving 16 different *Tripsacum* parents, which include both diploid and tetraploid *Tripsacum* species. No successive generations have been derived from any of those hybrids.

Preliminary evaluations indicate that *Tripsacum* contains high levels of resistance to insect pests. Our research plan for 1984-85 is to identify resistant *Tripsacum* parents and to advance the F_1 hybrids of those parents and maize to successive generations, with the long-term goal of transferring the resistance to maize.

Tripsacoid Maize

The wide-cross program at CIMMYT has recently accessioned a subsample of the tripsacoid maize populations developed at the University of Illinois in the USA and is combining this material with the Maize Program's Population 47 in an attempt to increase the population's level of resistance to southwestern corn borer (*Diatraea grandiosella*).

Future Plans

A detailed report on efforts to cross maize by sorghum, *Tripsacum*, and millet during the 1982A cycle is being prepared for publication. Research will be continued on maize-by-*Tripsacum* crosses. And although unpromising results were obtained with sexual combination of maize with sorghum and millet, other means of incorporating beneficial traits from these species and of accelerating the incorporation of *Tripsacum* genes into maize will be evaluated.

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Training

Training programs are an important aspect of CIMMYT's effort to assist developing countries in meeting their maize production needs. A sizeable share of the training consists of in-service courses, which are intended largely for younger researchers holding a B.Sc. or equivalent degree and have been attended, since their initiation in 1971, by 715 scientists from 79 countries (Table 45). The courses are designed to impart skills required in maize breeding, production research, and laboratory analyses. An interdisciplinary approach is employed to demonstrate the links between the activities of plant breeders, production research agronomists, laboratory personnel, technology transfer specialists, and the farmers who receive and use products of applied research, mainly in the form of improved varieties and appropriate practices.

Table 45. Countries of origin of maize in-service trainees, 1982-83

Region and country	Production agronomy	Maize improvement	Total
Africa			
Egypt	2	2	4
Ghana	5	1	6
Nigeria	2	1	3
Uganda	2	0	2
Guinea Bissau	1	0	1
Kenya	2	2	4
Senegal	0	1	1
Malawi	1	1	2
Cameroon	3	0	3
Tanzania	3	0	3
Zaire	1	0	1
Zambia	3	0	3
Benin	0	1	1
Congo	0	1	1
Mali	0	1	1
Total	25	11	36
The Americas and the Caribbean			
Colombia	1	0	1
Costa Rica	2	0	2
Mexico	4	0	4
Nicaragua	3	0	3
Panama	1	0	1
Dominican Republic	3	0	3
El Salvador	3	0	3
Guatemala	1	1	2
Paraguay	1	0	1
Haiti	3	0	3
Cuba	1	1	2
Ecuador	1	0	1
Jamaica	1	0	1
Honduras	0	2	2
Peru	0	2	2
Bolivia	0	1	1
Total	25	7	32
Asia			
Bangladesh	2	2	4
Nepal	3	0	3
Philippines	3	1	4
Thailand	3	3	6
Vietnam	2	0	2
Indonesia	1	0	1
Pakistan	2	5	7
Turkey	1	2	3
Syria	0	1	1
Nepal	0	1	1
Total	17	15	32
Grand total	67	33	100

The courses are of four types: 1) production agronomy research, 2) maize improvement, 3) experiment station management, and 4) protein quality analysis. The first two last five and a half months and are conducted simultaneously, so that participants from both courses can attend together lectures that are relevant both to production and breeding. In other lectures and in most of the field and laboratory sessions, the two groups are separate. The experiment station course is of five months duration, and the course in protein quality analysis takes from a few weeks to two months, depending on the previous experience and needs of the participants.

In addition to the in-service courses, the Maize Program provides predoctoral and postdoctoral fellowships for periods of one to two years, during which participants work in a specific area of the Center's maize research program. Fellowships are available as well for visiting scientists, who spend a few days to several months at CIMMYT.

Apart from their work at headquarters, training staff assist with in-country training courses and workshops initiated by outreach staff. During 1982-83 the training program at headquarters participated in events held in Costa Rica, Ghana, Kenya, Pakistan, Panama, Turkey, Uruguay, and Venezuela. By and large those activities were designed for agronomists and dealt with on-farm research techniques. This assistance is one of various ways in which headquarters staff support the efforts of outreach programs in strengthening national research capacities.

Regional Programs and Bilateral Projects

The concept of regional programs was approved by the CIMMYT Board of Trustees in 1973, and their decision was endorsed in 1976 by a review panel of the CGIAR's Technical Advisory Committee. The first regional maize program was established in 1974 for Central America and the Caribbean. Since then five more have been initiated, one each for the Andean region (1976), Asia (1976), the Middle East, (1979), East Africa (1980), and West Africa (1980).

The objective of each regional program is to sharpen the skills of national researchers in setting priorities, formulating research plans, and managing scarce resources effectively. Regional maize specialists work toward that objective through several means, the principal one being frequent and timely visits to their colleagues in national programs. The specialists are frequently present, for example, at important research planning meetings and are full participants in the discussion. They also visit the national programs' experimental fields at critical times during the growing season to work and confer with researchers on the day-to-day managment of their breeding and agronomy research programs. They also monitor International Progeny Testing Trials (IPTTs), Experimental Variety Trials (EVTs), and Elite Variety Trials (ELVTs) distributed from CIMMYT headquarters. On-farm investigation receives much attention from the regional specialists as well, and they often accompany national researchers on visits to on-farm trials and on information-gathering trips through maize production areas.

During these visits regional staff try to identify the most pressing needs of a national program and organize ways of meeting them. If, for example, a breeding program is limited by lack of equipment, the regional specialists can sometimes supply the items needed or can locate another source of funding for logistical support. Even more of the regional specialists' effort is devoted to meeting the universal demand within developing countries for technical training. Some of this demand they can satisfy through their visits to national programs and the rest by more formal means. In conjunction with senior national researchers or administrators, regional staff identify candidates for training at CIMMYT headquarters in Mexico and plan in-country training activities such as courses and workshops. These in-country events, which are often region-wide, promote cooperation among national scientists from different countries by providing opportunities to exchange ideas and research results.

For in-country training or other purposes, staff members in a regional program will from time to time call upon the services of other CIMMYT researchers at headquarters or in other regional programs. In this way the specialists build stronger links between national researchers and the CIMMYT Maize Program (a link that is crucial for ensuring that the program's research continues to be relevant to the needs of developing countries), and make a wider range of services available to national maize programs.

Each regional program shares a common purpose and is engaged to some degree in all of the activities described above. Even so, every program has its own unique character, which is reflected in the proportion of time and resources the regional specialists choose to devote to each activity. This apportionment of resources in turn is determined by the size of the region, the nature of its maize production problems, and the requirements of national maize research aimed at solving those problems. The following reports demonstrate, not only the commonality of the regional programs, but their flexibility, in that various CIMMYT researchers have shaped each regional program to suit a unique set of circumstances and needs.

In bilateral projects Maize Program staff work side-by-side with colleagues for extended periods, generally in a single national program. CIMMYT invests fewer resources in those projects than in the regional networks but continues to be receptive to them, since they offer unique benefits and are an important complement of the regional activities. The experience gained from bilateral projects contributes much to our knowledge about the development of national research capabilities, about the performance of the Maize Program's germplasm and other products, and about the appropriateness of its services.

The Program was involved in four bilateral projects during 1982-83. Two of those (one in Pakistan and the other in Tanzania) were begun in the early to mid-1970s with funding from the US Agency for International Development; the latter came to a close late in 1983. The third was initiated in Ghana during 1979 with support from the Canadian International Development Agency (CIDA) and reached the end of its first phase in 1983. We report in detail here on the breeding and agronomy research of that project. The fourth project, begun in mid-1983, is a regional effort affecting 13 countries in Central America and the Caribbean and is funded by the Swiss Development Cooperation. Unlike the regional programs, however, this project focuses on a single task, namely the improvement of national seed production capabilities. For brief summaries of the objectives and activities of the bilateral projects, see recent issues of the CIMMYT annual report.

Andean Region

The Andean region, which includes Bolivia, Colombia, Ecuador, Peru, and Venezuela, comprises three broad types of ecologies (the coastal plains, jungle, and highlands), each of which can be subdivided according to rainfall pattern, altitude, soil type, and so forth. There is thus wide variation in maize-growing conditions across the region and, consequently, in the

nature of the national programs served by staff of the Andean Regional Program.

The work of the regional program is distinct, though related, to the activities of the CIMMYT maize breeder stationed in Ecuador. Since 1977 he has been developing improved floury maize and *morocho* germplasm for national programs in the Andean region. Because that work is closely connected with the maize improvement program at CIMMYT headquarters and has centered upon the development and improvement of eight highland pools, details on this research are given in the report of the backup unit (pages 10-11).

Germplasm Improvement

CIMMYT germplasm has been employed by national programs in the region over the last 12 years. Not until the mid-1970s, however, did the amount of germplasm testing and utilization begin to approach its present high level. In 1976-77 materials from national programs and the Center were evaluated in a set of trials conducted at nine locations in the region. The results of those trials indicated that the CIMMYT germplasm was more widely adapted than the local material.

National researchers in the five countries of the region are now conducting a large number of IPTTs, EVTs, and ELVTs, from which they are selecting materials for use as source germplasm in their breeding programs or for release as varieties to farmers. Those materials are proving to be shorter, higher yielding, more disease resistant, and more broadly adapted than most local germplasm.

White-grain maize--Populations 21, 22, 29, 32, and 43 are being put to various uses in the breeding programs of Venezuela and Colombia, where white maize is preferred. Through full-sib selection in Population 22, for example, Venezuelan researchers have developed the variety La Maquina Guarabao and released it to farmers. Quite different work is being done with Populations 21 and 32, which serve as sources of inbred lines for the CENIAP-FONIAP (Center and Fund, respectively, for Agricultural and Livestock Research) hybrid program in Venezuela. Almost all the materials are being employed by The Polar Foundation, a private, nonprofit Venezuelan organization, which is developing broad-based populations by recombining experimental varieties from Populations 22, 29, 32, and 43.

Staff of the Colombian Institute of Agricultural and Livestock Research (ICA) have improved Population 21 through mass selection for prolificacy and yield. One product of that work, ICA V 155, was released in 1981, and another, ICA V 156 (developed for the Atlantic coastal area), will be released in 1984. An important component of ICA's breeding program are MBs (basic materials), two of which (MB 237 and MB 233) are made up in large part of Populations 22 and 43, respectively.

Yellow-grain maize—In Ecuador, Peru, and Bolivia, where yellow flint and dent maize are grown almost exclusively, Populations 24, 26, 27, 28, and 36 have formed an important part of the germplasm complexes of national programs. Open-pollinated varieties from those populations have been released, and they have served as sources of families and lines for hybridization.

Germplasm for jungle areas—In Peru the Cooperative Program for Maize Research (PCIM) of La Molina National Agricultural University has been responsible since 1975 for most maize breeding conducted for the jungle areas. Program researchers are currently improving Populations 24 and 28 through half-

Table 46. Results of variety trials conducted by INIPA in five departments of the high jungle of Peru, 1982B

	Yield (t/ha) at 15% grain moisture						
Varieties	Cajamarca (Jaen)	Junin (Pichanaqui)	Ayacucho (Sivia)	Cusco Sahuayaco	Cusco Pilcopata	Madre de Dios (Pto. Maldonado)	Mean across locations
Across 7728	7.12	6.36	8.22	7.10	3.50	2.64	5.82
La Máquina 7928	6.61	5.83	7.99	6.77	3.87	3.83	5.81
Ferke (1) 7928	6.63	5.65	8.22	6.31	3.54	2.19	5.42
La Calera (1) 7728	7.38	5.08	7.66	5.77	3.27	2.27	5.23
Sete Lagoas 7728	6.52	3.98	7.78	6.04	3.47	2.60	5.06
Across 8027	5.86	4.90	7.48	4.95	3.62	2.66	4.91
Across 7736	6.62	5.44	4.93	6.06	2.88	3.32	4.87
Poza Rica 7926	6.42	2.82	6.46	4.88	3.66	3.01	4.54
Across 7726	6.58	4.34	6.01	4.50	3.09	2.18	4.45
Across 7835	5.28	2.80	6.61	3.18	4.20	2.06	4.02
Check means	7.02	4.15	7.18	5.94	3.50	3.55	5.38
Mean	6.55	4.67	7.14	5.59	3.50	2.76	5.04

sib and full-sib selection. So far, three experimental varieties have been developed from those populations (PMC 748 and PMC 749 from Population 28 and PMC 750 from Population 24) and released to farmers. In 1979 La Molina initiated the north coast breeding program, in which Populations 26 and 36 are being used for hybrid development.

Maize improvement for the jungle zone is also being carried out at Tarapoto, Peru, by the recently formed National Institute for Agricultural and Livestock Research and Promotion (INIPA). In 1983, after a series of variety trials conducted throughout the Peruvian jungle area (Table 46), INIPA researchers chose the experimental varieties Ferke (1) 7928, Across 7728, and La Máquina 7928 to form their Jungle Complex, which is being improved in a half-sib breeding scheme. The advanced generation of the cross between Ferke (1) 7928 and Across 7728, named Marginal 28 Tropical, will be released in 1984, becoming the first variety to be released by INIPA for the jungle zone. The institute also has a hybrid program for that zone and is currently accumulating information through testing of diallel crosses generated with "across" varieties from Populations 24, 26, 27, 28, and 36.

Germplasm for coastal areas—In Colombia experimental varieties from Populations 26, 27, and 35 were recombined to form MB 115, from which the variety ICA V 109 was derived. It will be released in 1984 for the Atlantic coast.

In 1980 Ecuador's INIAP released INIAP 526, from the experimental variety San Andres (1) 7528, and a year later it was being planted along the central coast on about 30,000 ha, which is over half of that region's maize area. INIAP researchers have also extracted families from San Andrés (1) 7528, as well as from Santa Rosa 7624, Ferke (1) 7526, Suwan-1, and INIAP 515, for use in a hybrid program. The best hybrid developed so far, INIAP 550, made up of one family from San Andres (1) 7528 and another from INIAP 515, is scheduled for release in 1985 (Table 47).

Consultation With National Researchers

The contacts of regional staff with national scientists take several forms, two of the most important of which are participation in national research planning sessions and attendance at regional workshops.

Most of the national programs in the region hold planning sessions every year and invite regional staff. Work carried out during the previous year is discussed and research planned for the future. The main function of CIMMYT staff in these meetings is to contribute suggestions as to what germplasm and methods would be suitable for the research projects under consideration. During 1982-83 regional staff participated in seven planning sessions.

