MAIZE • PROGRAM • SPECIAL • REPORT

The Subtropical, Midaltitude, and Highland Maize Subprogram

M. Bjarnason, Technical Editor

CIMMYT

MAIZE+PROGRAM+SPECIAL+REPORT

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The CIMMYT Maize Germplasm Bank: Genetic Resource Preservation, Regeneration, Maintenance, and Use. S. Taba, technical editor.

Stress Tolerance Breeding: Maize that Resists Insects, Drought, Low Nitrogen, and Acid Soils. G.E. Edmeades and J.A. Deutsch, technical editors.

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 improving the productivity of agricultural resources in developing countries. It is one of 17 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of some 40 donor countries, international and regional organizations, and private foundations.

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Abstract: This publication describes subtropical, midaltitude, and highland maize ecologies in developing countries, maize germplasm products for those ecologies developed by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with national programs of developing countries, specific research goals and methodologies of the subprogram, and impacts resulting from the center's efforts on maize for such areas.

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Contents

Foreword: Current Status and Future Directions of the Maize Program

This publication is based on a briefing document developed for an external review of the subtropical, midaltitude and highland maize subprogram. The information it contains is particularly important and timely because of recent changes in both the personnel and directions of the subprogram and of the Maize Program as a whole.

Maize is grown on some 56 million hectares in the developing world; subtropical, midaltitude, and highland maize ecologies account for approximately 23 million hectares. The need to improve cultivars for these and other areas is emphasized by recent studies showing that the worldwide utilization of maize will increase 4.3% annually through the year 2000. Our challenge is significant! Before taking an in-depth look at research activities relating to subtropical, midaltitude and highland maize, it seems appropriate that we describe briefly the current status and future directions of the CIMMYT Maize Program.

Reduced Resources

Perhaps the most significant change in recent years is that the Program has become smaller. The number of core funded international staff positions, i.e. those supported directly by the Consultative Group on International Agricultural Research (CGIAR), has been reduced from 30 in 1990 to an expected 20.5 for the beginning of 1994. Despite this, the number of professional maize staff members (including postdoctoral fellows, associate scientists and visiting scientists) is significant, now totaling 38, with 26 of them being located at headquarters and 12 in outreach.

Maize breeding research in Mexico takes place at four CIMMYT experiment stations that range in elevation from near sea level to over 2600 meters above (Fig. 1), allowing us to meet many fundamental requirements of maize production in the developing world. In addition, staff at offices in seven locations throughout the developing world (Fig. 2) conduct breeding research that emphasizes constraints of regional importance and serve as front line contacts with national programs.

Future Emphasis on Breeding

In the future the Maize Program will no doubt emphasize breeding, with a corresponding reduction in agronomy and crop management research. This stems basically from resource constraints that have forced us to reduce activities, together with a belief that our largest impact accrues from crop improvement. We also recognize, though, that the distribution and efficient use of germplasm by national programs and farmers alike often depends on agronomic research. We are thus making a concentrated effort to increase and focus agronomic activities that enhance the impact of our improved maize in developing countries. With the same aim, the Maize Program will likely address the need to develop and transfer technologies for producing and distributing quality seed to farmers in developing countries. Our work in agronomy and seed technology, though, will have to be supported through special-project rather than core funding.

An Increasing Focus on Hybrids

CIMMYT's predecessor organization, the Rockefeller Foundation-Mexican Office of Special Studies initiated in Mexico in 1943, emphasized hybrids. However, CIMMYT work between the late 1950s and 1985 was directed almost entirely toward population improvement and the development of open pollinated varieties (OPVs). This was based on the recognition that the infrastructure for producing and marketing hybrid seed in developing countries was inadequate. The Maize Program began moving away from this scheme in 1985, introducing hybrid research as a special area. Since then, with improvements in expertise in developing countries and the increased participation of national and multinational seed companies, there has been a significant trend toward the development of inbreds and hybrids and the use of hybrids has increased substantially. Recent subprogram reviews have documented and encouraged the move toward inbreeding and the development of inbred lines, and it is apparent that the CIMMYT Maize Program must be involved in this activity. However, we are also convinced that we can continue to improve populations for the production of both OPVs and inbreds by modifying our procedures slightly and emphasizing those populations known to be useful for both purposes.

A final direction worthy of mention is the use of key sites for testing. International testing in the Maize Program involves a large number of locations but there is little control over the choice of sites used. This is because, at its inception, one of international testing's primary objectives was to distribute a wide range of improved germplasm to national programs. This objective has largely been met, so it is now logical to shift the focus of international testing in a way that reduces inefficiencies and provides more accurate information to breeders on the performance of the materials under improvement. Thus, although we are not anticipating severely restricting the distribution of test materials, we need to identify at least a few locations that will consistently give reliable test data to accurately characterize the performance and stability of experimental varieties and hybrids.

We hope you find the information in this report useful for your work. Please note that data concerning production areas and maize ecologies differ slightly among chapters. A current concern in the CIMMYT Maize Program is to improve our definition of maize ecologies and mega-environments, given their importance for targeting germplasm and interpreting research data. Feel free to contact individual scientists or the Maize Director's office for seed or for further information on methodologies and results discussed in this report.

D.C. Hess
Director

R.N. Wedderburn
Associate Director

The CIMMYT Maize Program

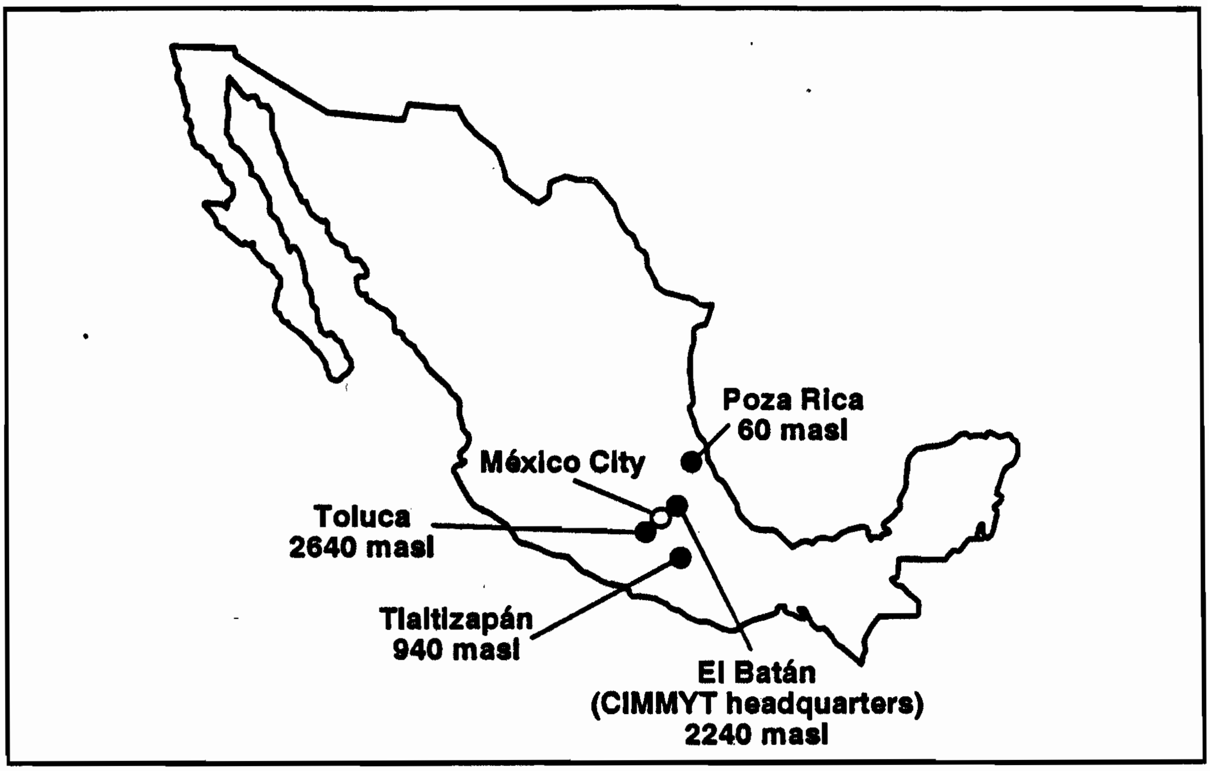
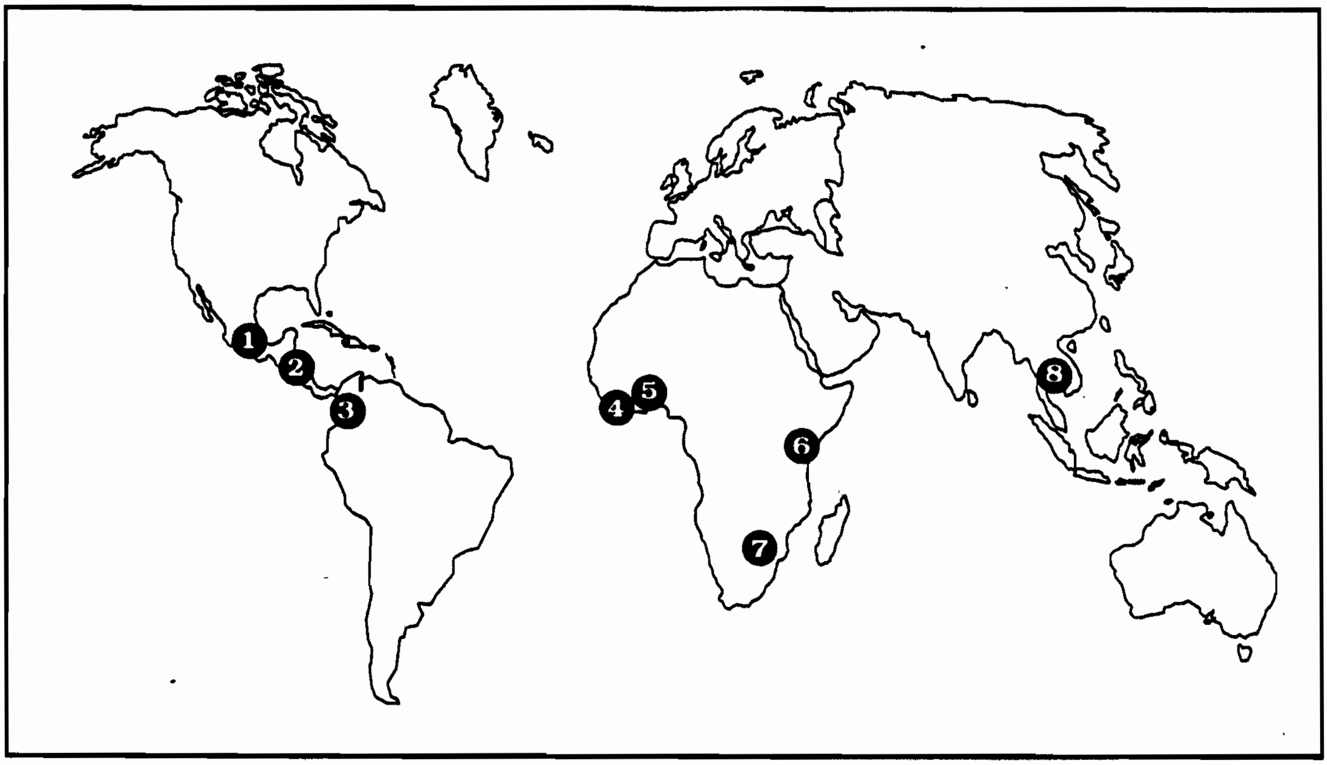