Every two years a regional maize workshop is held in one of the five Andean countries. In April 1982 the tenth workshop was held at Santa Cruz, Bolivia. Regional staff participated in the organization and financing of the workshop. This meeting and the PCCMCA (Central American Cooperative Program for

Table 47. Performance at various locations of the best ten out of 250 experimental family hybrids developed by INIAP in Ecuador, 1982.

	Yield (t/ha) at 15% grain moisture					
Hybrid[a]	Pichilingue	Hda. El Azucar	San Carlos	Sta. Barbara	Mean yield	Percentage of check yield[b]
Fam. 5 x Fam. 23 (INIAP 550)	9.01	6.03	5.61	8.80	7.36	127
Fam. 12 x Fam. 20	7.77	6.98	6.37	7.19	7.08	122
Fam. 5 x Fam. 21	8.62	6.83	5.62	6.94	7.00	120
Fam. 4 x Fam. 12	8.73	6.28	6.25	6.13	6.85	118
Fam. 8 x Fam. 25	9.17	6.51	6.69	5.04	6.85	118
Fam. 4 x Fam. 23	7.35	6.16	6.72	7.11	6.83	118
Fam. 4 x Fam. 22	9.46	5.49	5.25	7.07	6.82	118
Fam. 7 x Fam. 23	8.09	5.53	6.07	7.46	6.78	117
Fam. 13 x Fam. 23	7.87	6.13	6.77	6.14	6.73	116
Fam. 18 x Fam. 21	7.77	6.26	5.07	7.80	6.72	116
Fam. 6 x Fam. 20	7.85	5.23	5.06	8.65	6.70	116
Pioneer X-304C (check)	7.46	4.73	5.04	5.93	5.79	100
Mean	6.63	4.80	4.49	5.33		
C.V. (%)	12.3	14.4	17.2	20.0		
LSD	1.60	1.35	1.50	2.07		

[a] Families 4 and 5 were extracted from San Andrés (1) 7528; 6, 7, and 8 from Santa Rosa 7624; 13 from Ferke (1) 7526; 18 and 20 from Suwan-1; and 21, 22, 23, and 25 from INIAP 515.

[b] Ninety-two of the family hybrids outyielded the check (Pioneer X-304C).

the Improvement of Food Crops) workshop are the only events that have been held with regularity over the years. They have proven to be extremely valuable opportunities for maize researchers to exchange ideas, discuss common problems, and present research findings.

Training

During 1982-83 in-service training courses at CIMMYT headquarters were attended by a total of eight persons from the Andean region (see Table 45 in the section on training). In addition, four on-farm research courses were begun or completed during that period in various countries of the region. Two were begun at Tarapoto and Cuzco, Peru, and will end in 1984, one was completed at Barquisimeto, Venezuela, in 1982 and another at Santa Cruz, Bolivia, in 1983. A total of 122 maize workers participated in the courses, which were based upon an approach referred to as the *call system*. With that approach course participants come together for periods of one to two weeks at key stages in the research cycle and then resume their normal duties during periods between those "calls."

Asia

The Maize Program has been cooperating with national programs in Asia for more than 15 years. For the first 10 years of that period, the Center was involved with the Inter-Asian Corn Program, which had its headquarters in Thailand under the sponsorship of the Rockefeller Foundation. Then, in 1976, with the Foundation's encouragment, CIMMYT established the Asian Regional Maize Program, which is currently staffed by a breeder/pathologist and agronomist/physiologist based at Kasetsart University in Thailand. In addition to carrying out regional program activities, those scientists participate in the Downy Mildew Resistance Collaborative Research Program, involving Thailand's National Maize and Sorghum Program and CIMMYT.

Nine countries in Asia (Burma, China, India, Indonesia, Nepal, Pakistan, the Philippines, Thailand, and Vietnam) produce about 50% of the 154 million tons of maize grown annually in the developing world. In such a large and diverse region, there is wide variation both within and among countries in the constraints to maize production and in other circumstances. It is important therefore that CIMMYT regional staff be familiar with local situations, as well as with the latest developments at CIMMYT headquarters, so as to provide national program scientists with assistance in germplasm development, production agronomy research, plant protection, seed production, and training. Toward that end regional staff spent 131 days outside Thailand during 1983 on visits to various Asian countries.

Germplasm Development

Across Southeast Asia the germplasm requirements of farmers vary considerably as to maturity period and grain type. Almost all maize farmers in the region, however, require resistance to the downy mildew (DM) disease in any improved germplasm they adopt. So that national maize research programs can better satisfy those germplasm needs, regional staff are helping them broaden their breeding populations through the introduction of CIMMYT germplasm. An important part of that effort is the development of DM resistance in Thailand in three of the Center's advanced maize populations. This work is described on page 16 in the report on population improvement.

The regional specialists also assist in the development of more efficient breeding and testing systems. Some of the end products of those systems—varieties that have good agronomic type, give high, stable yields, and are resistant to DM—have been adopted by Asian farmers and are now widely used in the region. Some released varieties have been derived from the broad range of materials evaluated by Asian national programs participating in CIMMYT's international maize testing network. Five varieties based on that germplasm have been released in Burma, three in China (where over 200,000 ha are being planted to Tuxpeño-1), two in India, one in Nepal, three in Pakistan, two in the Philippines, one in Taiwan, and one in Vietnam.

The degree to which those varieties are adopted depends very much on the effectiveness of national seed production and distribution programs. In Thailand, for example, a joint venture involving public and private seed companies has resulted in the distribution of improved seed over more than 80% of the country's maize growing area. Similar progress can no doubt be achieved in other countries as they improve their seed production systems.

In a number of countries, the private sector has become active in research on both open-pollinated and hybrid maize and in marketing and distribution of improved seed. In Southeast Asia the largest area sown to hybrids (75,000 ha or about 2.3% of the total) is in the Philippines, where these materials have been promoted by the government's Maisan Program. It is expected that in Indonesia over 1000 t of hybrid seed, enough to cover 50,000 ha, will be used, and seed sales in Thailand have reached a total of about 200 t, which is sufficient for 10,000 ha. About 11% of the summer maize and 70-80% of the winter maize crop is sown to hybrids in India, but probably less than 5% in Nepal. Most of the production (75%) in Taiwan, with the exception of that in mountainous areas, is hybrid maize. In China 90% of the maize area is planted to hybrids.

The public research programs of those countries have devoted some of their resources to inbred line development, in some cases using CIMMYT populations improved through recurrent selection. Regional staff have given some guidance to those programs in developing breeding systems that are suitable for line development and population improvement.

There is renewed interest in quality protein maize (QPM) in some countries of the region, particularly where maize is used for swine feed. During 1982 a team of nutritionists and staff from CIMMYT headquarters visited the region to review the possibilities for QPM development in China, Taiwan, and Thailand. Chinese scientists have identified high-yielding QPM varieties (Tuxpeño-1 QPM, for example) for cultivation in South China and anticipate that within a few years those varieties will replace Tuxpeño-1, currently grown on 200,000 ha, and perhaps spread to an even larger area. Taiwan is initiating a QPM program, and Thai scientists are intensifying their breeding and selection in one QPM population. Seed of that population has been increased and will be grown and tested on a large scale during 1984 by a swine farmers' cooperative in Thailand.

Production Research

The opportunities and staff available for on-farm research vary within the region. The CIMMYT agronomist and economist have identified and are working with those national programs that show the most promise for development of an on-farm research capability.

In Vietnam and Burma, for example, preliminary testing and subsequent verification of varieties in large plots have led to rapid acceptance of improved materials by farmers. The new varieties are generally being promoted as components of improved production technology packages.

In other countries regional staff are assisting in research aimed at developing a set of improved practices that would be acceptable to many farmers and could be adopted by them sequentially. Thai researchers and extension officers, for example, are emphasizing planting methods and chemical weed control (in conjunction with zero tillage) for both open-pollinated varieties and hybrids.

In Pakistan researchers are focusing on improved varieties and methods of planting maize for both grain and forage production. Researchers in Nepal have helped farmers boost productivity through more intensive cropping, use of earlier maturing varieties, and cultivation of winter maize under irrigation. In the upland terraced areas of the country, yield increases depend largely on accessibility of fertilizer and proper management of the maize crop for both fodder and grain. National researchers have addressed those issues by dividing the upland areas into three different research zones and designing appropriate on-farm trials for each.

In 1982 a team of CIMMYT staff and other scientists visited China to review the prospects for production of quality protein maize. Here maize breeder Li Jingxiong (far right) and other staff of China's maize research program conduct a tour of experimental fields for CIMMYT staff Surinder Vasal (second from right), Eva Villegas (far left), and Bobby Renfro (second from left), consultant Norman Borlaug (fourth from left), and animal nutritionist Jim Maner (fifth from left) of the International Agricultural Development Service.

In East Java, Indonesia, regional staff participated in an informal survey of maize growers. One purpose of the survey was to demonstrate the usefulness of this technique for delineating recommendation domains and identifying research opportunities. Recommendation domains are areas where farms and farmers' practices are similar enough that a set of recommended practices is applicable over the entire area. National researchers and regional staff have designed a set of trials for developing recommendations on the use of late-maturing, high-yielding varieties, improvement of plant stand establishment, and more intensive cropping through shortening of the period between crops.

Training
In 1983, 22 maize workers from various countries in Asia participated in courses offered at CIMMYT headquarters, and 12 visiting scientists worked within the research program in Mexico for periods of about one month (see Table 45 in the section on training). Seven representatives of various countries in the region attended Presentation Week, an event held at headquarters that is intended to acquaint agricultural leaders with the Center's work.

Eighteen national researchers accompanied regional staff on their visits to national programs during 1983 to promote regional cooperation and to assist in evaluation of trials. Two Nepalese scientists spent one crop season in Thailand to receive training in techniques of DM resistance breeding and to manage materials in a cooperative program, involving the national programs of Nepal and Thailand, for development of DM-resistant varieties.

In 1982 and 1983, the regional agronomist assisted in a two-week training program for production agronomists and extension workers in Pakistan. Afterwards, when maize experiments were in the field, the course content was reviewed in a "travelling seminar." Regional staff have also attended a number of national maize workshops and given lectures and seminars on various aspects of maize research.

Mexico, Central America and the Caribbean

Thirteen countries are currently participating in the activities of this regional program: Barbados, Costa Rica, Dominica, the Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Saint Kitts, and Trinidad and Tobago. Two important objectives of the program are to develop ties between participating national institutions and the CIMMYT Maize Program and to foster cooperation among maize researchers in the region. In pursuing those objectives, regional staff concentrate primarily on germplasm development and on-farm research.

In both areas national programs in the region have made considerable progress, replacing old varieties with improved varieties and hybrids (planted on 60% of the lowlands in Guatemala, for example) and developing alternative production practices, which farmers are adopting at a high rate in the Dominican Republic, El Salvador, Honduras, and Panama. The impact of this work on maize production in the region has been substantial. Most countries are reducing importation of maize: Guatemala and El Salvador are producing all the grain they need for local consumption; and Honduras is exporting increasing amounts of maize to other countries in the region. Even so, there is still much room for improvement, particularly in the development of more efficient commercial maize production and in the improvement of seed production systems.

Germplasm Development

Regional staff are working closely with national scientists in designing appropriate breeding procedures and developing improved varieties or hybrids through more efficient use of the germplasm available. The aim of this work is to provide farmers with materials that have both high yield potential and yield stability. The principal means of achieving that goal is to use germplasm (such as CIMMYT maize populations) in which selection has been done for stable yields across locations and for tolerance to drought stress and resistance to diseases and insect pests, which contribute to yield stability.

Use of CIMMYT germplasm—Breeders in national programs and regional staff select outstanding full-sib families from IPTTs, and remnant seed of those selections is recombined at Center headquarters for variety formation. Regional staff also assist in conducting EVTs and ELVTs and in planning projects for development of such traits as drought tolerance and resistance to corn stunt and ear rots. During 1982-83 a number of IPTTs, EVTs, and ELVTs were conducted, as indicated in Table 31 in the section on international testing.

Analysis of yield stability is regularly conducted for EVTs planted in the region. The information generated through this analysis is of great value to breeders since it enables them to select high-yielding, stable varieties on the basis of across-site data. Breeders in national programs request basic seed of such materials from CIMMYT, which they either use as improved varieties for further selection (to improve husk cover, for example) or as source germplasm for their breeding programs.

Regional maize testing—Every year various Central American and Caribbean countries conduct a regional PCCMCA trial, which includes commercial hybrids and varieties. The countries rotate responsibility for preparing and distributing the trials, with assistance from the regional program, which supplies field books, handles shipping of the trials, and analyzes the data. In 1983 the trials were prepared by ICTA in Guatemala. For the first time, a quality protein maize variety (Nutricta, developed by Guatemalan researchers) was tested in the regional trial; it performed as well as varieties having the normal grain type.

Regional germplasm exchange—The regional trials, along with other exchanges of germplasm within the region and visits by national scientists to programs in neighboring countries, are all important ways of promoting regional cooperation. Germplasm exchange is strongly supported by staff of the regional program, particularly in their travels from one country to another.

During 1982-83 varieties, families, and lines selected for corn stunt resistance were taken to Honduras, while families selected in Honduras for resistance to downy mildew were shared with researchers in Guatemala and El Salvador. Cytoplasmic-genetic male sterile germplasm from Guatemala was made available to El Salvador. Seed of the population RPM x C17, developed and selected for ear rot resistance in Costa Rica, was sent to Honduras. Commercial varieties developed in Guatemala (ICTA B-1, La Máquina 7422, and Nutricta) have been made available to Honduras, Belize, and Nicaragua, and the varieties Chanin, Don Marshall, Barcena 71, and Compuesto V301, developed for the Chimaltenango area of Guatemala (1500-1800 m above sea level), were sent to Honduras and Costa Rica. At La Esperanza, Honduras, the performance of Barcena 71 was superior to that of local varieties.

Hybrid research—Hybrid programs have grown substantially in the region. These are not new but have been maintained to varying degrees in some countries since 1954. Early programs did not succeed because the infrastructure necessary for hybrid seed production was lacking. Even so, researchers in El Salvador have been producing good hybrids since 1963, and now Costa Rica, Guatemala, and Honduras have strong hybrid programs as well.

Among the new hybrids and varieties released in 1982-83 were Guaymas B-101 (La Máquina 7422), Guaymas 150), and Guayape B-102 in Honduras. In trials conducted at 23 sites from 1981 to 1983, these materials outyielded the local varieties. Guaymas (1) 8022 is now being evaluated extensively in farmers' fields. Three other new varieties (Honduras A-502, B-104, and B-105) that perform well under conditions of low moisture have been released. Two varieties that are resistant to downy mildew (DMR-1 and DMR-4) are in the final stages of testing and will be released in 1984. A double-cross hybrid, Honduras H-27, has given excellent performance and will be released in 1986.