Figure 1. CIMMYT maize experiment stations in Mexico as of August 1993.



1. El Batán, Mexico (headquarters)
2. Guatemala City, Guatemala
3. Cali, Colombia
4. Bouaké, Côte d'Ivoire
5. Kumasi, Ghana
6. Nairobi/Njoro, Kenya
7. Harare, Zimbabwe
8. Bangkok, Thailand

Figure 2. CIMMYT Maize Program locations as of August 1993.

1
Chapter

Research on Maize for the Subtropics

M.S. Bjarnason *

The Subtropical and Midaltitude Mega-environments

About 16.6 million hectares of the developing world's total maize area is planted to germplasm of subtropical adaptation. Of this amount, some 7 million hectares are grown at midaltitudes (900-1800 m above sea level) within the tropics, mostly in eastern and southern Africa, which has 6.6 million hectares of maize at these elevations (Table 1). The other 10 million hectares or so are mostly found in lowland areas at subtropical latitudes (between 23.5° and 35° north and south). The countries which grow more than 100,000 ha of subtropical/midaltitude germplasm are presented in Table 2. In allocating time and resources to a given germplasm class, we consider its relative size, the prevalent biotic and abiotic constraints, and the strength of national programs and alternate suppliers for that particular germplasm. The major stresses across the various categories of subtropical germplasm are as follows:

Biotic stresses:

Diseases
- Northern corn leaf blight (*Exserohilum turcicum*)
- Common rust (*Puccinia sorghi*)
- Ear rots (various species)
- Stalk rots (various species)

Insects
- Armyworms
- Stem borers
- Corn earworms
- Weevils

Abiotic stresses: Drought, acid soils, low N availability.

Past Accomplishments

From 1972 to 1985, the Maize Program at CIMMYT was organized in two major sections, the backup and advanced units (Vasal et al. 1982). In addition, a separate unit developed quality protein maize; selection for special traits, such as drought resistance, was handled by the "special projects" unit. The backup unit developed germplasm with a broad genetic base that could be used either as new populations for further improvement and distribution through international testing or as a source of superior families for introgression into advanced populations. The germplasm was classified into gene pools based on ecology, maturity, grain color and texture. Twelve subtropical and temperate gene pools have been developed and improved (Table 3).

* Head, subtropical, midaltitude, and highland subprogram.

The pools were initially improved by means of modified ear-to-row selection (Lonnquist 1964) with some modifications. Major emphases included reduced plant height, uniformity in maturity and grain type, and improved grain yield. Later, selection for disease resistance was intensified, notably to *E. turcicum*, *P. sorghi*, and fusarium ear and stalk rots. In 1983, a program was started to increase resistance to *E. turcicum* in the eight subtropical pools employing a selection scheme with alternate generations of full-sib and S1 families. Progress from four cycles of selection was published by Ceballos et al. 1991, and the results are summarized in Table 4.

The advanced unit was responsible for work with several subtropical populations. Yield and various other characteristics were improved through a modified full-sib recurrent selection scheme in CIMMYT's international testing network. This scheme has also been used in developing open pollinated experimental varieties which are high yielding and have good agronomic characters.

Eaton et al. (unpublished data) evaluated results from four-to-seven cycles of selection for grain yield, disease resistance, and agronomic traits in four subtropical populations. Selection pressure for resistance to *E. turcicum* and *P. sorghi* was increased in the last two cycles of selection. Three of the four populations were inoculated with ear rot fungi (*Fusarium moniliforme* and *Gibberella zeae*), and at two locations characterized by high levels of *E. turcicum* and *P. sorghi*. The results from five Mexican environments are summarized in Table 5. Gains per cycle for grain yield ranged from 3.8 - 4.6%. All populations showed improvement for resistance to *E. turcicum* and three populations had improved *P. sorghi* resistance. There was improvement in two of the three populations under selection for ear rot resistance.

In 1985 a separate hybrid program was established at CIMMYT to gather information on heterotic patterns among CIMMYT's pools and populations (Beck et al. 1991, Han et al. 1991). This program focused on the development of hybrid oriented germplasm, as well as inbred lines and hybrids for both tropical and subtropical areas. Efforts on the development of hybrid oriented germplasm and inbred lines also increased in other parts of the Maize Program. In 1991, 65 subtropical inbred lines were made available to cooperators and in 1992, 22 subtropical quality protein maize (QPM) lines were made available.

The Subprogram Today

In 1991 the Maize Program was restructured into four subprograms (lowland tropical germplasm; subtropical, midaltitude and highland germplasm; source and stress resistance germplasm; and agronomy and physiology) and four across-program activities (crop protection; germplasm bank; international testing; and training). Hybrid research was distributed across subprograms, and the subtropical subprogram became responsible for all subtropical germplasm development activities, including population formation, improvement of populations formerly handled by the advanced unit, and inbred line and hybrid development.

Objectives

The broad objectives of the subtropical subprogram are the development and improvement of germplasm suitable for the subtropical mega-environments listed in Table 1. The populations and hybrids developed should show good performance both under stresses encountered in target areas and under optimal conditions--in other words, they should possess both high yield potential and good yield stability. We seek to improve those traits through the breeding activities described below.

Yield potential

- Recurrent selection in broad based populations
- Development of heterotic groups
- Development of inbred lines and hybrids

Yield stability

- Disease resistance
  Selection for resistance to *E. turcicum*, *P. sorghi*, *Fusarium* ear and stalk rots
- Insect resistance
  Selection for resistance to Southwestern corn borer (SWCB)
- Abiotic stresses
  Selection for lodging resistance and reduced anthesis-silking interval in high density nurseries

We use the following CIMMYT experiment stations in Mexico for the various activities:

Station	Cycle	Activities
Tlaltizapán	Summer and winter	Yield trials, breeding nurseries, high density evaluations, ear and stalk rot inoculations, SWCB infestations
El Batán*	Summer	*E. turcicum* and *P. sorghi* screening, breeding nursery
Poza Rica	Winter	*E. turcicum* screening, breeding nursery

*Given that El Batán is not representative of the subtropical/midaltitude ecology, we have considered establishing a midaltitude station in Mexico. To date this has not been possible for lack of funding.

Breeding methodology
Two major decisions are involved in the organization of efficient maize improvement programs: choice of breeding materials and the organizational system to be followed. The major phases in the organization of the program are population formation, population improvement, and inbred line and hybrid development.

Germplasm sources -- The program is largely based on the advanced subtropical populations and improved pools that were developed in the past. However, in recent years we have intensified the introduction of new germplasm from other subprograms within CIMMYT and from breeding efforts independent of CIMMYT. These germplasm sources include:

- Germplasm bank materials, e.g. promising Tuxpeño accessions from subtropical areas in Mexico.
- Special character germplasm from the entomology and pathology units, the stress program, and the physiology program. Examples include lines with high levels of borer resistance, and a source of prolificacy.
- Early and extra early populations, and elite inbred lines from the lowland tropical subprogram.
- Populations and hybrids from national programs and seed companies in subtropical and midaltitude areas of the world, e.g. Brazil, Egypt, Mexico, and Pakistan.
- Temperate populations and inbred lines from public breeding programs at universities in the USA and Europe, e.g. from Iowa State University and North Carolina in the USA, and University of Stuttgart-Hohenheim in Germany.

Population formation -- New populations were formed based on heterotic patterns suggested by genetic background or combining ability information, and on the complementarity of parents for desired traits.

New populations are tested in trials in Mexico. Superior populations are evaluated in preliminary evaluation trials (PET) at selected international sites, and eventually they may enter the international testing network.

Population improvement --

Recurrent selection in advanced populations - The following six subtropical populations are being improved in the international testing network, the international progeny testing trial (IPTT) system:

No.	Name	Description	Cycles of Selection
34	Blanco subtropical	Intermediate/late white semiflint	9
42	Eto-Illinois	Late white semident	9
44	AED-Tuxpeño	Late white dent	9
45	Amarillo Bajio	Intermediate yellow dent	6
46	Templado amarillo cristalino	Early yellow flint	5
47	Templado blanco dentado	Intermediate white dent	4

These populations have been handled in modified recurrent full-sib selection according to the scheme outlined by Vasal et al. (1982), with some modifications in recent years. The number of progenies tested was reduced in 1989 from 250 to a variable number depending on the population, but starting in 1992 a uniform number of 190 progenies has been evaluated together with six checks in a 14 x 14 simple lattice. For intra-family improvement between seasons of IPTT testing, two generations of self-pollination are obtained by planting a nursery of the FS families in the same season that the IPTT is grown in Mexico. The following season S_1 families are again self-pollinated, and the S_2 families grown out before recombination. With this modification another season becomes available for intra-family selection, which in these populations has been mainly for disease resistance and lodging resistance. It also provides an opportunity to evaluate more homogenous S_2 progeny and to eliminate lines which do not respond well to inbreeding. Some of these populations have given rise to high yielding experimental varieties that have been released by national programs. We believe that these populations are also good sources of inbred lines and are thus moving toward the integration of population improvement and hybrid development. In addition, given our clients' increased interest in hybrids, we plan to shift selection in international testing toward a scheme that accomodates the development of hybrid oriented germplasm (see the section *Future Plans*).

Improvement of new populations -- Several promising new populations have been formed and are undergoing improvement in Mexico. These populations often comprise two major components: one with a high level of resistance to subtropical foliar diseases and another that is less resistant but which contributes other traits of interest, such as borer resistance, earliness, and/or prolificacy. Several new populations were formed from advanced inbred lines (S_3-S_4) developed under disease pressure. Several types of germplasm "in the pipeline" are listed in Table 6. Normally, we conduct two-to-three cycles of intrapopulation selection (S_1 or S_2 selection) for resistance to *E. turcicum* and *P. sorghi*, as well as other traits of interest, before major emphasis is given to yield.

For yield improvement we have developed S_1 or S_2 lines that can be crossed to appropriate testers for evaluation in Mexico. A simple selection index is used to identify families for recombination based on data from the testcross trials. Multi-stage selection is applied to improve both stress tolerance and yield. S_1 and S_2 lines are screened at high densities for resistance to lodging and for reduced anthesis-silking interval. Artificial inoculations are used for *E. turcicum* screening, and natural inoculations for *P. sorghi*. Certain populations are also infested with southwestern corn borer.

Table 7 lists data on the performance of F_1 crosses of the heterotic populations developed in 1988, SIW-HG88A and B (Subtropical intermediate white 88 A and B) and the late heterotic groups SLW-HG88A and B are presented. Considerable heterosis was observed in several of these crosses, particularly between the intermediate heterotic groups A and B. These heterotic populations also have good per se performance and can provide valuable source germplasm for future hybrid work. Table 8 contains information on the performance of various intermediate and late maturing new populations in comparison with certain existing advanced populations. Some of the new germplasm seems very promising, particularly crosses of the semi-prolific midaltitude tropical population (SPMAT) from the physiology group with populations and pools from the subtropical subprogram. In future efforts, we will focus on the most promising of these populations and exploit their potential in reciprocal recurrent selection and hybrid development.

Inbred Line and Hybrid Development

In recent years, one spin-off of the recurrent selection programs mentioned above has been superior early generation inbred lines. Those that performed well in pest and high-density nurseries were evaluated for general combining ability in the S_2 to S_4 generation. We have started evaluating lines in single crosses and recycling superior lines within heterotic groups. The performance of the highest yielding, subtropical, late white testcrosses is shown in Table 9. We are confident that we can develop productive inbreds with good combining ability. So far, our research has exploited mainly the heterosis between the Tuxpeño and Eto/Eto-related groupings. We are using inbreds from other CIMMYT programs, both at headquarters and in Zimbabwe, and have also introduced inbreds of subtropical and temperate adaptation available from other public sources. Our approach involves the systematic introgression of lines from well defined heterotic groups into our own germplasm. This season we began evaluations in a diallel of crosses among nine key lines used in our Zimbabwe research program and two tester lines from headquarters research. The aim in part is to foster the coherence of breeding efforts at both locations. We estimate that about 50% of the subprogram's resources are now devoted to inbred line and hybrid development (although this estimate may be somewhat misleading because population improvement and inbred line development are closely integrated).

This year we are growing testcross trials in Mexico of all germplasm types in the subprogram, and two testcross trials with early germplasm are being evaluated in Pakistan. Trials are grown on

CIMMYT stations and by public and private cooperators. Two subtropical international hybrid trials (white and yellow grain) were distributed in 1994.

Special Research Projects

Population diallel

This work is aimed at evaluating combining ability among key populations used in midaltitude, subtropical, and temperate areas. The following germplasm is being used:

- Populations 34, 42, 44 and 47 from CIMMYT
- Southern Cross, Salisbury White, NPP ES (Zimbabwe)
- Cateto (Brazil)
- BSSS, BS 26 (Corn Belt)

We conducted the first season of evaluation in Mexico in 1993, and plan to evaluate during additional seasons and in other countries.

Host plant resistance to fusarium moniliforme ear and stalk rot

In collaboration with the pathology unit, we are screening advanced inbred lines from various sources for resistance to this disease, with the objective of identifying reproducible, stable sources of resistance (see Chapter 5). We recently completed the second season of evaluations.

RFLP fingerprinting of midaltitude and highland lines

We are working with CIMMYT's applied biotechnology laboratories (see Chapter 7) to characterize midaltitude maize lines from eastern and southern Africa, highland lines from Mexico, QPM lines, and temperate check lines, using restriction fragment length polymorphisms (RFLPs). Specific objectives are to:

- Expand the database accumulated during CIMMYT participation in phase I of a European network on molecular markers supported by the Pan-European Funding Organization (EUREKA). Add data on germplasm from the Harare, Zimbabwe, highland, and QPM breeding programs.
- Provide information on the genetic relationships between germplasm used in eastern and southern Africa and that of the subtropical, midaltitude, and highland subprogram at CIMMYT headquarters.
- Provide further information on genetic diversity among QPM lines announced by CIMMYT.
- Study 'linkage drag' in QPM materials.

Molecular analysis is complete for 20 probes with two enzymes. Tests using an additional 20 probes with two enzymes were completed in fall 1993. Statistical analyses are underway.

Future Plans

We are aware of the increased presence of alternate suppliers of improved varieties, particularly in the more productive areas in target countries. CIMMYT should take advantage of this, seeking cooperation in evaluating germplasm and providing them with improved germplasm for further refinement and eventual distribution to farmers, with due recognition for our contribution. CIMMYT's role may include supplying good inbreds to small seed companies which cannot afford large research programs or developing products for marginal maize production areas that require such traits as earliness or resistance to specific biotic and abiotic stresses. Often national research systems and large seed companies are reluctant to invest in the longer term efforts needed to develop such products, and CIMMYT has a comparative advantage because of its germplasm base and technical expertise.

In recent years the subtropical subprogram has devoted substantial effort to developing disease resistance in its germplasm, with good progress. Excellent sources of insect resistance have been developed by the stress group, and the physiology subprogram has made good progress in development of methodologies and germplasm for drought resistance. In the future, the subtropical subprogram should devote more of its resources to incorporating this germplasm into agronomically desirable insect- and drought-resistant products suited to stress prone areas in target countries, with cooperation and guidance from the stress and physiology specialists. To accomplish this, the subprogram requires a clearer definition of its role with respect to the stress and physiology units. In addition, to compensate for the shift in resources described above, emphasis on other types of germplasm (possibly 'general purpose' populations) will have to be reduced.

Research in the subprogram is already moving towards the development and improvement of heterotic populations, inbred lines and hybrids. This stems from national programs' increased interest in such products and their increased capacity to utilize them in the target areas we serve. Breeding schemes will be designed to develop open pollinated varieties for clients with an express need for that type of germplasm.

For population improvement, we propose working with not more than three groups of heterotic populations: intermediate yellow, intermediate white, and late white. This research could follow the "comprehensive breeding system" first described by Eberhart et al. 1967, to generate improved open pollinated varieties, variety crosses, traditional hybrids, and inbred lines. The reciprocal populations from each pair could be yield tested in two different years to distribute the workload for cooperators interested in each type of germplasm.