In its hybrid program, ICTA in Guatemala employs full-sib families selected from IPTTs. Three hybrids with yellow grain and five with white have been developed using those materials. The quality protein maize variety Nutricta has shown high yield potential and will be produced on a large scale. Two varieties (V-302 and V-304) have been developed for the Chimaltenango area of Guatemala, and one (Toto Amarillo) has been selected for the highlands. A new hybrid (HB-83, which is a late-maturing, white dent material) has given excellent results.

Haitian researchers have found that La Máquina 7827 and La Máquina 7928 are superior to the local variety (Chicken Corn), even in low-yielding environments under a low level of management.

In the Dominican Republic, CESDA-28 (Across 7728) has been released for commercial seed production, and Poza Rica 7827 and Across 7936 (CESDA 27 and CESDA 36, respectively) have shown much promise.

The National Research Center (CENTA) of El Salvador has released CENTA M3-B for areas in the eastern part of the country that receive limited rainfall and are subject to drought. At five test sites, this variety gave higher grain yields than the local criollo varieties (Table 48).

New varieties for Panama are Pichilingue 7928 and Guarare (1) 8128, which will replace the commercial varieties Tocumen 7428 and Across 7728.

Seed production—In most countries of the region, maize researchers depend heavily upon public sector organizations for seed production. Those organizations are subject to high staff turnover, a situation that can result in poor quality seed production. Guatemala and El Salvador have reasonably good seed production systems, however, and private seed enterprises are being developed in those countries.

In 1982 the regional program began to make available equipment for basic seed production to Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. Among the items provided have been seed dryers, special maize shellers for basic seed, cleaners and graders, and seed treatment equipment.

Production Research

Varieties selected or developed by national programs undergo further selection in trials conducted under farmers' conditions. On-farm experiments are even more

Table 48. Mean grain yields of CENTA M3-B in validation plots, El Salvador, 1982

Location	Mean yield (t/ha) CENTA M3-B	Criollo
Jocoro	2.62	1.59
Santa Rosa de Lima	2.47	1.70
El Carmen	2.05	1.80
Uluazapa	2.65	1.17
Nueva Esparta	2.27	1.83
Gotera	2.51	1.80

important as a means of developing appropriate technologies for specific maize-growing areas of a country. Although both on-farm and experiment station research are supported by the regional program, the former receives greater attention because it has been given high priority in various countries of the region.

Production research generally increased across the region during 1982-83. Much emphasis was placed on weed control and fertility levels. One of the results achieved by this research was effective control measures for *Cyperus rotundus* and *Rottboellia exaltata*. In the Dominican Republic, a new production research program was developed in which experiment station work is complemented by on-farm research.

Conservation tillage continued to be an important technical innovation in maize production across the region. In El Salvador, for example, very interesting variations on that method, involving hand-planting, are being practiced on 4000 ha. Researchers in Nicaragua and Panama are making good progress in research on mechanized conservation tillage practices.

Training

Eleven persons from the region took part in courses at CIMMYT headquarters during 1982 and 12 in 1983 (see Table 45 in the section on training). The regional program also sponsored five master's degree candidates in 1982 and four in 1983.

The regional agronomist supported production research primarily through informal training and consultation with national scientists during visits to their experiment stations and on-farm research sites. More formal training was provided as well, principally by means of national workshops on specific subjects in which national scientists had expressed an interest. There was also active participation in the "call system" approach to teaching on-farm research methodologies and in the follow-up work entailed by that approach.

East Africa

This program was established in 1982 and its work initiated with the arrival of a regional maize specialist late during that year. The start of the program, with headquarters at the International Laboratory for Research on Animal Diseases (ILRAD) in Nairobi, Kenya, is the most recent development in a lengthy history of scientific exchanges between CIMMYT and various countries in the region. Center staff have visited eastern and southern Africa fairly regularly, variety trials have been distributed widely there, and from 1973 until 1983 a Maize Program scientist was stationed in Tanzania as part of a bilateral project. In providing research support to the region, the maize specialist is concentrating, at least initially, on Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Zambia, and Zimbabwe.

This report describes regional activities of the maize specialist during 1983, much of which he spent travelling in the region becoming familiar with the needs and circumstances of various national programs.

Germplasm Improvement

Breeding programs in East Africa are putting germplasm from Center headquarters or from CIMMYT and IITA breeders in Nigeria to various uses. In Kenya, for example, a number of varieties are showing promise, most notably a varietal hybrid developed by the Kenya Seed Company through a cross between Populations 49 and 32. This hybrid (Pwani) is being tested in the coastal areas of the country.

Scientists in Burundi have tested experimental varieties and found that three from Population 43—Across 7643, Across 7843, and Ferke (1) 7643—outyield all local entries. Remnant seed of these materials sent from Mexico has been multiplied for evaluation in on-farm trials. In addition, seed of the streak-resistant versions of experimental varieties from Populations 22, 28, 29, 35, and 44 has been obtained from Nigeria for screening. Families of the Center's highland Pool 9 are also being grown, among which a number of promising families have been identified.

One of the varieties found to be superior in Burundi (Across 7843) is also doing well in northern Zambia. A maize breeder there is evaluating a number of other materials as well, including the experimental varieties San Andrés 8043, Los Diamantes (1) 8043, Cotaxtla 8043, Across 8043, Ilonga 8043, Kwanuaso 8043, Across 7934, Across 7842, Chuquisaca (1) 7842, Gemmeiza 8047, Across 8047, and Mexico 8049 and Populations 10, 11, and 12. Seed of Pirsabak (1) 7930, Pirsabak (2) 7930, Across 7844, and TL 9044 is being increased for further evaluation.

A variety from Tanzania, EV 8076 (made up of about 50% Tuxpeño germplasm) is doing well in Zambia. Scientists in the former country have just released three new varieties based entirely or partly on germplasm from CIMMYT: EV 8076 (Staha) EV 8188 (Kito), and EV 7992 (Ilisua). The first and third contain 50 and 10% Tuxpeño germplasm, respectively, and the second is made up entirely of germplasm from the Center.

The maize program in Zimbabwe grew IPTTs 22, 43, and 44 during 1982-83 and is conducting IPTTs 21 and 49 in 1983-84. They have also requested EVTs 12, 13, 14B, 15A, 15B, 16A, and 16B and ELVTs 18A, 18B, and 20. This germplasm is being screened to find materials suitable for the low veldt or grassland, where the popular hybrid SR52 is not being grown. Population 49 is showing promise both as a source of breeding material (specifically to reduce the plant height of tall hybrids) and for direct use as a variety.

Consultation With National Scientists

While visiting maize scientists across the region, the maize specialist participates in their work in a variety of ways and provides different types of services, depending on the requirements of particular programs. In Kenya, for example, he and the country's senior maize breeder prepared a plan for the national maize improvement program, which is currently being reviewed by the Ministry of Agriculture. The maize specialist has also been appointed by the director of agricultural research to serve on the national maize specialists committee and the variety release committee.

In Kenya and Rwanda, the regional specialist has attended seminars on various research issues, and in the latter country was part of a mission whose purpose was to evaluate a project for adaptive research on maize production. He has played a similar role in Zambia, where he helped evaluate an agricultural research and extension project as a member of a three-man team at the request of the US Agency for International Development.

Another broader purpose of visits like these is to identify the needs of national programs for equipment and supplies that they may have difficulty purchasing as a result of budget limitations or lack of foreign exchange. Almost all of the countries visited by the maize specialist during 1983 obtained various items, ranging from pollinating bags and tape measures to knapsack sprayers and moisture meters.

On some visits CIMMYT staff are accompanied by representatives of national programs, primarily as a means of keeping those scientists informed about research in neighboring countries and of thus promoting regional cooperation. During trips to Malawi and Zambia, for example, the director of the Center's Maize Program and the regional maize specialist were joined by Ethiopia's national maize research coordinator and the director of the national agricultural research stations of Kenya.

Training

A substantial portion of the regional specialist's time was devoted to making arrangements for in-service and in-country training. During 1983 a total of nine persons from the region participated in in-service courses in Mexico (see Table 45 in the section on training). In addition, three scientists from Zambia visited CIMMYT headquarters and Guatemala to gain a better understanding of balanced programs of population improvement and hybrid development.

CIMMYT regional maize specialist Wayne Haag and maize breeder Murat Bengi examine entries in a variety trial at the Samsun station in northern Turkey.

Middle East

Approximately 2.5 million ha are under maize cultivation in the countries that make up this region. The area planted to maize has increased only slightly (7%) over the past decade, whereas increases in yield and production have been substantial at 21 and 30%, respectively. In spite of increased production, however, maize imports have risen dramatically, reflecting a tremendous increase in demand fueled largely by rapidly expanding poultry industries.

Nine countries in the region participated in the Maize Program's international maize testing network during 1982-83, but the activities of the regional program were concentrated in three of them, Egypt, Syria, and Turkey. The first and third are the region's major producers of maize, and Syria is making a vigorous effort to expand its production, especially as a second crop following wheat.

Germplasm Improvement

The Egyptian program continued with its two-pronged approach to providing farmers with high-yielding germplasm that is resistant to late wilt disease (*Cephalosporium maydis*), one approach involving the development of open-pollinated varieties from populations and the other hybrids.

A modification was made in the recurrent selection methodology used in some populations, such that the S_1 method is now being used to improve Composite-2 and Composite-5. Three new experimental varieties were formed during 1982-83, EV-6 from Composite-2, EV-1 from Composite-5, and EV-1 from Composite 4. In the production of foundation seed, Composite-2 (EV-2) has been replaced by Composite-2 (EV-4), though the name Giza-2 has been retained.

Several single-cross (including SC-8, SC-9, and SC-10) and double-cross hybrids (such as DC-201, DC-202, and DC-203) were tested at experiment stations and in farmers' fields. The main efforts of the hybrid program were to improve the matching of the American Early Dent and Tep.-5 single-cross parents for production of double-cross hybrids. DC-202 currently appears to be the most promising hybrid.

Egyptian scientists continued participating in the international maize testing network, receiving several IPTTs, EVTs, and ELVTs, as indicated in Table 31 in the section on international testing. The program continues to show interest in the subtropical Populations 33, 34, 44, 45, and 47 (from which Egyptian scientists regularly extract inbred lines) and in the tropical materials Tuxpeño C17 and Gemmeiza 7421.

The maize program in Turkey is improving three populations, TMP-1, TMP-2, and TMP-3 (formerly designated Samsun-1, Samsun-2, and Adapazari-1, respectively), stressing grain yield and resistance to stalk rot (*Fusarium* spp.). No new varieties were developed from those populations during 1982-83, though the previously released varieties Ada, Sapanca, Arifiye, and K3/74 continued to be distributed.

Turkish scientists are expanding their work on the development and testing of hybrids, using germplasm from the US Corn Belt. During 1982-83 three single-cross (TTM-812, TTM-813, and TTM-815) and two double-cross hybrids (TCM-811 and TCM-816) were released.

Increased emphasis was given to the problem of borers (*Ostrinia nubilalis* and *Sesamia cretica*), a task being supported by staff at CIMMYT through training, consultancies, and materials. The Turkish program also continued to cooperate with the Center by handling nurseries of Population 48 and Pool 30.

The efforts of the Syrian national program are directed toward the development of early maturing hybrids and varieties for regions where maize is cultivated as a second crop after wheat. For that purpose early lines from Agaiti-72 were resynthesized to form Early Agaiti EV, work in which headquarters staff participated by growing winter nurseries. Other promising materials being handled by Syrian scientists are Syn-1 and Population-D, which should be able to compete with the currently grown imported hybrid LG-11.

Seed Production

As improved varieties and hybrids are developed, demand for seed is increasing rapidly, and countries in the region are attempting to respond in various ways. In Egypt two local seed producers, the National Seed Company and the Egyptian Seed Company, were formed to help meet the rising demand for improved seed. During 1982-83 the two firms distributed approximately 2000 and 3500 t, respectively, and in 1983 about 1000 t of the Pioneer hybrid P-514 were distributed. Seed production in Egypt during 1983 was estimated to be 7000 t of Giza-2, 500 t of DC-202 and DC-203, and 400 t of P-514. Prospects are fairly good for distribution of the entire 7000 t in 1984.

In Turkey considerable emphasis has been placed on the agronomy of seed production and on the accumulation of sufficient quantities of breeder's and foundation seed to meet anticipated demand. All objectives in the production of foundation seed were met during 1982-83, but major policy issues will have to be resolved before equal success can be achieved in large-scale production of certified seed of hybrids developed by the national program.

Some of the country's demand was met during 1982-83 through importation of seed, the sale of which to farmers was subsidized by the government. Currently, government officials are encouraging joint ventures between international seed companies and Turkish investors. Though a considerable amount of seed was imported, seed of locally developed open-pollinated varieties was distributed in modest amounts (200-300 t).

On-Farm Research

On-farm evaluation has become an integral part of the Egyptian national program, and all materials emanating from the breeding program are adequately tested in farmers' fields before being released.

In Turkey on-farm research has also taken root, particularly in the northern part of the country along the Black Sea. With some assistance from CIMMYT headquarters staff, recommendation domains (areas in an agroclimatic zone where farms and farmers' practices are similar enough that a given recommended practice should be widely applicable) have been delineated and a systematic research approach applied that involves surveys of farmers and on-farm experiments. The current focus of this research is stand establishment.

Experiment Station Development

This activity was given high priority by all three countries participating in the regional program, but especially by Syria and Turkey. In the latter country, an experiment station was established at Antalya; land levelling was completed, drains installed, and fences, roads, and buildings constructed. Researchers are now planning to set up an insect-rearing laboratory at Antalya to support development of resistance to borers. In addition, various improvements were made in the research facilities at Adana, Adapazari, and Samsun, with strong support from CIMMYT headquarters in the form of consultancies, equipment, and supplies.

The Turkish Program has been provided with other equipment and materials, not only to facilitate research, but to build the program's capacity to document its work.

Staff Development

Visiting scientists and in-service course participants from Egypt and Turkey travelled to Mexico for various types of training programs (see Table 45 in the section on training). In addition, Egyptian and Syrian researchers visited the Turkish maize program, following visits by Turkish scientists to Egypt. Staff of the Egyptian and Syrian programs attended a "travelling seminar" in Pakistan as part of an effort to increase contacts, not only within regions, but between them.

The need for stepped-up efforts in training was underscored by the departure of some national program staff to positions in private seed companies, which are growing steadily in the region. To safeguard the future development of national programs, departing staff will have to be replaced promptly, and higher priority must be given to the improvement of human resources.

West Africa

West Africa contains several diverse agroecological zones that extend across the region in horizontal bands. Differences between zones are determined mainly by variation in rainfall, which generally decreases from the Atlantic coast northward. The five major vegetation zones of West Africa are the forest, derived savanna, Guinea savanna, Sudan savanna, and Sahel. Other zones include the narrow strip of coastal savanna that cuts across Ghana and Togo and the midaltitude area in Cameroon that stretches into Nigeria and in which maize is an important crop.