One breeding scheme that can be applied is reciprocal recurrent selection based on topcrosses of S_2 families (Table 10). Intense selection for standability and disease resistance would be practiced during development of S_1 and S_2 families. S_2 families not eliminated before flowering would be topcrossed to the appropriate tester; at the same time plants used for topcrossing would be selfed. Superior S_2s could also be recombined to form OPVs for clients who require them. Alternatively, topcrosses could be made in isolated fields and selected S_2 lines, grown from remnant seed, selfed further after the information on topcross performance becomes available. In either case, testers could be single crosses from the reciprocal populations, and these single crosses could be changed as new lines are developed. Single crosses would be easy to use and may also facilitate the identification of superior three-way and double-cross hybrids.

We would prefer to test at least 196 testcrosses in international progeny testing trials (IPTT), and keep selection intensity below 10% for population improvement. Additional lines close to the selected ones in performance could be funneled into the hybrid program. Yield tests should be grown at a minimum of three-to-four locations with two replications each. The locations should be chosen carefully to represent the target mega-environment precisely and have well qualified and genuinely interested cooperators. Cooperators evaluating the testcrosses should have access to the lines for further advancing and crossing to their own testers. CIMMYT would request information on the testcross performance of our lines with the cooperators' testers. Only more advanced CIMMYT lines would be made available.

Another possible approach is reciprocal full-sib (S_2 x S_2) recurrent selection (FR) outlined in Table 11 (modified after Eberhart et al. 1992). In this scheme, lines with similar maturity from the reciprocal populations are paired, and crosses are made among them. At harvest time the seed of crosses is bulked to be grown for evaluation, e.g. about 200 crosses. The key advantage of FR over reciprocal recurrent selection (RRS) is that only one set of n (S_2 x S_2) crosses are required for FR, whereas, for RRS a set of n S_2 x tester testcrosses are required for the seed parent and for the pollen parent populations (a total of 2n testcrosses). As pointed out by Eberhart et al. (1992)and already discussed above, using S_2 lines instead of S_1 lines has advantages when two seasons per year are available. Although the time for a cycle of selection is extended from two years to three, expected gain per year is the same. The problem we see with this scheme is that one may fail to identify lines with superior combining ability, if crossed with a very poor partner. In addition, some good lines may not get crossed at all, if their partner is eliminated before flowering.

For other germplasm types and in breeding for resistance to specific stresses, we should concentrate on pedigree breeding. The proposed future plans for each germplasm type are presented in Table 12. In resistance breeding where screening of large populations would be expensive, such as borer resistance and drought, well defined sources of resistance should be crossed to elite lines within the same heterotic group, and new lines developed under the appropriate stresses. S_3 families could be crossed to a single cross or inbred line from the opposite heterotic group, and evaluated in at least one 'hot spot' for the particular stress. This 'hot spot' may be available or may have to be created artificially. Products from pedigree breeding efforts would be inbred lines and hybrids. Efforts to characterize advanced lines as suitable seed parents or pollen parents would be made before announcement. For cooperators requiring open pollinated varieties, synthetics could be formed by recombining the 8-10 best lines; 4-to-5 from each heterotic group.

Finally, we should continue to introduce new germplasm from sources within CIMMYT and elsewhere, both to take advantage of the progress made outside the subprogram and to maintain a broad genetic base in our populations.

Proposed future allocation of resources
- 25% Population improvement
- 60% Inbred line and hybrid development
- 15% Special projects

Staff resources available to the program
1.0 Breeder/subprogram coordinator
1.0 Postdoctoral fellow
1.0 Agronomist assistant
3.5 Field assistants

Issues for consideration
1. The future niche of the program:
   - Low yielding environments vs. high yielding.
   - Germplasm with special characters vs. 'general purpose' populations.
2. Hybrids vs. population improvement.
3. The need for a midaltitude experiment station in Mexico.
4. The division of responsibilities between the subtropical program and the stress and physiology programs.

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Table 1. Extent of various maize germplasm types in subtropical and midaltitude ecologies.

Germplasm type	Subtropical	Midaltitude in Africa	Total
	Area (000 ha)		
Early white flint/dent	522130	652	
Early yellow flint/dent	1,017	--	1,017
Intermediate white flint	371--	371	
Intermediate white dent	1,879	2,294	4,173
Intermediate yellow flint/dent	1,048	--	1,048
Late white flint	3881,800	2,188	
Late white dent	7732,064	2,837	
Late yellow flint/dent	3,992	333	4,328
Total	**9,990**	**6,621**	**16,611**

Table 2. Countries that grow more than 100,000 ha of subtropical/midaltitude maize.

Africa	America	Asia
Zimbabwe	Brazil	India
Tanzania	Mexico	Pakistan
Kenya	Colombia	China
Egypt		Nepal
Ethiopia		Vietnam
Malawi		Afghanistan
Angola		
Zambia		
Mozambique		
Cameroon		
Uganda		
Nigeria		

Table 3. Subtropical and temperate gene pools.

No.	Description
27	Subtropical early white flint
28	Subtropical early white dent
29	Subtropical early yellow flint
30	Subtropical early yellow dent
31	Subtropical intermediate white flint
32	Subtropical intermediate white dent
33	Subtropical intermediate yellow flint
34	Subtropical intermediate yellow dent
39	Southern temperate range gene pool
40	Intermediate temperate range gene pool
41	Northern temperate range gene pool
42	CIMMYT-German gene pool

Table 4. Mean area under the disease progress curve (AUDPC) for northern corn leaf blight for early (Pools 27-30) and intermediate (Pools 31-34) subtropical maize populations planted under high disease pressure at El Batán and Poza Rica, Mexico.

			AUDPC Cycle of selection			
Pool	C_0	Et_1	Et_2	Et_3	Et_4	Gain per cycle
27	18.9	12.4	9.3	5.0	3.8	-19.9**
28	17.7	12.8	8.2	5.9	4.4	-18.8**
29	16.6	12.0	9.4	6.3	4.1	-18.5**
30	16.9	11.6	8.9	5.9	4.6	-17.5**
Mean	17.5	12.2	9.0	5.8	4.2	-18.9**
31	9.5	5.5	4.7	2.8	2.4	-17.8**
32	8.7	4.6	4.3	2.6	1.5	-18.7**
33	11.6	9.5	5.8	3.7	2.1	-21.5**
34	11.2	8.1	5.9	5.2	3.4	-16.5**
Mean	10.3	6.9	5.7	3.6	2.3	-18.8**

** Significant at the 0.01 probability level.
LSD (0.01) for comparisons of cycles within populations was 1.87 and 1.51 for early and intermediate populations, respectively.

Gain estimated as the coefficient of regression (b) expressed as percent of the actual value of AUDPC of C_0.

Source: Ceballos et al. (1991).

Table 5. Percent gain per cycle and coefficient of determination for four traits in four advanced populations.

Population	Cycle of selection	Yield (t/ha)	Yield (%)	Ear height (cm)	Ear height (%)	Resistance to *E. turcicum* (1-5)[a]	Resistance to *E. turcicum* (%)	Resistance to *P. sorghi* (1-5)[a]	Resistance to *P. sorghi* (%)
33	4	4.0*	(0.76)[b]	-		-3.0**	(0.30)	-	
44	7	4.6	(0.78)	-2.1**	(0.96)	-4.0	(0.65)	-4.1	(0.10)
45	5	3.8*	(0.99)	-1.2*	(0.63)	-3.8	(1.00)	-3.0	(0.75)
48	7	4.0*	(0.94)	-2.9*	(0.71)	-1.9	(0.57)	-	

[a] Rating scale of 1-5 (1 = excellent; 5 = poor).
[b] Coefficient of determination.
*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 6. Products under development for various germplasm classes.

Subtropical early

Populations derived from crosses of subtropical CIMMYT pools and white populations with populations from Pakistan.

Population from a cross of an early subtropical pool with an early tropical pool.

S_2-S_5 lines, mostly of crosses of subtropical x tropical.

Subtropical early yellow

Populations derived from crosses of subtropical CIMMYT pools and populations with populations from Pakistan.

Populations derived from crosses of subtropical sources for disease-and borer resistance with early tropical materials.

The Population SEY90, derived from crosses of pools 29 and 30 with S_2 lines derived from early maturing temperate Pioneer hybrids.

Crosses of early subtropical sources for disease resistance with early northern European inbreds.

S_2-S_4 lines from crosses of subtropical x tropical.

Subtropical intermediate white

Population 500, SIWDENT-1, 50% derived from lines selfed out of commercial Mexican hybrids, and 50% from disease resistant lines from intermediate maturing CIMMYT pools.

Population SIW-HG88A, subtropical intermediate heterotic group A (Tuxpeño type), derived from lines from Mexican commercial hybrids.

Population SIW-HG88B, subtropical intermediate heterotic group B (Eto type), derived from Mexican commercial hybrids. Population [SPMAT c4/P500 c0]{W} derived from a cross between SPMAT, a semi-prolific population from the physiology program, and Population 500.

Population [SPMAT c4/PL 32] {W}, derived from a cross between SPMAT and pool 32.

ETS91P49, a synthetic selected from resistance to E. *turcicum* derived from Population 49 (Tuxpeño Planta Baja C_{17}).