Germplasm Requirements

Because the rainy season is of a different length in each vegetation zone, maize germplasm of various maturity groups is required to meet the needs of the entire region. Farmers in zones having a long rainy season with bimodal distribution and those in the Guinea savanna, which has one long rainy season, must have full-season tropical materials. In the Sudan savanna, tropical and subtropical materials of intermediate maturity have performed well. Early maturing varieties are needed in the northern Sudan savanna and Sahel, for the short rainy season of areas with bimodal rainfall distribution, and in the coastal savanna. Specially adapted materials are required for the midaltitude areas of the North and Northwest provinces of Cameroon and for Nigeria's Jos Plateau.

Most of the maize produced in West Africa is used as food. White grain is widely preferred, except in the Sudan savanna and Sahel, where farmers have traditionally grown yellow maize. The demand for yellow grain has increased during recent years as a result of expansion in the livestock industry. The biggest maize producer in the region is Nigeria, followed by Ivory Coast, Cameroon, Benin, and Ghana. The major constraints to maize production in these countries are erratic rainfall, low soil fertility, poor agronomic practices, and various diseases, among the most important of which are tropical rust and blight and maize streak virus.

Most improved tropical germplasm used in the region's national breeding programs, though it has good resistance to tropical rust and blight, is susceptible to maize streak virus. Since that deficiency has reduced the yield stability of the improved material, the two CIMMYT maize breeders assigned to the West Africa Regional Program during 1982-83 concentrated much of their effort on the development of streak resistant germplasm. This work was carried out at the International Institute of Tropical Agriculture (IITA) near Ibadan, Nigeria, where the regional program is based.

Several approaches are being taken to enhance the yield stability of improved germplasm that has been distributed by CIMMYT's international maize testing program and has performed well in Africa. One approach is to improve Population 43 (La Posta) for streak resistance, work that was begun at IITA in 1980. Another is to convert experimental varieties (EVs) from several other populations to streak

resistance through backcrossing. In addition, the Center's maize breeders at IITA had primary responsibility during 1982-83 for Pool 16, TZESR-W, and early and late, white back-up pools. Details about the progress of the program's germplasm work are given on pages 14-16.

Consultation With National Researchers

Much of the regional staff's time and resources were committed to assisting national programs across the region, from Senegal in the west to Cameroon in the east. The regional staff visited most national maize programs in the region at least once or twice a year to consult with national scientists and research administrators, to evaluate national and international trials, and to participate in research planning.

Monitoring of trials was especially important since a considerable number were conducted throughout the region. In addition to the various types of trials dispatched by CIMMYT to national programs across West Africa (see Table 31 in the section on international testing), 79 streak-resistant variety trials and progeny trials were distributed in the region by IITA. The regional maize staff tried to visit most of the national programs that received these trials to evaluate them with national maize researchers. EVs considered promising by national researchers were subjected to further selection under local growing conditions or used in various other ways by the national breeding program.

In consulting with national researchers, regional staff sought opportunities for providing modest logistical support, which is often of great help to national programs that lack foreign exchange for purchasing certain essential items abroad. Several programs were provided with equipment and supplies, such as shellers, balances, moisture testers, and pollination bags.

Although regional staff devoted most of their consultation time to monitoring trials and attending to other day-to-day concerns of national programs, they also looked into one fairly new area of research for the region. In 1983 a CIMMYT mission (consisting of two scientists from the Center's headquarters, a consulting animal nutritionist, and the two regional staff members) visited several national programs in West Africa to explore the possibilities for utilization of quality protein maize. The group found considerable interest in some countries in using this type of maize for human food and animal feed.

Training

The regional staff helped select candidates from national programs for training at CIMMYT, were heavily involved in IITA training activities, and organized additional training events for national scientists in the region. During 1982-83, 19 national staff from the region participated in the two six-month in-service training courses conducted at CIMMYT headquarters (see Table 45 in the section on training). Visiting scientists from the region also came to CIMMYT for periods of one week to three months to become acquainted with the Center's Maize Program, its breeding materials, and procedures.

The regional staff served, in addition, as resource persons for a three-month training course in maize production conducted by IITA in 1983. In another training program offered within the region, national scientists were brought to IITA to participate in the work on streak resistance. In 1982, three maize workers from Ghana spent 10 days at IITA for that purpose, and in 1983 two other workers (one each from Ghana and Togo) were at the Institute for six weeks, becoming familiar with the techniques of breeding for streak resistance.

The Ghana Grains Development Project

The Ghana Grains Development Project (GGDP) was launched in 1979 with a view to making the country self-sufficient in maize. The project is a bilateral venture between the Canadian International Development Agency (CIDA) and the government of Ghana that involves CIMMYT (as CIDA's executing agent), the Crops Research Institute (CRI, as Ghana's executing agent), the Grains and Legumes Development Board (GLDB), and the Ministry of Agriculture (MOA). To assist the national program with meeting project objectives, CIMMYT has had an agronomist based at Kumasi, Ghana, since 1979. In addition to maize, the GGDP has a cowpea component, which is directed by staff of the International Institute of Tropical Agriculture (IITA) in Nigeria. In this report only maize-related activities will be considered. The project has divided its activities along institutional lines, with CRI emphasizing population improvement, back-up pool development, germplasm screening, and experiment station-based agronomy research, while the other Ghanaian organizations handle the economics, on-farm research, and extension activities.

About Ghana

Ghana is in the lowland tropics of West Africa, lying between 4° and 12° N latitude. It has an area of 239,000 km^2 and a population of 12 million, 63% of whom are engaged in agriculture in rural areas. Rainfall is divided between a major and a minor rainy season in the south, but falls in a single season in the north. The natural vegetation changes from savanna at the coast to rain forest, then to derived savanna (transition), before becoming full-fledged Guinea savanna in the northern third of the country. The principal food crops grown are plantains, yams, cassava, maize, sorghum, groundnuts, cowpeas, rice, and millet. Although maize is the most important cereal

grown, covering 400,000 ha, Ghana has exported maize only once in the past decade, and it has been more normal for about 50,000 t of maize to be imported each year.

Small-farmer holdings (less than 2 ha) account for an estimated 90% of national production. Traditionally, land is prepared by slashing and burning vegetative cover without cultivation. Almost all weeding is done manually. Plant densities are low, averaging 24,000 plant/ha. The majority of maize is intercropped, primarily with cassava and cocoyam in southern Ghana, and with sorghum, millet, groundnuts, and cowpeas in the Guinea savanna. After harvest maize is often stored unhusked in cribs, where insect damage may cause considerable losses prior to sale or consumption.

Research Objectives

The general objectives of the maize breeding program are: to increase grain yield and resistances to lodging, diseases, and insects; to develop varieties for particular ecological zones and for the major and minor rainy seasons; and to develop varieties with improved nutritional characteristics for humans and animals. Agronomic research aims to develop suitable growing practices for improved varieties that are tailored to the various ecological zones of Ghana and to the needs of small farmers. The end result of the research process is the development and promotion of extension information through the MOA and the GLDB.

As an aid to identifying more specific research objectives, surveys of farmers' circumstances were conducted by economists from GLDB and CIMMYT in four key maize-producing regions in 1979-81. Data from these surveys, coupled with analyses of on-farm trial data over the same period and field observations by project staff, were crucial in identifying farmers' production problems that merited further agronomic research or that led to changes in breeding objectives. One result has been the following identification of varietal requirements for Ghana:

- 120-day white dent varieties for the forest and transition zones in the major rainy season and the Guinea savanna. These varieties meet about 60% of the national varietal requirement.
- 105-day white dent varieties for the minor rainy season in the forest and transition areas, accounting for about 20% of maize grown.
- 90-day yellow flint varieties for early plantings in the Guinea savanna, accounting for 5% of production.
- 90-day soft white dent varieties for use in the coastal and Guinea savanna, accounting for about 5% of production.
- 110-day yellow dent varieties for use throughout Ghana, accounting for about 10% of maize varietal requirements.

Another result of the surveys and other findings has been a considerable emphasis upon on-farm research as an effective tool for developing grower recommendations. Clear differences were observed between experiment station conditions and those prevailing in farmers' fields. For example, the weed *Cyperus rotundus* was found to dominate most of the arable station land, but was rarely found in farmers' field. Fertilizer and cultivation histories are very different also. The experiment stations have a long history of continual maize cultivation, using high levels of chemical fertilizer and tractor-powered cultivation methods. In contrast, the majority of farmers do not apply chemical fertilizer, they rarely cultivate maize on a continuous basis, and about 50% prepare land for planting by slash and burn methods. For those reasons, the majority of agronomic research was conducted in farmers' fields at sites widely scattered throughout the maize-growing regions of Ghana.

Although the majority of maize in Ghana is intercropped, the national maize program has chosen to focus much of its initial research on monocropped maize. As this simple system becomes better understood, then intercropping can be systematically added to the research agenda.

Research Approach

Training staff from the CRI, GLDB, and MOA to conduct a maize breeding program or on-farm trials and extension demonstrations has been a key component of the research program. Some staff have gone for graduate training in Canada and the United States, and 6 from CRI and the GLDB were each trained for six months in maize production or improvement at CIMMYT during 1982-83. Those trainees and the 15 previously sent for training at CIMMYT form an indispensable technical core within the national maize program. Each year a two-day in-service training program for all staff has been conducted, immediately prior to planting, at each of the seven regional headquarters. These interactive sessions are attended by all persons who will actually conduct the trials or demonstrations. In a classroom session, each participant is given a summary of the previous year's research results, an annually updated version of grower recommendations, and specific instructions for conducting the coming year's field program. The remainder of the training program is field oriented: each person participates in laying out a trial, calibrating and maintaining a sprayer, and applying fertilizer. In 1982, 236 staff of the GLDB attended these sessions, and in 1983, as more staff of the MOA were included, numbers rose to 398.

CRI has nine experiment stations at which variety and progeny testing is carried out. These are (from north to south) Manga, Nyankpala, Damongo, Ejura, Kwadaso, Fumesua, Kpeve, Pokoase, and Ohawu. The breeding program is divided between the north (based at Nyankpala) and the south (based at Kwadaso), and

germplasm specific to either the Guinea savanna or the forest and derived savanna is handled at each center.

The on-farm trial program is coordinated from Kumasi, where the GLDB is headquartered. Field books, seed, fertilizer and all other trial imputs are distributed to each location prior to the onset of the rains. A local supervisor, in conjunction with a cooperating farmer, selects a site and sows the trial at the same time as the farmer sows the balance of the field. Research trials are usually replicated two to three times at each site, and as many sites are sown as possible. Normal practice is to sow six 5-m-long rows per plot, with a target plant density of 50,000 plants/ha, and a total plot number per site of less than 40. Verification demonstrations, part research and part demonstration, are unreplicated at each site, and comprise three large plots, each 11 x 20 m. The currently recommended variety (La Posta) is normally grown in agronomic trials, and seed is treated with Furadan to prevent stand reduction by birds.

Soon after on-farm trials are sown, inspection by CIMMYT-trained staff begins, and soil samples from each site are taken where appropriate. Harvest is usually carried out on a carefully planned schedule by the same staff, and harvested produce remains the property of the farmer. The grain moisture content of each plot is determined at each site with a portable moisture tester, and shelling percentage is assumed to be 80%. Following harvest, field books are brought to Kumasi for checking and analysis by microcomputer, using programs developed by project staff. Single-site analysis of all recorded variables is followed by across-site analysis of those sites whose data appear reliable. Sites are grouped by ecological zone and by cropping and fertilizer history, where appropriate.

Each year, several months prior to planting, a national maize workshop is held. At this three-day meeting of selected leaders in policy, research, and extension, results from the previous year's research are presented and discussed. Changes are made in maize-growing recommendations when required, and in the light of current research information, plans for the research and extension activities of the coming year are drawn up and approved.

A full record of the activities of the GGDP is presented in an annual report, which is widely circulated throughout Ghana. The current maize growers' recommendations, which form the basis of extension messages about the crop, are distributed to all extension officers.

Maize Research Highlights

Survey data from 1979-81 highlighted a number of production problems, which were the focus of the on-farm research program in those years. Trials were conducted on varieties, the relative importance of density, weed control, fertilizer and variety, chemical and manual weed control, factors affecting stand establishment, variety by planting

Harvest of an on-farm variety trial in the Guinea savanna belt of northern Ghana.

density interactions, rates and times of application of nitrogen and phosphorus fertilizers, and the relationship between nitrogen response and weed control. Planting arrangements and the effects of ridging were examined, and in response to poor plant growth in parts of the Guinea savanna, a trial was conducted to observe the effects of applied zinc.

Additional observations of farmers' field and the results of previous trials prompted the trials conducted in 1982-83, which are reported below. In 1982 rainfall was moderate, although the minor season was unusually dry; but 1983 was the driest year in the last 40 at many locations, and average yields of trials fell by 20%.

Major-season variety trials— Varieties included in these trials, from CRI, CIMMYT, and IITA, had previously undergone at least one year of testing on station. They were compared with the local variety used by the cooperating farmer at each site. All varieties were grown at a realized density of 44,000 plants/ha, and fertilizer was applied at a rate of 90-60-60 kg $N:P_2O_5:K_2O$/ha. Weeds were controlled by applying atrazine-based herbicides or by hand-weeding at three and six weeks after planting. Each trial consisted of three replications at each site. Usable results were received from 23 sites in 1982 and 16 sites in 1983. In both years the trials were conducted throughout all ecological zones of Ghana.

The results from 1982 (Table 49) show the general superiority of La Posta and related varieties and were typical of results obtained from similar trials conducted in 1983 and in other years. La Posta-derived varieties have generally shown a 10 to 12% yield advantage over locally improved varieties. In addition, La Posta varieties lodged slightly less and yielded 30 to 50% more than farmers' varieties but were inferior to them in husk cover. Local varieties have smaller kernels with a softer texture. A decision was taken at the end of 1983 to release Ejura (1) 7843, a locally selected version of CIMMYT's La Posta population. Varieties from Population 22 (Mezcla Tropical Blanca) yield very well and are shorter and therefore more resistant to lodging but possess a harder grain than is readily acceptable in Ghana.

Time of application and placement of starter fertilizer— Present maize-growing guidelines recommend that phosphorus-bearing fertilizer be applied at planting in a 2-cm-deep hole and 5 cm away from the seed but that side-dressed nitrogen be applied to the surface of the soil four weeks after planting. The farmers' practice is to apply compound fertilizer and side-dressed nitrogen to the soil surface several weeks after emergence, usually while weeding is in progress. This prevents the loss of fertilizer should crop establishment fail.

These factors were examined in a trial conducted at 13 sites in 1982 and at 13 different sites in 1983. The trial had a randomized complete block design in which two application times (at planting versus three weeks afterwards), two fertilizer placement methods (buried 5 cm deep 7 cm to one side of the seed or applied on the surface 7 cm from the seed), and three forms of starter fertilizer were arranged in a 2 x 2 x 3 factorial in two replications at each site. The forms of starter fertilizer were: 1) compound 15-15-15 applied at 60-60-60 kg $N:P_2O_5:K_2O$/ha, with a side-dressing of 30-0-0 at four weeks; 2) triple superphosphate applied at 0-60-0 and side-dressed with 90-0-0 at four weeks; and 3) ammonium sulphate applied at 60-0-0 and side-dressed with 30-60-0 at four weeks. These forms of fertilizer added to a total 90-60-60 kg $N:P_2O_5:K_2O$/ha, for the first form and to 90-60-0 for the other two. The variety was La Posta, grown at 45,000 plants/ha.

Results (Table 50) varied slightly between years, showing a signifcant 5.3% advantage in applying starter fertilizer at planting in 1982 but no effect due to time of application in the drier year, 1983. In neither year

Table 49. Performance of maize varieties in different ecological zones in Ghana during the major season of 1982

Variety	Grain yield (t/ha) at 15% moisture: Forest	Transition	Guinea savanna	All sites	Plant height (cm)
Poza Rica 7843	3.97	4.89	4.02	4.35	216
Ejura (1) 7843	3.97	4.73	4.09	4.31	218
La Posta CRI	3.93	4.63	3.92	4.20	236
Poza Rica 7822	4.12	4.59	3.64	4.14	196
Composite W EV80	3.77	4.87	3.55	4.12	246
Giant Comp.	3.98	4.56	3.44	4.02	243
Poza Rica 7721E	3.80	4.42	3.57	3.96	178
La Posta CRI EV80	3.79	4.51	3.46	3.96	223
Golden Cryst. EV80	3.54	4.62	3.43	3.93	212
Composite 4 EV80	3.34	4.53	3.65	3.91	228
Tuxpeño PB C16	3.27	4.04	3.49	3.65	171
Local	2.75	3.54	2.96	3.13	248
Mean	3.69	4.49	3.60	3.97	218
Number of sites	6	9	8	23	22
LSD (0.05)	0.46	0.36	0.50	0.25	6
C.V. (%)	19.0	15.0	24.5	19.1	7.5

did the different placement methods have an effect on yields. These findings validate the farmers' practice of surface application of fertilizer several weeks after planting. The forms of fertilizer showed variable effects. In 1982 phosphorus-bearing fertilizers gave a 10% yield advantage over ammonium sulphate, but in 1983 the advantage went to the compound fertilizer, which was the only fertilizer used that contained potassium. Across both years the response to phosphorus application at sowing, as opposed to three weeks after sowing, was a 3% yield increase. This small response to phosphorus made available during early establishment is consistent with the relatively low response to applied phosphorus found in other trials. The 6% yield increase arising from applied potassium was larger than that observed in trials conducted on alfisols in Ghana a decade previously. The more recent finding may indicate that on some of the well-used maize soils this nutrient is becoming limiting; soil analyses confirm that supposition.

None of the interactions among main factors was statistically significant. The effect of heavy rainfall during crop establishment on surface-applied fertilizer has yet to be determined, but the findings reported here suggest that farmers' current practice is fully defensible and is a successful risk-aversion strategy.

Response of maize to applied zinc and compound fertilizer— Observation trials conducted on soils of the Guinea savanna in 1981 showed that application of zinc sulphate alleviated many of the micronutrient deficiency symptoms present in maize grown on these well-used soils. A simple trial was devised to assess the scope and magnitude of zinc deficiency in Ghana and was distributed widely throughout the country. Since most farmers do not use fertilizer, zinc response was determined in the presence and absence of applied fertilizer. The trial design was a randomized complete block in which six treatments were replicated twice at each location. Among the treatments were 0, 4.2, 8.4, and

Table 50. Influence of application time, placement, and form of fertilizer on grain yield in Ghana during the major seasons of 1982 and 1983

Treat-ment	Time of application	Placement method	Form of fertilizer	Yield (t/ha) at 15% grain moisture 1982	1983	Mean
1	Planting	Buried	15-15-15	4.47	3.29	3.88
2	Planting	Buried	TSP	4.09	2.96	3.53
3	Planting	Buried	Amm. sulph.	4.21	3.28	3.75
4	Planting	Surface	15-15-15	4.45	3.34	3.90
5	Planting	Surface	TSP	4.52	2.97	3.75
6	Planting	Surface	Amm. sulph.	3.94	3.23	3.59
7	3 weeks	Buried	15-15-15	4.05	3.46	3.76
8	3 weeks	Buried	TSP	4.17	2.98	3.58
9	3 weeks	Buried	Amm. sulph.	3.63	3.35	3.49
10	3 weeks	Surface	15-15-15	4.34	3.60	3.97
11	3 weeks	Surface	TSP	4.34	3.12	3.73
12	3 weeks	Surface	Amm. sulph.	4.01	2.75	3.38
Main effects						
Time of application:		At planting		4.31	3.18	3.75
		3 weeks		4.09	3.21	3.65
Difference significant (0.05)?				Yes	No	
Placement		Buried		4.11	3.22	3.67
		Surface		4.30	3.17	3.74
Difference significant (0.05)?				No	No	
Form		15-15-15		4.33	3.42	3.88
		TSP		4.33	3.01	3.67
		Amm. sulphate		3.95	3.15	3.55
Difference significant (0.05)?				Yes	Yes	
General mean				4.20	3.19	3.70
Number of sites				13	13	26
LSD (0.05)				0.41	0.39	
C.V. (%)				17.7	22.3	

12.6 kg zinc/ha, applied as commercial grade zinc sulphate in the fertilizer hole at planting time. At all four of those rates, zinc was applied with 90-60-60 kg $N:P_2O_5:K_2O$/ha. The remaining two treatments were 0 and 8.4 kg zinc/ha with no fertilizer added. The variety used was La Posta, grown at 44,000 plants/ha. Soil samples were collected as 20 cores from the top 15 cm of the soil profile at each trial site midway through the season. These were sun dried, ground, and analyzed according to standard laboratory procedures.

The largest response to zinc was obtained in the Guinea savanna (Table 51), where, with fertilizer, plots receiving 4.2 kg zinc/ha outyielded those with no zinc by a statistically significant 0.71 t/ha, or by 20%. Higher rates of zinc applied did not give significant increases in yield. In the absence of fertilizer, the response to zinc was much smaller, indicating that on these soils nitrogen was far more limiting than zinc. In a similar trial conducted in 1983, a significant response to zinc was not recorded on these soils, suggesting that in this very dry year, water was more limiting than zinc. The response to applied zinc appeared to decline at sites further south and became essentially zero, or even negative, in the forest zone. When second-order polynomial regressions of yield upon the rate of zinc applied were fitted to the response data from the different zones, it was observed that the optimum rate of applied zinc increased as one moved from the forest zone to the Guinea savanna (Table 51). Soil organic matter was highly correlated with extractable soil zinc (r = 0.62**, 50 df) and with extractable soil boron (r = 0.84**, 50 df), and all three parameters declined in roughly the same manner from the southern forest to the northern Guinea savanna (Table 51). The response of yield to applied zinc was significantly negatively correlated with percent organic matter (r = -0.50*, 50 df), and with extractable soil zinc (r = -0.43*, 50 df).

One disturbing aspect of this study was the apparent decline in yield at high levels of zinc application in the forest and transition zone (Table 51). It was thought that induced copper deficiency might have brought about the decline, but a subsequent series of trials conducted in 1983 under dry conditions did not confirm whether that was indeed the cause.

The addition of very small quantities of zinc to compound fertilizer at the manufacturing plant seems to be a highly cost effective method of addressing this major micronutrient deficiency in the Guinea savanna and transition areas of West Africa.

Table 51. Influence of zinc and compound fetilizer levels and of selected soil attributes in the top 15 cm in various ecological zones of Ghana during the major season of 1982

Treatment		Grain yield (t/ha) at 15% moisture)				
Zinc (kg/ha)	Fertilizer $N:P_2O_5:K_2O$	Forest	Transition	Coastal sav.	Guinea sav.	All sites
0	90-60-60	4.16	4.44	4.07	3.59	3.97
4.2	90-60-60	4.48	4.54	3.81	4.30	4.33
8.4	90-60 60	4.00	4.74	4.32	4.30	4.34
12.6	90-60-60	3.86	4.39	3.95	4.25	4.16
0	0-0-0	2.74	3.01	2.56	1.53	2.27
8.4	0-0-0	2.92	2.52	2.35	1.73	2.25
Mean		3.69	3.94	3.51	3.28	3.55
Number of sites		10	11	6	20	47
LSD (0.05)		0.42	0.41	0.41	0.40	0.22
C.V. (%)		17.9	17.3	11.0	27.3	20.6
Mean soil pH		6.2	6.2	6.6	6.2	6.3
Mean % organic matter		2.5	1.7	1.9	0.9	1.5
Zinc (micrograms/g)		2.1	1.6	2.1	0.5	1.1
Boron (micrograms/g)		0.4	0.3	0.4	0.2	0.3
Predicted level of zinc applied for optimum yield (kg/ha)		3.8	6.4	7.3	8.5	7.2

Maize-cowpea intercropping trial—Intercropping of cereals and legumes in the savanna is commonly practiced as a means of diversification, protein production, weed control, and fertility maintenance. It is one approach toward establishing a stable agricultural system in a region where, because of annual burning and overcropping, nitrogen is acutely deficient. Earlier trials indicated that the spacing of maize and cowpea exerted considerable influence on the productivity of the intercropping system. In an effort to identify the planting arrangements of maize and cowpea that produced the most grain, a trial consisting of factorial combinations of four maize and four cowpea densities was planted at seven sites in the savanna during 1983. The experimental design was a randomized complete block in two replications at each site. An early variety of maize (Selección Precoz) was sown in rows 100 cm wide, and maize density was varied within the row to give realized densities of 0, 20,100, 35,100, and 44,900 plants/ha. A cowpea variety (TVx 1843-1C) was sown in zero, one, two, or three rows between the rows of maize to give realized cowpea densities of 0, 36,900, 63,300, and 78,000 plants/ha. Normal insecticide protection of the cowpeas (consisting of two applications of Decis and two of endosulphan) was provided, and all plots received 90-60-60 kg $N:P_2O_5:K_2O$/ha.

Yields of both crops were low (Table 52) because of severe drought. Maize yields, in pure and intercropped stands, responded positively to increased density and were reduced significantly when an intercrop of cowpea was introduced. Cowpea yields also increased with increasing cowpea density in pure stands and intercropped stands. The land equivalent ratio (LER) was highest at the higher densities of maize and cowpeas (Table 52), indicating that land was being used with high efficiency under these circumstance.

A crude estimate of protein and carbohydrate production was obtained by assuming that maize was 10% crude protein and cowpeas 25% and that carbohydrate constituted the balance of harvested dry matter. Maximum protein production ocurred when maize was grown at 46,000 plants/ha and cowpeas at 61,000 plants/ha. Maximum carbohydrate production occurred at a similar maize density but at a lower (35,000 plants/ha) cowpea density.

Lack of available soil moisture was the probable reason that maize was more affected by cowpeas as an intercrop than vice versa. Cowpea is known to be more drought tolerant than maize. In wet years maize yield is often unaffected by the presence of a cowpea intercrop.

Table 52. Influence of plant spacing on maize and cowpea performance in the savanna zone of Ghana in 1983

Treatment (densities)	Yield (t/ha) Maize (15% grain moisture)	Cowpea (sun-dry)	Land equivalent ratio	Protein produced (kg/ha)	Carbohydrate produced (kg/ha)
M1 C2	—	1.17	—	293	878
M1 C3	—	1.38	—	345	1035
M1 C4	—	1.39	—	348	1035
M2 C1	2.06	—	—	206	1854
M2 C2	1.65	0.81	1.49	368	2093
M2 C3	1.36	0.77	1.32	329	1802
M2 C4	1.31	1.10	1.43	406	2004
M3 C1	2.58	—	—	258	2322
M3 C2	2.10	0.71	1.42	388	2423
M3 C3	1.92	0.86	1.36	407	2373
M3 C4	1.56	0.93	1.27	389	2102
M4 C1	2.32	—	—	232	2088
M4 C2	2.24	0.78	1.63	419	2601
M4 C3	2.04	0.91	1.54	432	2519
M4 C4	1.68	0.83	1.32	376	2135
Overall mean	1.90	0.97	—	346	1891
Number of sites	6	7	—	—	—
LSD (0.05)	0.35	0.26	—	—	—
C.V. (%)	28.0	44.6	—	—	—

Verification demonstration trials— The objectives of these trials are to demonstrate to farmers two alternative technologies in comparison with the farmers' own, to verify under realistic conditions the recommended production technology, and to collect data on yields and costs of production. If the improved varieties show superior performance, there should be an increase in dissemination of seed of those materials.

Each trial consisted of three plots each measuring 20 x 10.8 m. In plot A seed of the recommended variety, La Posta, was sown in rows (with two seeds planted per hill and not thinned), giving a density of 41,000 plants/ha. The crop received 91-38-38 kg $N:P_2O_5:K_2O$/ha and was hand-weeded twice during growth. Plot B demonstrated an intermediate level of inputs. The crop was planted in the same manner as plot A; but the fertilizer application rate was reduced by half, and the plot was weeded only once. In plot C farmers were encouraged to grow the best crop of maize they could, using their own variety and methods. Records of all practices performed on all plots were kept by the trial supervisor, and two to three field days (at planting, silking, and harvest) were held for local farmers at the trial. Grain yields from a 57-m^2 subplot were weighed, and plot yields in bags per acre were calculated by use of a simple formula that assumed 25% grain moisture and a shelling percentage of 80.

These unreplicated trials were distributed to 203 sites throughout the maize-growing regions of southern and central Ghana in 1982 and to 222 sites in the maize-growing regions of the country in 1983. Yields in 1983 (Table 53) were reduced by drought and by streak virus infestation (the seed in these trials was not treated with Furadan prior to sowing). The procedures used for calculating variable costs, net benefits and marginal rates of return (the latter listed in Table 53) are those described by Perrin et al. (1979). In all ecological zones (except in the coastal savanna during 1983, when the sample of farmers was small) and in both years, adoption of the intermediate input level option (plot B) by farmers gave larger returns to capital invested than did the next step in intensification, the adoption of production methods used in plot A. This outcome reflected an average 72% yield increase of B over C, but an increase of only 16% of A over B. In 1983 the yield margin of B over C fell from 1.48 to 1.07 t/ha, showing that under moisture stress the response to factors other than water is reduced.