Population MBR-ETW, derived mainly from the MBR population from the entomology unit, with some introgression from the MDR (multiple disease resistant) population from the pathology unit.

Inbred lines (S_1 to fixed lines) from various sources.

Subtropical intermediate yellow

Population [SPMAT/PL 32] {Y}, derived from a cross between SPMAT and pool 32, selected for yellow grain color.

Population [SPMAT/PL 34], derived from a cross between SPMAT and pool 34.

Synthetics formed from lines from crosses of subtropical populations with B73 and Mo17.

MBR-ETY, population derived from MBR from the entomology unit with some introgression from subtropical MDR germplasm from the pathology unit.

Introductions of yellow populations from Brazil.

Introductions of tropical populations selected for temperate adaptation in Iowa.

Inbred lines (S_1 to fixed lines) from various sources.

Subtropical late white

Population 600, SLAWDENT-1, 50% derived from lines selfed out of commercial Mexican hybrids, and 50% from disease resistant lines from late maturing CIMMYT pools.

Population SLW-HG88A, subtropical late heterotic group A (Tuxpeño type), derived from lines from Mexican commercial hybrids with good combining ability and a tester line from Population 42 (Eto x Illinois).

Population SLW-HG88B, subtropical late heterotic group B (Eto type), derived from lines from Mexican commercial hybrids with good combining ability and a tester line from Population 34.

Population STHG-B, subtropical heterotic group B, was developed by the hybrid program by recombining 42 lines from CIMMYT

Subtropical populations and pools with good combining ability and a tester line from Population 44.

Population SLWF 91, subtropical late white flint, broad based population mainly based on flint inbred lines derived from commercial Mexican hybrids.

Population [SPMAT c4/P600 c0] {W}, derived from a cross between SPMAT and Population 600.

Various synthetics formed based on heterotic patterns.

Tamaulipas Tuxpeño Olotillo, selected from the germplasm bank.

San Luis Potosí Celaya Tuxpeño, selected from the germplasm bank.

Various introductions.

Inbred lines (S_1 to fixed lines) from various sources.

Subtropical late yellow

Population SLY90, subtropical late yellow, formed by recombining inbred lines derived from Southern African populations and hybrids from AGROCERES Brazil.

Populations from Brazil.

San Luis Potosí Tuxpeño Olotillo from the germplasm bank.

Inbred lines (S_1 to fixed lines) from various sources.

Table 7. Mean grain yield of F_1 population crosses, their parents, and checks at Tlaltizapán 1991B and 1992A, and Nayarit 1991.

Entry	Grain yield (t/ha)	High parent heterosis (%)	Days to silk
SIW-HG88A/SIW-HG88B	10.28	28.3	72.1
SIW-HG88A/Population 42	9.81	22.5	69.5
SIW-HG88A/Population 44	9.94	12.7	72.4
SIW-HG88B/Population 42	9.56	22.6	70.6
SIW-HG88B/Population 44	9.34	5.9	70.6
SLW-HG88A/SLW-HG88B	9.18	11.8	72.4
SLW-HG88A/Population 42	8.50	13.3	71.1
SLW-HG88A/Population 44	9.11	3.3	71.9
SLW-HG88B/Population 42	8.87	8.0	71.6
SLW-HG88B/Population 44	9.69	9.9	71.4
Population 42/Population 44	9.12	3.4	69.4
SIW-HG88A	8.01	-	72.9
SIW-HG88B	7.80	-	72.7
SLW-HG88A	7.50	-	73.8
SLW-HG88B	8.21	-	75.5
Population 42	7.11	-	68.6
Population 44	8.82	-	69.9
Population 500	8.53	-	67.6
Population 600	8.59	-	72.0
DC508 CIMMYT	8.02	-	67.5
LSD (0.05)	1.30		2.1
CV	11.3		2.1

Table 8. Results from a trial of intermediate and late populations, Tlaltizapán, Morelos 1992 B and 1993 A, and CUTSESA, Michoacán, 1992. (Total 36 entries.)

Entry	Rank	Yield (t/ha)	Days to silk	Ear height (cm)	Ears per plant	Rust rating[1]
[SPMATC4/PL32]{W} C_0	1	7.50	71	108	1.28	3.5
[SPMATC4/PL32]{Y} C_0	2	7.41	71	110	1.28	3.5
Pop. 500 (SIWDENT-1) C_1	3	7.32	77	119	0.94	2.0
Pop. 500 (SIWDENT-1) C_0	4	7.28	76	108	1.00	3.0
[SPMATC4/P500C0]{W} C_0	5	7.16	72	107	1.20	4.0
Pop. 600 (SLAWDENT-1) C_1	6	6.95	77	115	0.96	3.5
$SPMATC_5$	7	6.84	71	112	1.35	4.0
$SLWF91C_0$	8	6.83	80	119	1.09	3.5
Pop. 44 C_8	10	6.83	78	113	1.02	1.5
Pop. 42 C_8	11	6.81	74	110	1.00	1.0
H430 (Pronase)	25	6.20	81	109	0.97	4.0
LSD (0.05)		1.04	3	13	0.16	1

[1] Data from El Batán (1 = excellent, 5 = poor).

Table 9. Performance of highest yielding subtropical late white testcrosses compared with checks, Tlaltizapán and Nayarit, Mexico, 1992B. (Total 182 entries.)

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Rust rating[1]
Line 35 x T1 [2]	10.6	59.5	136	3.5
Line 28 x T1	10.6	60.5	145	2.5
Line 28 x T2	10.4	60.0	147	4.0
Line 17 x T2	10.1	59.0	138	3.0
Line 57 x T2	10.1	60.3	125	2.5
Line 75 x T1	10.1	61.8	141	3.0
Line 27 x T2	10.0	60.0	141	3.0
Line 5 x T2	10.0	60.0	139	2.5
Population 600	8.2	58.0	134	3.0
Pioneer 3288	8.1	61.0	146	3.0
T1 x T2	7.8	60.0	136	4.0
LSD (0.05)	2.3	2.2	13	1.0

[1] Data from El Batán (1 = excellent, 5 = poor).
[2] T1 = Tester 1, synthetic of elite lines of Tuxpeño type. T2 = Tester 2, synthetic of elite lines of Eto type.

Table 10. Schedule for reciprocal recurrent selection based on testcrosses of S_2 families.

Year 1	
Season A	Self and mass select for highly heritable traits among 7,800 plants (300 5 m rows, 26 plants/row), save 1,200 S_1 ears.
Season B	Plant 1,200 S_1 progenies in high-density and disease nurseries, mass select and self within rows.
Year 2	
Season A	Plant 400-500 S_2 lines in a disease nursery and for testcrossing to a single cross tester from the opposite heterotic group, save 190 testcrosses. Self in lines selected for testcrosses if done in breeding nursery.
Season B	Yield trials (14 x 14 lattice).
Year 3	
Season A	Intermate 15-to-18 selected lines. Advance about 30 best lines for inbred line development.
Season B	Intermate.

Note: The reciprocal population would be handled the same way, but each activity in a different year.

Table 11. Schedule for reciprocal full-sib (S_2 x S_2) recurrent selection with two seasons per year.

Year 1	
Season A	Self and mass select among 7,000-to-10,000 S_0 plants for highly heritable traits.
Season B	Plant about 1,200 S_1 progeny rows in high density and disease nurseries, S_1 selection among rows, self and mass select within rows.
Year 2	
Season A	Plant about 400 S_2 lines from each population in disease nursery, and in paired rows (400 pairs) for producing testcrosses of 190 selected SP-S_2 x PP-S_2 lines (SP = seed parent, PP = pollen parent).
Season B	Conduct yield trials of 190 SP-S2 x PP-S_2 testcrosses + checks.
Year 3	
Season A	Intercross 12-to-20 selected S_2 lines within each breeding population.
Season B	Intercross F_1s within each breeding population.

Table 12. Future activities in CIMMYT research on maize for the subtropics and midaltitude zones.

Germplasm type	% effort	Breeding strategy	Products
SEW*	10	Pedigree breeding, test crosses in target countries.	Inbreds, hybrids, synthetics, OPVs.
SEY	10	Pedigree breeding, test crosses in target countries.	Inbreds, hybrids, synthetics, OPVs.
SIW	15	Two heterotic populations, 501 (HG"A") and 502 (HG"B"), improve in reciprocal recurrent selection (RRS; S_2 x tester). Also pedigree breeding.	Inbreds, hybrids, synthetics, OPVs, special trait germplasm.
SIY	15	Two heterotic groups: Amarillo Bajío (Pop. 45) and related dents, and Amarillo Subtropical (Pop. 33) and other flints. Use RRS (S_2 x tester). Also pedigree breeding.	Inbreds, hybrids, synthetics, OPVs, special trait germplasm.
SLW	25	Use a pair of heterotic dent populations, Pop. 44 and other Tuxpeño types vs. Pops. 42 and 33. Improve through S_2 x tester RRS. Improve flint lines in pedigree breeding for making dent x flint hybrids.	Inbreds, hybrids, synthetics, OPVs, special trait germplasm.
SLY	10	Two heterotic groups of lines, yellow Tuxpeño types vs. others (Cateto, Suwan, etc), pedigree breeding, Test cross in target countries.	Inbreds, hybrids, synthetics, OPVs, special trait germplasm.
Special projects	15	Research on combining ability, cycles of selection trials, disease resistance, RFLP fingerprinting and marker facilitated selection.	Publications, useful information.

* SEW = subtropical early white; SEY = subtropical early yellow; SIW = subtropical intermediate white; SIY = subtropical intermediate yellow; SLW = subtropical late white; SLY = subtropical late yellow.

Chapter 2

Research on Maize for Highland Regions

J. E. Lothrop *

Maize has a much broader range of temperature adaptation than other important cereals such as wheat, rice, barley, and sorghum. In very warm tropical lowland regions, mean growing season temperatures may exceed 26°C, while in the coolest highland regions the mean may be as low as 12.5°C.

Tropical highland maize is little known compared with other classes of maize germplasm such as lowland tropical, subtropical, midaltitude, or temperate. It is an extremely ancient class of maize and may have been the first maize domesticated. Despite this, it has received little attention from plant breeders, and only in the last few years has the private sector shown interest in developing hybrids for highland farmers of the Americas.

CIMMYT estimates that highland maize is grown on some six million hectares in developing countries. In many instances it is grown by farmers living in high, isolated valleys separated by mountains in nearly inaccessible areas. For these poor farmers it is truly the "staff of life." The myriad of highland environments complicates breeding, as does the farmers strict requirements for specific grain textures, colors, and cooking qualities. Fortunately, there are a few key classes of highland germplasm that are of such paramount importance that CIMMYT could justify allocating some of its limited resources to focus on a long term effort to improve them and achieve a major impact in farmers' fields.

CIMMYT and the national agricultural research systems alone can make only a minor impact. Private sector participation will be necessary in most cases to allow farmers access to improved, high quality seed. We at CIMMYT are pleased that the private sector is utilizing the fruits of CIMMYT's long term breeding efforts to enter several key highland maize production areas.

Highlands: The Cradle of Maize?

Several lines of evidence point to the domestication of maize (*Zea mays* L.) in Mexico about 7,000 years ago (Mangelsdorf 1974; MacNeish 1985; Goodman 1988) and in Peru about 4,000 years ago (Grobman and Bonavia 1978). Kato (1984) proposed that maize was domesticated in four centers, two of which were located in central Mexico. Highland maize most likely originated in the higher altitude centers. Many experts agree that maize was derived from teosinte and especially the Mexican teosintes (Galinat 1988,1992; Beadle 1977; McClintock 1977). Molecular

* Breeder, highland maize.

evidence suggests that maize was domesticated from *Z. mays* subsp. *parviglumis*, which presently does not grow at high altitudes in central Mexico (Doebley 1990). Galinat (1992) proposed two major domestications based on an analysis of ear morphology, one from *Z. mays* subsp. *parviglumis* and the other from *Z. mays* subsp. *mexicana*, which still grows as a maize mimicking weed in and around maize fields in the highlands of central Mexico (Eagles and Lothrop 1993). However, data from Kato (1984) and Doebley (1990) indicate a lack of reciprocal maize-teosinte introgression, even where the two species are contiguous in highland areas.

Others suggest that maize coevolved with teosinte (Mangelsdorf 1974). Wilkes (1979) hypothesized that maize was domesticated in the central highlands of Mexico from an ancestral wild highland maize. From this prototypic maize, cold tolerant highland maize genotypes evolved early on in Mexico and perhaps Guatemala. Domestication was a long process involving both human and natural selection, rather than a single dramatic event. The highland maize genotypes of the Andean region of South America probably originated in Guatemala (Goodman and Brown 1988; McClintock 1977). By the time the Spanish conquerors arrived in the 1500s, native Americans had selected and domesticated a wide variety of highland maize types grown as high as 3,000 m above sea level (masl) in Mexico and 3,800 masl in the Andean highlands. The main grain types selected were semident, floury, *morocho* (floury with a corneous cap), popcorn, and sweet corn.

Highland Maize's Global Spread

Europe

Europeans collected maize in the Americas from all elevations and took the seed to Europe for testing. Highland germplasm, especially Mexican highland germplasm, was well represented among the initial introductions grown in Spain during the late 1490s (Trifunovic 1977). It is possible that some of the cold tolerance in the European flints traces back to highland introductions. In recent years there has been an upsurge of interest in highland tropical maize among European maize breeders working at high latitudes with cool maritime climates. The recent availability of tropical highland inbred lines has greatly enhanced the probability of successful introgressions of highland maize into northern European maize genotypes. Important to CIMMYT is that "spin-offs" from this research are likely to be useful in the temperate highlands of developing countries.

Africa

The introduction in Kenya in 1959 of Ecuador 573 (Gerhart 1975), a tropical highland transition zone maize, has had a great impact in Kenya, Tanzania, Ethiopia, and adjacent countries. CIMMYT successfully introduced highland tropical maize in the highlands of Lesotho in the mid-1970s. Current efforts by CIMMYT to introduce true highland maize genotypes into areas where maize is not now grown may significantly improve African farmers' circumstances by increasing the diversity of suitable crops in zones now predominated by barley, wheat, potatoes, peas, pyrethrum, and broad beans. In tropical highland transition zone areas, selections from CIMMYT Pool 9A (late white semi-flint) have been or are being increased and made available to farmers in Burundi and Ethiopia, and the pool is used in breeding programs in Rwanda, Zimbabwe, Cameroon, Zaire, and Mozambique. Inbred lines from Pool 9A are being evaluated for combining ability in Kenya's tropical highland transition zone. Pool 9A is being converted to streak resistance at CIMMYT's research station in Harare, Zimbabwe. This is important since maize streak virus seems to be gradually moving upward in altitude in Africa.

Asia

CIMMYT is also introducing highland maize genotypes into Asia. A selection from Pool 9A has been increased for distribution to farmers in the tropical highland transition zone (mid-hills) of eastern Nepal, and Batán 8686 has been released to farmers in the highland tropics of Yunnan province, People's Republic of China. New materials are being tested in the mid-hills of the Himalayan zone in Afghanistan, Pakistan, India, China, and Nepal.

Genotype x Environment Interaction in Highland Regions

Small changes in elevation, especially at the higher altitudes, can cause large genotype-by-environment interactions (G x E). In the coldest zones, highland maize grows in environments where temperatures are very close to maize's lower limit, and maximum temperatures rarely exceed 25°C. This germplasm is so finely tuned to the cold that it is unproductive in the warmer highland environments. CIMMYT mega-environment data show that there are more maize environments per unit land area in the highlands than in the lowlands (CIMMYT 1988).

As an example, the vegetative period of a variety selected at CIMMYT's experiment station at El Batán, Mexico (15.9°C mean growing season temperature, 2250 masl), when planted 300 m higher at CIMMYT's experiment station at Toluca, Mexico (13.3°C mean growing season temperature, 2550 masl), will increase 25-30 days and its grain-filling period about 20 days. Thus, only the earliest varieties adapted at El Batán mature before frost occurs in Toluca, and they do not have enough cold tolerance (biomass production) to be competitive with the best varieties from the Toluca Valley. Therefore, it is necessary to breed maize genotypes specifically for each environment. True highland maize grows in areas with mean growing season temperatures of 12.5° to 17°C. It is convenient to breed maize at Toluca (13.3°C) for extremely cold environments with temperatures of 12.5 to 15°C, and at El Batán (15.9°C) for the warmer highland environments with temperatures of 15 to 17°C. In practice it has proven practical to breed maize with broad adaptation within these two agroecologies, but not materials that are adapted to both.

Since highland maize evolved in Mexico and farmer-breeders there have practiced selection for over 7,000 years, there are locally adapted landraces for every valley. This is also true for the Guatemalan and Andean highlands. Most *criollo* (landrace) varieties are so fine tuned to the requirements of their particular valley that they fail miserably when planted in other valleys at a lower or higher elevation only a few kilometers away. However, a few *criollos* and several improved varieties and hybrids have reasonably broad adaptation.

In a few areas, such as Mexico's central plateau, there are large relatively homogeneous highland maize environments where a few broadly adapted varieties or hybrids could generate sufficient sales to entice private seed companies. A local seed company began competing with the Mexican parastatal company in the mid-1980s, and by 1993 most major transnationals had expressed interest in CIMMYT's improved highland maize germplasm (especially inbreds), and a few had already started breeding programs and selling hybrids in some highland areas of Mexico. Africa's tropical highland transition zone, centered in Kenya, Tanzania, and Ethiopia, as well as tropical highland areas of China's Yunnan province, have some seed industries. But most highland areas are not likely to be served by seed companies in the near future.

The proliferation of highland valleys parallels the range of production constraints and grain quality requirements that are encountered in this ecology. Frequent stresses include cold, frost, and hail--as would be expected in the highlands--but drought is also a limiting factor. Major biotic constraints are *Puccinia sorghi* rust, *E. turcicum* leaf blight, *Fusarium* ear and stalk rots, and corn earworm (mainly in soft endosperm materials). In addition to biotic and abiotic stresses and G x E, a central consideration for this ecology is the strict requirements of highland inhabitants regarding grain textures, colors, and sizes. In Mexico and Guatemala, hard grain types must meet *tortilla* and *tamale* quality standards. Floury (soft endosperm) Cacahuacintle types are consumed in *pozole* (a soup) in Mexico. In South America, floury types must have good quality characteristics for *choclo* (green roasting ears) and *tostadas* (roasted dry kernels), while *morocho* (soft endosperm but with a corneous cap) types must make good *mote* (a food made from boiled dry whole grains). In Africa, *ugali* (a kind of thick porridge) must be high quality. In Asia, highland maize is often ground into grits and boiled like rice, so semident-to-flint types are preferred. The work of CIMMYT and national program cooperators for the highlands must therefore focus on specific target areas and classes of germplasm to be effective.