An important factor in the adoption of new practices is the riskiness, or robustness, of the technology. When the proportion of verification/demonstrations in which farmers failed to recover their variable costs was examined, it was found that in the drought year of 1983 the two recommended technologies had similar failure rates (5.9%), while the farmers' own technology failed in 9% of cases.

Marginal rates of return from investments made in options A and B are certain to fall in the future. During 1982-83, the price of fertilizer was extensively subsidized, and the price of maize was very high because of drought and the return of refugees from Nigeria. Large changes in factor prices are expected in 1984-85 as subsidies are lifted. It is likely that the lower level of inputs represented by plot B will then be the only viable technology option out of those presented to the farmer in the current verification demonstration. That will be especially so for farmers who rent or sharecrop land. Approximately 6,000 farmers attended field days in each of the two years under review.

Table 53. Maize yields and marginal rates of return (MRR) from verification demonstrations conducted in different ecological zones of Ghana during the major seasons of 1982 and 1983

	Grain yield (t/ha) at 15% moisture				
	Forest	Transition	Coastal savanna	Guinea savanna	Across zones
1982					
Yield, plot A	3.93	3.83	3.72	—	3.88
Yield, plot B	3.48	3.20	3.20	—	3.38
Yield, plot C	1.93	1.88	1.70	—	1.90
MRR, from plot B to plot A (%)	263	273	270	—	272
MRR, from plot C to plot B (%)	583	327	401	—	381
Number of sites	122	71	10	203	
1983					
Yield, plot A	3.53	2.93	4.45	2.00	3.20
Yield, plot B	3.03	2.50	3.33	1.65	2.70
Yield, plot C	1.70	1.58	2.05	1.18	1.63
MRR, plot B to plot A (%)	511	336	1727	123	430
MRR, plot C to plot B (%)	675	496	1138	204	593
Number of sites	104	77	15	26	222

Appendix 1: Maize Gene Pools

Normal Maize

The normal gene pools being improved by the CIMMYT Maize Program are described below, with emphasis on their components and primary features and on the traits for which selection is being practiced. Data on the progress being made with these materials are reported in the section of this report entitled "Gene Pool Development and Improvement."

Pool 1 (Highland Early White Floury)—This pool is based primarily on the race Cacahuacintle of Mexico but also includes other germplasm from the highlands of Colombia, Bolivia, Peru, Ecuador, and Mexico. A small proportion of the germplasm comes from temperate areas of the USA and Europe. Selection emphasis is for large floury seeds and resistance to ear rots and earworm. In 1983 half-sib families of this pool were tested through the international progeny testing system at Cocha Bamba (Bolivia), Santa Catalina (Ecuador), Andenes Cusco (Peru), and El Batán (Mexico).

Pool 2 (Highland Late White Floury)—This pool is based mainly on the races Cuzco Gigante of Peru and Hualtaco of Bolivia but also contains germplasm from Kenya and Cuba. Selection is being practiced for large floury seeds and resistance to ear rots and earworm.

Pool 3 (Highland Early Yellow Floury)—This pool is based essentially on the same germplasm as is Pool 1, except that yellow floury kernels have been selected. Selection is being practiced for the same traits as in Pool 1. In 1983 half-sib families of this pool were tested through the international progeny testing system at Cocha Bamba (Bolivia), Santa Catalina (Ecuador), Caja Marca (Peru), and El Batán (Mexico).

Pool 4 (Highland Late Yellow Floury)—This pool is based primarily on the race Chilo of Ecuador, but also contains other germplasm from the Andean countries, Mexico, Africa, and the USA. It is being selected for large floury seeds and resistance to ear rots and earworm. In 1983 half-sib families of this pool were tested through the international progeny testing system at Santa Catalina (Ecuador), Caja Marca (Peru), and El Batán (Mexico).

Pool 5 (Highland Early White Morocho)—This gene pool is based on early white *morocho* (seed that has a hard flint texture outside and is soft inside) genotypes of Peru, Bolivia, Colombia, and Ecuador, with some germplasm from Mexico, the USA, and Europe. Selection is being practiced for large seed type and resistance to earworm and ear rots.

Pool 6 (Highland Early Yellow Morocho)—This gene pool is based on early yellow *morocho* genotypes from the same Andean countries as those mentioned in the description of Pool 5. It also has germplasm from the highlands of Mexico and Africa, and from the USA, Europe, and Indonesia. Selection is being practiced for the same traits as in Pool 5.

Pool 7 (Highland Late White Morocho)—Originally a mixture of late white and yellow *morocho* types form the highland areas of the Andean countries, this material was changed to a white pool in 1982. Some of its components are from the highlands of Mexico and Africa and from the USA. Selection is being practiced for better seed type and resistance to ear rots and earworm.

Pool 8 (Highland Late Yellow Morocho)—This pool was formed with the yellow segregates selected from Pool 7.

Pool 9 (Highland Late White Dent)—This pool was developed by crossing materials well adapted to the African highlands and includes materials from the Kenyan highlands, collections of races from Colombia, Ecuador, and Guatemala, and tropical lowland Tuxpeño from Mexico. It is late and tall. Selection is being practiced for resistance to foliar diseases.

Pool 15 (Tropical Early White Flint)—This pool is based on crosses among a large number of early and late white flint materials from Mexico, the Caribbean, Central and South America, and Asia. Selection is being practiced for early maturity, better plant type, good yield, and tolerance to high plant density and stalk rot.

Pool 16 (Tropical Early White Dent)—The white dent materials used in forming this gene pool are from the same geographical areas as the materials that make up Pool 15. Selection is being practiced for early maturity, better plant type, good yield, tolerance to high plant density, and resistance to stalk rot.

Pool 17 (Tropical Early Yellow Flint)—This pool is the same as Pool 15, except that yellow flint segregants were used in its formation.

Pool 18 (Tropical Early Yellow Dent)—This pool is the same as Pool 17, except that yellow dent segregants were used in its formation.

Pool 19 (Tropical Intermediate White Flint)—Nearly 30% of the germplasm in this pool is downy mildew resistant material from the Philippines. The pool also has materials from Cuba, Mexico, Argentina, Honduras, El Salvador, Colombia, Ecuador, India, and central and southern USA. It is intermediate to late in maturity and has good plant type and yield potential. Selection is being practiced for improved shelling percentage and resistance to the sugarcane borer, *Diatraea saccharalis* (F.).

Pool 20 (Tropical Intermediate White Dent)—This pool consists mainly of materials from the Philippines, India, and Southeast Asia. A small fraction of the component germplasm is from Mexico and various Central American countries. The pool is similar in plant type and yield to Pool 19 and is being improved for ear rot resistance.

Pool 21 (Tropical Intermediate Yellow Flint)—This gene pool is based on yellow flint materials from Mexico, Cuba, the Dominican Republic, Colombia, Argentina, Ecuador, Costa Rica, Uruguay, St. Vincent, Guatemala, Surinam, and India. It is relatively tolerant to stunt. Selection emphasis is on improved shelling percentage and resistance to sugarcane borer.

Pool 22 (Tropical Intermediate Yellow Dent)—This pool is made up of materials from Mexico, Cuba, the Dominican Republic, Antigua, Brazil, Peru, Ecuador, Argentina, Colombia, India, Puerto Rico, and several Central American countries. It has good yield potential and plant type and is being improved for stalk rot resistance.

Pool 23 (Tropical Late White Flint)—This pool is based on white flint selections from crosses among materials from Mexico, Colombia, the Caribbean, Guatemala, Panama and other Central American countries, India, Thailand, and the Philippines. It is late maturing and has relatively short plants and excellent yield potential. Selection is being practiced for stalk rot resistance.

Pool 24 (Tropical Late White Dent)—This gene pool is based mainly on Tuxpeño germplasm from Mexico but also contains some materials from Central America. It is being selected for increased resistance to fall armyworm (*Spodoptera frugiperda* (J.E. Smith).

Pool 25 (Tropical Late Yellow Flint)—This gene pool, made up of materials from Mexico, Central America, the Caribbean, Ecuador, Colombia, and Argentina, is relatively tall and has good yield potential. Selection is being practiced for ear rot resistance.

Pool 26 (Tropical Late Yellow Dent)—This pool is made up mainly of materials from Central America, Mexico, Asia, Colombia, and the Caribbean. It also contains a small amount of germplasm from the US Corn Belt. The pool is tall and relatively tolerant to stunt and has good yield potential. It is being selected for fall armyworm resistance.

Pool 27 (Temperate Early White Flint)—This subtropical pool is made up mainly of materials from Pakistan but also contains germplasm from the USA, China, Lebanon, and several European countries. It is variable in plant type and other agronomic characters but has good yield potential. Selection is being practiced for tolerance to high density and for resistance to ear and stalk rots and leaf diseases.

Pool 28 (Subtropical Early White Dent)—This pool is based on white dent selections from crosses between white flint materials from Pakistan and yellow flint and dent materials from Europe, China, Lebanon, Mexico, Guatemala, and the US Corn Belt. Since it has undergone only a few cycles of selection, the pool is more variable than some older pools. It is early maturing and has good yield potential. Selection is being practiced for tolerance to high density and for resistance to ear and stalk rots and leaf diseases.

Pool 29 (Temperate Early Yellow Flint)—This pool is based on materials from Europe, Lebanon, the US Corn Belt, China, Pakistan, Indonesia, and South America. It has excellent plant type and yield potential and is being improved for tolerance to high density and for resistance to ear and stalk rots and leaf diseases.

Pool 30 (Temperate Early Yellow Dent)—This pool consists of materials from Europe, China, Lebanon, Mexico, South America, and the US Corn Belt. It is early maturing and has good plant type and yield. The pool is being improved for tolerance to high density and for resistance to ear and stalk rots and leaf diseases.

Pool 31 (Temperate Intermediate White Flint)—This pool is based on white flint segregates from crosses among materials from Mexico, the US Corn Belt, Brazil, Uruguay, Argentina, China, Pakistan, Yugoslavia, Lebanon, Guatemala, Venezuela, Peru, Cuba, Antigua, and the Dominican Republic. It is relatively uniform in plant height and maturity and has good yield potential. It is being improved for resistance to leaf diseases and ear and stalk rots.

Pool 32 (Temperate Intermediate White Dent)—This pool has the same gene base as Pool 31 but is better in plant type and yield and has deep white dent kernels. It is being selected for resistance to the southwestern corn borer, *Diatraea grandiosella* (Dyar).

Pool 33 (Temperate Intermediate Yellow Flint)—This pool is essentially the same as Pool 31, except that it has yellow-orange flint kernels. The pool is being selected for resistance to ear rot, stalk rot, and leaf diseases.

Pool 34 (Temperate Intermediate Yellow Dent)—This pool is made up of crosses among Mexican lowland and highland materials and germplasm from the US Corn Belt, southern USA, Yugoslavia, Hungary, China, Lebanon, Guatemala, Honduras, Chile, Antigua, Cuba, the Dominican Republic, Peru, and Pakistan. It has a short plant type, well-placed ears, and good yield potential. Selection is being practiced for resistance to ear and stalk rots and leaf diseases.

Pool 39 (STR, southern temperate region)—This pool is based on germplasm from tropical (both lowland and highland), subtropical, and temperate areas of Mexico, Pakistan, the USA, Africa, Central America, the Caribbean, and Bolivia. It is designed to serve winter maize-growing areas in the tropics and subtropics and low-latitude temperate areas (34° to 40° N and S). Selection is being practiced for earliness and resistance to leaf diseases and ear and stalk rots.

Pool 40 (ITR, intermediate temperate region)—Based on materials from Bulgaria, Spain, Hungary, France, Turkey, Yugoslavia, Pakistan, Poland, and West Germany, this pool is designed to serve maize growing areas in the intermediate temperate range (40° to 46° N and S latitude) and the winter maize-growing areas of the tropics and subtropics. Selection is practiced for the same traits as in Pool 41.

Pool 41 (NTR-1, northern temperate region)—This pool is based primarily on US germplasm but also includes materials from China, Korea, and Lebanon. It is designed to serve maize-growing areas 46° to 52° N and S of the equator and may also be useful in winter maize-growing areas of lower latitudes. Selection is being practiced for early maturity, cold tolerance, and resistance to leaf diseases and ear and stalk rots.

Pool 42 (NTR-2, northern temperate region)—This gene pool is the result of an effort to introduce tropical germplasm into temperate areas. The pool is being handled in cooperation with the University of Hohenheim, West Germany. It is based on germplasm from Mexico, Peru, Bolivia, Pakistan, China, Hungary, the USA, and Yemen. Selection is being practiced for earliness, standability, cold tolerance, and resistance to leaf diseases.

Quality Protein Maize

The quality protein maize (QPM) gene pools being improved by the CIMMYT Maize Program are listed below along with the components of each pool. For comments on the improvement of these materials, see the section of this report entitled "Quality Protein Maize Improvement."

Pool 15 QPM (Tropical Early White Flint QPM)—Early maturing families from the populations Tuxpeño-1 QPM, Mezcla Tropical Blanca QPM, Blanco Cristalino-1 QPM, (Mix. 1 x Colima group 1) x ETO QPM, Tuxpeño Caribe QPM, and La Posta QPM plus Blanco Cristalino-2 QPM, Pool 16 QPM, and Pool 20 QPM.

Pool 17 QPM (Tropical Early Yellow Flint QPM)—Amarillo Cristalino-2 QPM, flint families from Antigua x República Dominicana QPM, Mezcla Amarilla QPM, and phyllacora-resistant selections from Amarillo Cristalino-2 QPM.

Pool 18 QPM (Tropical Early Yellow Dent QPM)—Antigua x República Dominicana QPM; early maturing, dent families from Amarillo Cristalino-2 QPM; Mezcla Amarilla QPM; and Amarillo Dentado QPM.

Pool 23 QPM (Tropical Late White Flint QPM)—White flint QPM pool; white flint QPM families from the populations Tuxpeño-1 QPM, Mezcla Tropical Blanca QPM, Tuxpeño Caribe QPM, and La Posta QPM; Pool 23 QPM; and phyllacora-resistant families from White Flint QPM pool.

Pool 24 QPM (Tropical Late White Dent QPM)—Tropical White Dent QPM pool, dent QPM families from Pool 23 QPM, and phyllacora-resistant families from Tropical White Dent QPM pool.

Pool 25 QPM (Tropical Late Yellow Flint QPM)—Tropical Yellow Flint QPM pool, Amarillo Cristalino-1 QPM, and phyllacora-resistant families from Tropical Yellow Flint QPM pool.

Pool 26 QPM (Tropical Late Yellow Dent QPM)—Tropical Yellow Dent QPM pool, Amarillo Dentado QPM, and phyllacora-resistant families from Tropical Yellow Dent QPM pool.