Highland Maize Breeding at CIMMYT

The aim of the highland unit is to develop improved open pollinated varieties (OPVs), synthetics, populations, lines, and materials classified by heterotic groups for key traditional highland areas--that is, high altitude zones at tropical latitudes--as well as nontraditional areas, such as winter maize zones at intermediate latitudes and cool temperate regions at higher latitudes. This work is conducted in part on two CIMMYT experiment stations in the Mexican highlands, allowing us directly to address the major requirements of nearly half the world's highland maize farmers. Maize germplasm developed on-station and with cooperators is then tested worldwide through the international trial EVT 17 and extensively in Mexico, Guatemala, Africa, and the Himalayan region (especially Yunnan province of China). We expect to expand cooperative efforts in Africa's highland transition zones, once Pool 9A is endowed with resistance to maize streak virus, an important disease in that region.

Special characteristics

Most unimproved highland germplasm (especially Mexican) has notoriously weak roots, tillers, a low harvest index, and an intolerance to inbreeding. In addition, it lacks sufficient genetic variability for these traits to permit much improvement. To get around these limitations, at CIMMYT we adopted the strategy of assembling populations that included exotic (mainly temperate and subtropical) germplasm to allow rapid improvement for agronomic traits. Backcrossing and recurrent selection were used to develop populations with improved agronomic traits without losing favorable cold tolerance genes. The resulting gene pools and populations were improved using modified half-sib recurrent selection and full-sib recurrent selection, respectively. As tolerance to inbreeding depression has improved, selfing to the S_2 stage has been practiced as part of population improvement and elite lines are being selfed to homozygosity. The partially and fully inbred lines which result can be used to form special trait synthetics, open-pollinated source populations, and heterotic groups that better tolerate inbreeding.

Root lodging, tillering, and ear proliferation at a node--People knowledgeable about Mexican highland maize genotypes know that the greatest weakness of this material is its susceptibility to root lodging. Mexican farmers long ago recognized this problem and try to cope with it by routinely "hilling up" highland maize three times during the vegetative stage. Still, high winds accompanying summer showers cause widespread root lodging in many seasons, especially when manure or medium-to-high levels of N fertilizer are applied. Such fields cannot be machine harvested (a rare practice in the Mexican highlands) and even harvesting by hand is difficult. Yields may be greatly reduced when root lodging occurs during the period from just before to just after anthesis. For example, during 1988 in the Toluca Valley, one of the best farmers planted an improved variety with good management in two large fields. In the unlodged field he harvested 6 t/ha and in the badly lodged field slightly over 1 t/ha. In the highland subprogram at CIMMYT, we select against root lodging by 1) using high levels of N fertilizer, 2) planting on the ridge without hilling up, and 3) using densities of 53,000 plants/ha in the breeding nursery, and 66,000 and 98,000 plants/ha in yield trials.

Tillering is partially-to-completely dominant to nontillering under our conditions and in our germplasm. It is a polygenic trait, and heritability is low because of large environmental and G x E effects. Sometimes crosses between two nontillered plants produce families or hybrids that are completely tillered. After eight years of selection against tillering, we have greatly reduced this problem but not eliminated it. Many visitors have noticed that genotypes tiller in El Batán that they have never seen tiller elsewhere. The four main factors promoting tillering at El Batán are: 1) N levels of 150 kg/ha, 2) cool but not cold soil and air temperatures (Miedema 1982), 3) high solar radiation per unit of plant development in the early vegetative stage (Edmeades 1993), and 4) short daylengths. The importance of high N cannot be overemphasized. Maize in farmer's fields just across the highway from CIMMYT has no tillers under low N management. When one selects an ear from a nontillered plant of a landrace variety under low N conditions in the highlands of Mexico, it will invariably tiller profusely on the experiment station at El Batán. The good side of this situation is that El Batán is an ideal location to select for nontillering. In the CIMMYT highland maize unit, we select against tillering in all maize types except some forage maize genotypes.

Ear proliferation at a node is another undesirable characteristic of Mexican highland germplasm. It seems to be associated with a tendency for tillering. The tiny ear shoots that arise next to the main ear shoot almost never produce any grain and represent a waste of photosynthate. We have been selecting against this trait. As with tillering, heritability is low and progress has been slow but steady.

Adaptation to cool temperatures--Natural and farmer selection in cool highland areas has led to the development of maize types that are uniquely adapted to cooler regions. In recent experiments carried out in growth chambers (Ellis et al. 1992), it was shown that optimum growing temperatures for cultivars based on highland tropical Cónico and Cacahuacintle germplasm were 6-12 °C lower than those for lowland tropical Tuxpeño germplasm, subtropical germplasm, and temperate germplasm. On the other hand, the two highland cultivars were the only ones killed by a constant temperature of 37°C! Besides a lack of heat tolerance, germplasm bank accessions of highland materials often are deficient for several important agronomic traits, and there may also be problems with grain texture, low tolerance to inbreeding, and photoperiod sensitivity.

CIMMYT breeds true highland maize genotypes in Mexico at experiment stations with growing season mean temperatures of 15.9°C (El Batán) and 13.3°C (Toluca). Probably, the most important adaptive mechanism of highland maize to cope with cool temperatures, (especially nights below 10°C), is an enzyme system that allows it to continue metabolizing efficiently at temperatures too low for other maize types. In the very cool Toluca environment, all nonhighland maize genotypes are somewhat yellow (due to low chlorophyll concentration and not lack of N) and grow very slowly in the vegetative stage. The ability of highland maize to maintain a high chlorophyll concentration under very cool temperature regimes has been well documented (Eagles 1986; Stamp 1985). Secondary plant characters such as purple and highly pubescent stems play a role in helping the plant maintain favorable temperatures under cool conditions. The Mexican national maize program uses 6°C as the base temperature for highland maize when calculating heat units. This is 4° less than the usual standard of 10°C.

Purple stem color--It is commonly observed that the stem of most highland maize germplasm is a deep purple, and often highly pubescent. Dark stem colors have been shown to increase plant temperatures in Canada (Chong and Brawn 1969). We have tested the value of purple versus green stems in two highland gene pools after two generations of phenotypic assortative mating for stem color.

In a 1988 yield trial at Toluca, the purple stemmed selections yielded a significant 19% more grain than the green stemmed selections when averaged over the two gene pools. Stem temperatures at mid-morning were 0.5°C warmer in purple plants. In Pool 10A the yield advantage of the purple stemmed selection was 36%. Associated with the higher yield of the purple plants were increased plant height and reduced ear rot. Deep purple stem color is one of the most important criteria for selection in CIMMYT highland populations being bred for the coolest environments.

Frost and hail tolerance--Frost and hail occur in many highland environments. Farmers who plant maize in very high valleys are aware of the paradox that there is a greater probability of frost damage in the lowest part of the valley than higher up on the slopes. No maize can survive prolonged freezing temperatures. However, there is genetic variability for the ability to survive light frosts. A 10 September 1988 frost of -0.8°C in Toluca caused no significant damage to local maize genotypes, but completely burned the leaves of exotic maize genotypes. In the same location spring frosts are common, and less damaged genotypes recover quicker and yield more.

We normally experience three-to-five hailstorms or more per growing season at our El Batán and Toluca stations. Heavy hail damage at anthesis causes maximum yield losses. Local highland maize genotypes have evolved a leaf architecture that confers partial resistance to hail damage. Leaves are thick, leathery, narrow, and extremely droopy.

Drought stress and deep planting--Drought stress is extremely common in the tropical highlands. An estimated 2.8 million hectares (81%) in this mega-environment is planted to maize genotypes that are usually or frequently subject to moisture stress. Most of these areas receive less than 1,000 mm of precipitation. By the same token, evapotranspiration is relatively low in cool highland environments. Five hundred millimeters of well-distributed rainfall is sufficient for acceptable yields on soils with good water-holding capacity using improved varieties or hybrids of early-to-intermediate maturity. Most *criollo* varieties have an ASI (anthesis silking interval) of 5-12 days under moderate stress and very poor root development. Improved CIMMYT populations have much better root strength and a reduced ASI. Both traits were introgressed from temperate and subtropical materials. Besides selecting for yield, reduced ASI, and better roots in moderately early populations with high yield potential, we are also taking advantage of the possibility of somewhat escaping or avoiding drought stress by developing populations that are much earlier than *criollo* varieties. These materials are planted when "reliable" rains begin and can reach physiological maturity before frost occurs most seasons. Of course, their yield potential is limited, but they would provide farmers with a profitable option in addition to barley, wheat, or triticale.