Pool 27 QPM (Subtropical Early White Flint QPM)—Pool 27 QPM and early maturing, white flint families from Blanco Subtropical QPM and Pool 31 QPM.

Pool 29 QPM (Subtropical Early Yellow Flint QPM)—Templado Amarillo Cristalino-2 QPM and early maturing, yellow flint families from Amarillo Subtropical QPM, Amarillo Bajio QPM, Pool 33 QPM, and Compuesto de Hungria QPM.

Pool 31 QPM (Subtropical Intermediate White Flint QPM)—Flint families from Temperate White QPM.

Pool 32 QPM (Subtropical Intermediate White Dent QPM)—Dent families from Temperate White QPM and Blanco Subtropical QPM and Pool 31 QPM.

Pool 33 QPM (Subtropical Intermediate Yellow Flint QPM)—Flint families from Temperate x Tropical QPM, Amarillo Bajio QPM, and Pool 34 QPM.

Pool 34 QPM (Subtropical Intermediate Yellow Dent QPM)—Dent families from Temperate x Tropical QPM and Pool 33 QPM; Amarillo Subtropical QPM; and ETO x Illinois QPM.

Appendix 2: Maize Populations

The normal and quality protein maize (QPM) populations being improved at CIMMYT are listed below, with information about their components and principal features. For further information on the improvement and testing of these materials, refer to the sections of this report entitled "Population Improvement" and "Quality Protein Maize Improvement" and to the reports of the Center's international maize testing program.

Population 21 (Tuxpeño-1)
Components—Tuxpeño race collections Veracruz 48, Veracruz 143, Veracruz 174, Michoacan 137, Michoacan 166, V-520C, and Colima group 1 x Mix. 1 and 16 families from Pool 24.

Description—This tropical lowland, late-maturing, white dent population has excellent standability and a relatively short plant type. It is fairly tolerant to most foliar diseases and performs well in many areas of the lowland tropics. Since 1977 it has been undergoing improvement for resistance to fall armyworm.

Countries where progeny tests were conducted:

1983—Iboperenda (Bolivia), Poza Rica (Mexico), and Rattray-Arnold (Zimbabwe).

Population 22
(Mezcla Tropical Blanco)
Components—Tuxpeño, ETO blanco (Experimental Tulio Ospina, Medellin, Colombia), Antigua group 2 white selection, (Colima group 1 x Mix. 1) x ETO, Pfister hybrids, Compuesto Centro Americano, Lineas de El Salvador, V-520C, Nicarillo selección blanca, and 13 families from Pool 24.

Description—This tropical lowland, late-maturing, white dent-semident population has a very broad genetic base and has performed well in the tropical regions of Mexico, Central America, northern South America, East and West Africa, and India. Since 1980 it has been selected for downy mildew resistance by Thailand's national program under the coordination of CIMMYT's Asia maize regional program.

Countries where progeny tests were conducted:

1982—U.P. Los Baños (the Philippines), Maracay (Venezuela), Alajuela (Costa Rica), Los Diamantes (Costa Rica), Rattray-Arnold (Zimbabwe), and Suwan (Thailand).

Population 23
(Blanco Cristalino-1)
Components—White segregates from Mezcla Amarilla, Antigua x Tipos Cubanos, and Antigua x Cupurico plus Población Cristalina x Tuxpeño, Cuba 20, Granada 9D, CWF, Nicaragua syn. II, Harinoso de Ocho, and seven families from Pool 23.

Description—This tropical lowland, intermediate-maturity, white semiflint population has relatively short plant height and less foliage than many tropical materials. It is suitable for the lowland tropics of Mexico, Central America, northern South America, West Africa, and Southeast Asia. It is being improved for resistance to sugarcane borer.

Countries where progeny tests were conducted:

1982—Palmira (Colombia), Poza Rica (Mexico), Bouake (Ivory Coast).

Population 24
(Antigua-Veracruz 181)
Components—Tuxpeño race collection Veracruz 181 and Antigua Group 2 (Antigua collections 1D to 8D). Description—This lowland tropical, late-maturing, yellow semident population is medium in plant height and has performed well in the lowland tropics of South America, Central America, Mexico, southern Africa, and Southeast Asia. It is being improved for resistance to fall armyworm.

Countries where progeny tests were conducted:

1982—Capinopolis (Brazil), Pichilingue (Ecuador), Piura (Peru), Poza Rica (Mexico), Guarare (Panama), and Suwan (Thailand).

Population 25
(Blanco Cristalino-3)
Components—One hundred families from cycle 14 of Pool 23.

Description—This tropical lowland, late-maturing, white flint population is medium in plant height. During selection emphasis is placed on stalk rot resistance and uniformity of plant type.

Population 26 (Mezcla Amarilla)
Components—Tuxpeño Cuban flints, Antigua, ETO amarillo, some Corn Belt x Tuxpeño crosses, and 22 families from Pool 21.

Description—This tropical lowland, intermediate-maturity, yellow semiflint population has relatively short plants and has performed well in the tropical lowlands of South America and parts of Asia. In selection emphasis is placed on earliness and ear rot resistance.

Countries where progeny tests were conducted:

1983—Iboperenda (Bolivia), Piura (Peru), Guanacaste (Costa Rica), Poza Rica (Mexico), and Ferkessedougou (Ivory Coast).

Population 27 (Amarillo Cristalino-1)
Components—Tuxpeño, Cuban flints, ETO amarillo, and 15 families from Pool 25

Description—This tropical lowland, intermediate- to late-maturing, yellow flint is medium in plant height and has performed well in the lowland tropics of South America, the Caribbean, India, and Southeast Asia. It is being improved for borer resistance.

Countries where progeny tests were conducted:

1982—U.P. Los Baños (the Philippines), Jardinopolis (Brazil), Pichilingue (Ecuador), Alajuela (Costa Rica), Poza Rica (Mexico), and Coimbatore (India).

Population 28 (Amarillo Dentado)
Components—Tuxpeño, Caribbean and Brazilian germplasm, ETO amarillo, and nine families from Pool 26.

Description—This tropical lowland, late-maturing, yellow dent population has relatively tall plants and high yield potential. It has performed well in the tropical lowlands of Mexico, Central America, South America, and parts of Asia. The population has undergone four cycles of improvement with international progeny testing, during which special attention has been given to reduction in plant height. Since 1980-81 it has been undergoing improvement for downy mildew resistance by Thailand's national program under the coordination of CIMMYT's Asia regional maize program.

Countries where progeny tests were conducted:

1983—Iboperenda (Bolivia), Guarare (Panama), San Cristobal (Dominican Republic), Farako-Ba (Burkina Faso), and Suwan (Thailand).

Population 29 (Tuxpeño Caribe)
Components—Tuxpeño, Cuban flints, and ETO.

Description—The high yield potential of this tropical lowland, late-maturing, white dent population has been demonstrated in Mexico, Central America, Egypt, and parts of Africa and Asia. In selection emphasis has been placed on reduced plant height.

Countries where progeny tests were conducted:

1983—Capinopolis (Brazil), Maracay (Venezuela), Alajuela (Costa Rica), Poza Rica (Mexico), and Kaniama (Zaire).

Population 30 (Blanco Cristalino-2)
Components—Thirty-six families from cycle 8 of Compuesto Selección Precoz (derived from the early fraction of all of CIMMYT's tropical, late-maturing populations), crosses of tropical x temperate materials, and 49 families from cycle 6 of Pool 15.

Description—This tropical/subtropical, early maturing, white flint population has relatively short plants and is being improved for earliness and ear rot resistance.

Countries where progeny tests were conducted:

1983—Poza Rica (Mexico), Santa Rosa (Nicaragua), Sanguere (Cameroon), and Baka (Malawi).

Population 31 (Amarillo Cristalino-2)
Components—Ninety-six families from cycle 8 of Compuesto Selección Precoz (derived from the early fraction of all of CIMMYT's tropical, late-maturing populations), crosses of tropical x temperate materials, and four families from cycle 6 of Pool 17.

Description—This tropical/subtropical, early maturing, yellow flint to semiflint population has relatively short plants. Since 1980 it has been undergoing selection for downy mildew resistance by Thailand's national maize program under the coordination of CIMMYT's Asia regional maize program.

Countries where progeny tests were conducted:

1983—Piura (Peru), Tocumen (Panama), Pirsabak (Pakistan), Muneng (Indonesia), and Suwan (Thailand).

Population 32 (ETO Blanco)
Components—Eleven ears selected in Colombia from advanced crosses of Colombia 1 (Blanco Comun and Blanco de Urrao) and Venezuela 1 (Cuban yellow flints) with germplasm from Argentina, Brazil, Cuba, Mexico, Puerto Rico, the USA, and Venezuela. The white segregates originated from ETO Blanco (or Diacol V-351).

Description—This subtropical, intermediate-maturity, white flint population has a short plant type. It has been grown successfully in the Andean region (at elevations below 1500 m asl), parts of West Africa, Egypt, India, and Southeast Asia. Its performance in the lowland tropics has been improved considerably, and it is currently being selected for ear rot resistance. Its excellent combining ability with Tuxpeño has long been recognized.

Countries where progeny tests were conducted:

1982—U.P. Los Baños (the Philippines), San Jerónimo (Guatemala), Poza Rica (Mexico), and Mandya (India).

Population 33
(Amarillo Subtropical)
Components—Two hundred seventy-five half-sib families selected from cycle eight of recurrent selection in Pool 33 and yellow segregates from crosses of germplasm from Mexico, the US Corn Belt, Brazil, Uruguay, Argentina, China, Pakistan, Yugoslavia, Lebanon, Guatemala, Venezuela, Peru, Cuba, Antigua, and the Dominican Republic.

Description—This subtropical-temperate, intermediate-maturity, yellow flint population has a broad genetic base and medium to short plants. It is being improved for ear rot resistance.

Countries where progeny tests were conducted:

1982—Chuquisaca (Bolivia), Ribeiro Preto (Brazil), Tlaltizapán (Mexico), Antalya (Turkey), and Potchefstroom (South Africa).

Population 34
(Blanco Subtropical)
Components—Palung Valley white, Synthetic 66, Pando, ETO blanco, Dwarf 1 tall, Población Cristalina, Tuxpeño Crema 1, Dwarf 1 short, PD(MS)6, Amarillo Peru, Sintético de 10 lineas.

Description—This subtropical, late-maturing, white semident population has a broad genetic base and relatively tall plants. Its high yield potential has been demonstrated in Pakistan, parts of India, southern Brazil, and subtropical regions of Mexico. It has undergone four cycles of selection with international progeny testing, during which emphasis has been placed on reduction of plant height.

Countries where progeny tests were conducted:

1983—Tlaltizapán (Mexico), Sakha (Egypt), and Babungo (Cameroon).

Population 35
(Antigua-República Dominicana)
Components—República Dominicana groups 2, 3, 7, 8, 9, and 15 crossed with Antigua group 2 (Antigua collections 1D to 8D).

Description—This tropical lowland, intermediate-maturity, yellow dent population has a short plant type and is tolerant to corn stunt. It performs well in Mexico, Central America, the Caribbean, and lowland tropical regions of South America, West Africa, parts of South Africa, Pakistan, India, and southern Africa. Currently, the population is being improved for stalk quality and standability.

Countries where progeny tests were conducted:

1982—Capinopolis (Brazil), Piura (Peru), Poza Rica (Mexico), Tocumen (Panama), Bouake (Ivory Coast), and Muneng (Indonesia).

Population 36 (Cogollero)
Components—Caribbean Composite involving 165 accessions from the Caribbean islands, about 50 families from IDRN population, 20 families from Pool 22 (Tropical Intermediate Yellow Dent), and 26 families from Pool 26.

Description—This lowland tropical, intermediate- to late-maturing, yellow semident population has tall plants and a broad genetic base. It has performed well in Central America, the lowland tropics of South America, and parts of Africa. It has undergone four cycles of improvement with international progeny testing, and emphasis has been placed on reduction of plant height during selection.

Countries where progeny tests were conducted:

1983—Jardinopolis (Brazil), Piura (Peru), Poza Rica (Mexico), Tocumen (Panama), and Ferkessedougou (Ivory Coast).

Population 42 (ETO-Illinois)
Components—Population 32 plus 7 US Corn Belt inbred lines resistant to common rust (*Puccinia sorghi*) and 18 US Corn Belt lines resistant to turcicum leaf blight (*Helminthospoprium turcicum*) used as differentials in worldwide evaluations.

Description—This late-maturing, white semident population is adapted to subtropical to cooler areas, possesses resistance (major genes) to *P. sorghi* and *H. turcicum*, and has performed well in the highlands of Africa. In selection emphasis is placed on reduced plant height and uniformity for white grain.

Countries where progeny tests were conducted:

1983—Iboperenda (Bolivia), Ponta Grossa (Brazil), Tlaltizapán (Mexico), Lambo (Tanzania), and Delhi (India).

Population 43 (La Posta)
Components—Tuxpeño synthetic composed of 16 inbred lines.
Description—This tropical lowland, late-maturing, white dent population has tall plants and has shown high yield potential in lowland areas of South America, Central America, and Mexico, in the humid tropics of West and Central Africa, and in parts of East Africa. It is being selected for reduced plant height and streak resistance in Nigeria under an IITA/CIMMYT cooperative program.

Countries where progeny tests were conducted:

1982—Catacamas (Honduras), Ciudad Obregón (Mexico), Santa Rosa (Nicaragua), Bouake (Ivory Coast), Ikenne (Nigeria), Rattray-Arnold (Zimbabwe), and Suwan (Thailand).

Population 44 (AED-Tuxpeño)
Components—American Early Dent (obtained from Egypt) and Tuxpeño (see components of Population 21).

Description—This late-maturing, white dent population has fairly tall plants and is capable of very high yields under favorable conditions. It has performed well in Egypt, Turkey, the highlands of Africa, and during the winter in India and Pakistan. In selection emphasis is placed on reduced plant height.

Countries where progeny tests were conducted:

1982—Tlaltizapán (Mexico), Sids (Egypt), Chitedze (Malawi), and Rattray-Arnold (Zimbabwe).

Population 45 (Amarillo Bajío)
Components—Inbred lines from Purdue University (USA); US13; Pfizer hybrids 347, 381, 383, 409, and 418; Hixanth; CBC Nebraska; Iowa stiff stalk synthetic; Tuxpeño; Cuban flints; Puerto Rico composite; and collections from the Dominican Republic.

Description—This subtropical-temperate, intermediate-maturity, yellow dent population has a broad germplasm base. In selection emphasis is placed on reduction of plant height.

Countries where progeny tests were conducted:

1982—Chuquisaca (Bolivia), Capinopolis (Brazil), Tlaltizapán (Mexico), Sids (Egypt), Hyderabad (India), and Islamabad (Pakistan).

Population 46 (Templado Amarillo Cristalino)
Components—Two hundred forty half-sib families from the fourth cycle of selection in Pool 29.

Description—This subtropical-temperate, early maturing, yellow flint population has a broad genetic base and has performed well in Asia and South America. It is being improved for uniformity of plant type and maturity. Emphasis is also placed on stalk rot resistance during selection.

Countries where progeny tests were conducted:

1983—Iboperenda (Bolivia), Cruz Alta (Brazil), Tlaltizapán (Mexico), Delhi (India), and Islamabad (Pakistan).

Population 47 (Templado Blanco Dentado-2)
Components—Two hundred seventy-six half-sib families from the eighth cycle of selection in Pool 32 (Temperate Intermediate White Dent).

Description—This temperate-subtropical, intermediate-maturity, white dent population has a short plant type and high yield potential. It has performed well in Asia and Africa and is being selected for resistance to southwestern corn borer.

Countries where progeny tests were conducted:

1982—Tlaltizapán (Mexico), Potchefstroom (South Africa), and Udaipur (India).

Population 48 (Compuesto de Hungría)
Components—Materials from the US Corn Belt and southern Europe and 54 half-sib families from Pool 30.

Description—This early maturing, yellow dent material has shown good yield potential in temperate regions, such as the Black Sea coast of Turkey, and has performed well as a winter crop in other areas. In selection emphasis is placed on resistance to leaf diseases and ear rots.

Countries where progeny tests were conducted:

1982—Ponta Grossa (Brazil), Tlaltizapán (Mexico), Adapazari (Turkey), and Pirsabak (Pakistan).

Population 49 (Blanco Dentado-2)
Components—Initial selection of 240 full-sib families from cycle 17 of Tuxpeño Crema 1 (see components of Population 21).

Description—The plant height of this lowland tropical-subtropical, intermediate-maturity, white dent population, has been considerably reduced, and it has been made earlier than the genetically related Population 21.

Countries where progeny tests were conducted:

1983—Poza Rica (Mexico), Masaya (Nicaragua), Sekou (Benin), Fumesua (Ghana), Ilonga (Tanzania), and Rattray-Arnold (Zimbabwe).

Population 61
(Early Yellow Flint QPM)
Components—Selección Precoz QPM, Pool 17 QPM, and Amarillo Cristalino-2 QPM.

Description—Tropical, early maturing, yellow flint.

Population 62 (White Flint QPM)
Components—White QPM (old QPM Population 40).

Description—Tropical, late maturing, white flint-semiflint.

Countries where progeny tests were conducted:

1983—U.P. Los Baños (the Philippines), Palmira (Colombia), Poza Rica (Mexico), and Kindia (Guinea).

Population 63
(Blanco Dentado-1 QPM)
Components—Tuxpeño-1 QPM, La Posta QPM, and Pool 24 QPM (Tropical Late White Dent QPM).

Description—Tropical, late maturing, white dent.

Countries where progeny tests were conducted:

1983—Alajuela (Costa Rica), La Máquina (Guatemala), San Jerónimo (Guatemala), Las Acacias (Honduras), Poza Rica (Mexico), and Suwan (Thailand).

Population 64
(Blanco Dentado-2 QPM)
Components—Tuxpeño Caribe QPM and Mezcla Tropical Blanca QPM.

Description—Tropical, late maturing, white dent.

Population 65 (Yellow Flint QPM)
Components—QPM families from Yellow Flint QPM pool, along with Yellow QPM (old QPM Population 39).

Description—Tropical, late maturing, yellow flint.

Countries where progeny tests were conducted:

1983—El Vallecito (Bolivia), Palmira (Colombia), La Molina (Peru), Poza Rica (Mexico), Guarare (Panama), and Ilonga (Tanzania).

Population 66 (Yellow Dent QPM)
Components—QPM families from Yellow Dent QPM pool, along with Amarillo Dentado QPM.

Description—Tropical, late maturing, yellow dent.

Population 67
(Templado Blanco Cristalino QPM)
Components—Pool 31 QPM and Blanco Subtropical QPM.

Description –Subtropical, intermediate maturity, white flint.

Population 68
(Templado Blanco Dentado QPM)
Components—Templado Blanco Dentado QPM and Temperate White QPM.

Description—Subtropical, intermediate maturity, white dent.

Population 69
(Templado Amarillo QPM)
Components—Templado Amarillo QPM (old Population 41) and Pool 33 QPM.

Description—Subtropical, intermediate maturity, yellow flint.

Countries where progeny tests were conducted:

1982—Tlaltizapán (Mexico).

Population 70 (Templado Amarillo Dentado QPM)
Components—Pool 34 QPM and QPM families from Temperate x Tropical QPM (HO) C4.

Description—Subtropical, intermediate maturity, yellow dent.

Appendix 3: Use of CIMMYT Maize Germplasm by National Programs (as of 1983)

Information about the use of CIMMYT germplasm in national maize research programs is not always easy to obtain, and the Maize Program does not expend a great deal of effort in trying to do so. For those reasons, the following list is not an exhaustive one.

Basic germplasm	Specific material	Name given by national program
Benin		
La Posta	Poza Rica 7843 (SR)	Poza Rica 7843 (SR)
Bolivia		
Amarillo Dentado	Poza Rica 7528	CIAT V105
Tuxpeño o2	Tuxpeño o2	Tuxpeño o2
Suwan 1 DMR	Suwan Saavedra	Suwan Saavedra
Brazil		
Amarillo Bajio-Varios Templados	—	EMPASC 151-CONDA
Suwan-1 DMR		EMPASC 152 Oeste
Burma		
Mezcla Tropical Blanca	Tlaltizapán 7322	—
Amarillo Cristalino-1	Satipo (1) 7627	Golden Yellow 3
Amarillo Dentado	La Calera (1) 7728	Golden Yellow 1
Cogollero	Petrolina 7736	Golden Yellow 2
Indonesia Early x Suwan 1	—	Shewewe 4
Antigua-República Dominicana	Across 7835	Shewewe 8
Amarillo Cristalino-2	Pichilingue 7931	Shewewe 9
Cameroon		
Tuxpeño C7	Tuxpeño C7	TZPB
China		
Tuxpeño-1	Tuxpeño-1	Mexican white-94
Tuxpeño-1	Tuxpeño Planta Baja C15	Mexican white-1
Colombia		
Tuxpeño-1	Tuxpeño C15	ICA V155
Tuxpeño-1	Tuxpeño C14	ICA V156
Tuxpeño Planta Baja x ETO B1	—	ICA H353
Braquítico	Braquíticos	ICA V258
La Posta	La Posta	PATIA-1
Mix (EVT13 1979)	Varios	ICA V-109
Cacahuacintle 431 x Cundinamarca 431	—	ICA H556
Costa Rica		
Tuxpeño-1	Tuxpeño-1	Tico V-1
Mezcla Amarilla	Mezcla Amarilla	Tico V-2 (Amarillo)
Mezcla Amarilla	Mezcla Amarilla x Tuxpeño Planta Baja	To be given
Mezcla Amarilla	Mezcla Amarilla	Tico V-5 (Blanca)
Dominican Republic		
Amarillo Cristalino-1	La Máquina 7827	CESDA 27
Amarillo Dentado	Across 7728	CESDA 28
Cogollero	Across 7736	CESDA 36
Ecuador		
Antigua-Veracruz 181	Santa Rosa 7624	INIAP-527
Amarillo Dentado	San Andrés 7528	INIAP-526
Pool 1	Compuesto Cacahuacintle	INIAP-101
Highland Population 4	BA 8104	INIAP-130

Basic germplasm	Specific material	Name given by national program
Egypt		
Tuxpeño-1 and La Posta	CIMMYT populations x Egyptian local materials	Geiza 2 EV 2
El Salvador		
Tuxpeño-1	Tuxpeño-1	H-8 (female parent)
Tuxpeño-1	ICTA B3	CENTA M3-B
La Posta	La Posta	CENTA M1-B
Ghana		
Amarillo Cristalino-2	Tocuman (1) 7931	—
La Posta	Ejura (1) 7843	—
Guatemala		
Tuxpeño-1	Tuxpeño-1	ICTA B-1
Tuxpeño-1	Tuxpeño-1	ICTA B-3
Mezcla Tropical Blanca	La Máquina 7422	La Máquina
Amarillo Dentado	La Máquina 7928	ICTA A-6
Blanco Cristalino-2	Blanco Cristalino-2	ICTA B-5 (Blanca)
Amarillo Cristalino-2	Amarillo Cristalino-2	ICTA A-4 (Amarillo)
Tuxpeño-1 x ETO Blanco	Tuxpeño-1 x ETO Blanco	ICTA T-101
Mezcla Tropical Blanca and Tuxpeño Caribe	Family 100 of Population 22 Family 5 of Population 29	HB67
Tuxpeño Caribe, Blanco Cristalino-1, and La Posta	Family of Population Family of Population Family of Population	HB-33, HB69, and HB65
Mezcla Tropical Blanca and Tuxpeño-1	Family of Population	HB-11 (male)
Mezcla Tropical Blanca	Family of Population	H-10 (male)
Blanco Cristalino-1 (male) x ICTA B-1 x ETO Blanco (female)	Family of Population	HB-19
ICTA A-2 x Amarillo Cristalino-1 (male) x Amarillo Dentado (female)	Family of Population Family of Population	HA-28
Pool 21 x Antigua-Veracruz 181 (female) x Mezcla Amarilla (male)	Pool 21 Mezcla Amarilla	HA-44
La Posta	La Máquina 7843	La Máquina
Haiti		
Amarillo Cristalino-1	Poza Rica 7427	Carolina
Amarillo Cristalino-1	La Máquina 7827	La Máquina 7827
Amarillo Dentado	Tocumen 7428	Tocumen 7428
Honduras		
Tuxpeño-1	Tuxpeño-1 C17	Hondureño Planta Baja
Tuxpeño-1	Tuxpeño-1	Honduras B-104
—	Tuxpeño (several)	Sintético Tuxpeño Hondureño
Mezcla Tropical Blanca	La Máquina 7422	Guaymas B-101
Amarillo Dentado	Tocumen 7428	Guaymas A-501
Blanco Cristalino-2	Blanco Cristalino-2	Honduras B-103 (Blanca)
Amarillo Cristalino-2	Amarillo Cristalino-2	Honduras A-502 (Amarilla)
La Posta	Tlaltizapán 7443	Guayape B-102

Basic germplasm	Specific material	Name given by national program
India		
Tuxpeño-1	Tuxpeño-1	Pathari Makka (male)
AED-Tuxpeño	Sids 7444	Lakshami
Ivory Coast		
Tuxpeño-1	Tuxpeño-1	Tuxpeño-1
Mezcla Tropical Blanca	La Máquina 7422	La Máquina 7422
Tuxpeño-Caribe	Poza Rica 7529	Poza Rica 7529
Antigua República Dominicana	Ferke (1) 7635	Ferke (1) 7635
Tuxpeño-Caribe	Poza Rica 7429 x (M162W x M164W)	IRAT 178
Tuxpeño	Tuxpeño Brachytic 2 x (M162 W x M164W)	IRAT 81
Lesotho		
Pool 4	Highland early yellow flint	Pool 4
Pools 1, 2, and 9	—	Pools 1, 2, and 9
Mexico		
Tuxpeño-1	Tuxpeño-1	V 524
Mezcla Tropical Blanca	Poza Rica 7822	V 455
Tuxpeño-Caribe	Tuxpeño-Caribe	V 454
La Posta	La Posta	VS 525
Blanco Dentado-2	Blanco Dentado-2	V 424
Pool 19	Tropical Intermediate White Flint	V 425
La Posta	Poza Rica 7843	V 526
Nepal		
Blanco Subtropical	Rampur 7434	Janaki
UNCAC 242 x Pichilingue	DMR-Amarillo 59	ARUN 2
Nicaragua		
Tuxpeño-1	Tuxpeño-1	NB-1
Mezcla Tropical Blanca	La Máquina 7422	NB-3
Mezcla Tropical Blanca	Poza Rica 7822	NB-4
Blanco Cristalino-2	Jutiapa 7930	NB-100
La Posta	La Máquina 7843	NB-5
Nigeria		
Tuxpeño-C7	Tuxpeño-C7	TZPB
Pakistan		
Blanco Subtropical	Pirsabak 7734	Kashmir Muniya
Amarillo Bajio	Yousafwala 7845	Kashmir Gold
Panama		
Amarillo Dentado	Tocumen 7428	Tocumen 7428
Amarillo Dentado	Across 7728	Across 7728

Basic germplasm	Specific material	Name given by national program
Peru		
Amarillo Dentado	Sete Lagoas 7728	PMV 748
Amarillo Dentado	Across 7728	PMV 749
Amarillo Dentado	Across 7728 and Ferke (1) 7928	Marginal 28
Tuxpeño-Caribe Yellow	—	PMC747
Mezcla Amarilla x Cogollero	—	H102
Highland Early White Floury	—	Cajamarca 101
Highland Early White Floury	—	Cuzco 101
Highland Early White Floury	—	Santa Ana 101
Highland Early White Floury	—	Mal Paso 101
Highland Early Yellow Floury x Varios	—	Choclero 301
Highland Late Yellow Floury x Varios	—	Choclero 401
Highland Early Yellow Morocho x Varios	—	Morocho 501
Philippines		
Amarillo Dentado	EV from Population 28 x Suwan 1	SMC 101
Cogollero	EV from Population 36 x Suwan 1	SMC 102
Senegal		
Antigua República Dominicana	Tocumen (1) 7835	Camara 1
Swaziland		
La Posta	Across 7843	—
Tanzania		
Tuxpeño-1	Tuxpeño-1	Tuxpeño
Tuxpeño (50%)	EV 8076	Staha
Blanco Cristalino-1	EV 8188	Kito
Tuxpeño	EV 7992	Ilisua
Turkey		
Compuesto de Hungría		ADA
Burkina Faso		
Tropical Early White Dent	—	Safita-2
Venezuela		
Blanco Cristalino-1	Across 7523	FUNIT 3
(Mix. 1 x Colima group 1) x ETO	Across 7425	FOREMAIZ-2
White H.E. o2	Across 7740	FUNIT 2
Mezcla Tropical Blanca	Across 7822	FUNIT 5
Amarillo Dentado	Obregón 7328	FUNIT 1
La Posta	Across 7843	FUNIT 4
Vietnam		
Tuxpeño C7	—	VM1
Zaire		
Tuxpeño-1 CII	Tuxpeño-1	Salongo II
Tuxpeño-1, (Mix. 1 x Colima group 1), and ETO	Cross of these three populations with Shaba Safi	PNM I
Tuxpeño-1 and ETO Blanco	Tuxpeño-1 x ETO	Kasai I
Tuxpeño-1 and ETO Blanco	(Tuxpeño-1 x ETO) x Shaba Safi	Shaba I