Drought at the seedling and early vegetative stages is so common in the highlands of Mexico that some partial resistance has been built up in farmer selections. In Mexico many farmers plant very deep (10-25 cm) to place seeds in residual moisture, permitting the crop to get started before the arrival of the rains. This allows farmers to plant a later maturing, more productive variety than would be possible if they waited for the arrival of the rains. But these varieties must be able to utilize residual moisture for growth for about 40-60 days in normal years. Michoacan 21 was identified (Palacios de la Rosa et al. 1964) as the source of the so-called *latente* trait. The latency effect is a temporary slowing or cessation of plant growth when drought stress occurs during the seedling and early vegetative stages, followed by enhanced recovery when rains come. Michoacan 21 is a *criollo* variety from an area where farmers plant highland maize using residual moisture. Although the *latente* effect occurs only during the vegetative stage, the ability to emerge from deep planting is useful in many situations. Many Mexican farmers in dry zones with no residual moisture also plant deep, so that plants will only germinate and emerge after a heavy rain, thus increasing the probability that they will survive the seedling stage until the rainy season begins in earnest.

We found that most non-highland maize genotypes (the Hopi and Navajo maize genotypes famous for their ability to emerge from deep plantings are related to semi-highland maize genotypes from northern Mexico) will not reliably emerge when planted much deeper than 13 cm. The ability to emerge from deep plantings is due to a capacity for mesocotyl elongation (Collins 1914). After three cycles of full-sib recurrent selection, we have developed populations that have a tropical highland background and will emerge reliably when planted 20 cm deep. We have also improved agronomic traits and reduced ASI in these populations and are attempting to extract inbred lines from them.

Highland Maize Mega-Environments

The CIMMYT highland maize program aims to develop improved germplasm for the coolest maize environments in developing countries. As of 1990, they contain an estimated 6.3 million ha of highland maize (Table 1). Most of this area is sown to hard grain types (93%), followed in importance by floury (4%) and *morocho* (3%) grain types. It is convenient to classify these cold environments into three mega-environments: 1) tropical highlands, 2) tropical highland transition zones, and 3) temperate highlands (Figure 1).

Tropical highlands

This zone encompasses an estimated 3.5 million ha (56% of the world total). Tropical highland maize grows in the latitudinal range 0-30^{o} north and south, normally at altitudes of 2,000-3,600 masl. Mean growing season temperatures vary from 12.5 to 17^{o}C, and night temperatures fall below 10^{o}C throughout the growing season. Daytime high temperatures rarely exceed 26^{o}C. Maize for this environment is unique for its extreme cold tolerance and is easily separated from the tropical highland transition genotypes, because in the tropical highlands night temperatures are too cool to allow significant natural epidemics of *Exserohilum turcicum*. The major foliar disease problem in unadapted materials in the tropical highlands is common rust (*Puccinia sorghi*). A low level of resistance to *E. turcicum* is required, and other diseases such as *Cercospora* are important in some areas. Fine stripe virus can be a problem in certain areas without a pronounced dry season. Ear and stalk rots incited by *Fusarium* spp. are a universal problem. Common smut (*Ustilago maydis*) is sometimes a problem, but in some highland areas corn smut (*cuitlacoche* in

Mexico) is considered a delicacy and sells for more than twice the price of maize grain. Insects are not generally a problem, although corn earworm (*Heliothis zea*) and *Euxesta* spp. are a serious problem in floury and, to a lesser extent, *morocho* germplasm in South America. Drought is the major abiotic stress. Some tolerance to freezing temperatures and cool nights is necessary, as is partial tolerance to hail damage.

Highland maize (represented by landraces developed through natural and human selection in the highlands of Mexico, Guatemala, and the Andean zone of South America) actually has a fairly narrow genetic base, lacking variability for certain traits necessary for modern, mechanized agriculture. These include greater resistance to root and stalk lodging, adaptability to minimum tillage systems, shorter plant and ear heights, tolerance to inbreeding, and a faster rate of grain drying in the field. It will be necessary to continue gradually introgressing exotic germplasm into tropical highland germplasm without significantly reducing its outstanding cold tolerance, grain quality, ability to emerge from deep planting (Mexican highland germplasm), and its partial resistance to hail damage. At present almost all tropical highland maize in the world is grown in Mexico, Guatemala, Lesotho, China, and the Andean zone. However, there is great scope for introducing improved tropical highland germplasm into the higher elevations of eastern and southern Africa, the Himalayan regions, and possibly West Irian Jaya, Indonesia-Papua New Guinea.

Tropical highland transition zone

This zone supports an estimated 2.5 million ha of maize, 40% of the world highland total. Tropical highland transition zone maize grows in the latitudinal range 0-30° north and south at altitudes as low as 1,200 masl and as high as 2,600 masl, but typically from 1,500-2,000 masl. Mean growing season temperatures vary from 17 to 19°C, and night temperatures during the growing season seldom drop much below 15°C. Conditions are often ideal for the development of the foliar disease *E. turcicum*, and all germplasm for this zone should possess high levels of polygenic resistance to blight as well as some *P. sorghi* resistance. Current breeding efforts involving maize for this zone are directed towards reducing plant and ear heights, improving *E. turcicum* resistance, introducing genes for resistance to the *Phyllachora maydis-Monographella maydis* (tar spot) complex important in the Americas, continuing development of Pool 9B, a yellow version of Pool 9A, and new intermediate maturity populations. Since hybrids are already important in this zone, emphasis is placed on line development and evaluation.

Important abiotic constraints of maize in the transition zone include low pH soils, drought stress in some areas, and occasional hail. Besides the diseases already mentioned, there are several ear and stalk rots caused by *Fusarium* and *Diplodia* spp. Important insect pests include *Chilo* and *Busseola* borers and the corn earworm. Since most of the area planted to maize of the Pool 9A type is located in Africa, it is essential to develop mutually beneficial collaboration with African researchers in this zone. Improved yellow transition zone maize is needed for areas such as Guatemala, Colombia, India, Nepal, China, and other Asian countries.

Temperate highlands

This zone in the developing countries represents an estimated 0.3 million ha (4% of the world highland total). Maize there must be adapted to the fairly long daylengths that occur during the growing season at latitudes of 30-42^{o} north and south. It must also be early, cold tolerant, and possess resistance to cool season diseases that occur in these high valleys at 1,000-2,500 masl. Mean growing season temperatures range from 14 to 20^{o}C., and both *P. sorghi* and *E. turcicum* resistance are required. Some resistance to *H. maydis* may also be necessary during the hottest part of the summer. *Fusarium* ear and stalk rots are also important. The corn earworm and European corn borer (*Ostrinis nubilalis*) are important insect pests. Abiotic stresses include heat, cold, hail, drought, and frost. A stress common in the Asian countries, especially Pakistan, is that initial plant densities are very high (about 150,000 plants/ha). Before flowering, the maize is thinned to 70,000-85,000 plants/ha, and the thinnings are fed to livestock. Germplasm resulting from crosses between tropical highland and early temperate germplasm is promising for this zone. The hypothesis that some types of highland maize might be useful as winter maize in subtropical zones is also being tested. Since the temperate highland zone is of a fairly limited extent, the CIMMYT highland subprogram will maintain work on development of germplasm for this zone as a relatively low priority.

Breeding Methodologies

In the 1970's the major breeding method used was modified ear-to-row (MER) selection. Seed from each ear selected the previous cycle was planted ear-to-row and detasseled, the male being a bulk of the best ears selected the previous cycle. Each gene pool was isolated by time and/or space, and undesirable plants in the male were detasseled before shedding pollen. Since this system required no hand pollinations, it was relatively inexpensive. It also allowed recombinations on a massive scale, mixing genotypes without regard to heterotic groups to develop very broad-based populations suitable for use in generating open-pollinated materials.

The elite fraction of the gene pools improved by MER was recombined to form populations. These populations were improved through international progeny testing trials (IPTTs). The first IPTTs for the highlands involved half-sib families from populations being improved at CIMMYT headquarters in the mid-1970s. The populations were discontinued after 1978 and replaced by floury and morocho populations for the Andean zone. Full-sib families were tested in Andean IPTTs developed at Quito, Ecuador. In both the half-sib and full-sib IPTTs, the best 10 families were recombined to form site specific and across sites experimental open-pollinated varieties.

Development and evaluation of new hard grain populations

Beginning in the 1984-85 winter season at CIMMYT headquarters, new pools and populations of the hard grain type (temporarily shelved while CIMMYT was concentrating on Andean floury and morocho materials) were formed. The pools combined flint and dent textures; intermediate maturity classes were eliminated. Improvement was by MER. Full-sib progenies of populations

85-88 (early white, early yellow, late white, and late yellow) were formed in the winter nursery at Tlaltizapán, Morelos (940m), and progenies were evaluated the following summer season in the highlands (Table 3). In order to proceed as quickly as possible, the recombination and progeny formation steps were combined so that one cycle could be completed in 2 generations (one year using a winter nursery). The populations were open to introgression of new germplasm from the pools and breeding nursery, and the best full-sibs were used for recombination, experimental variety formation, and selfing to generate inbreds. The second year of this program S_1 progenies were yield tested, but inbreeding depression was so severe at this point that the scheme was discontinued. All yield testing of progeny of these populations was done in Mexico, but their experimental varieties were tested internationally in Experimental Variety Trial 17 (EVT 17).

Two populations, 800 and 845 (early white and early yellow), targeted for the temperate highlands, were improved using a different scheme (Table 4). Since *E. turcicum* is very important in this mega-environment and innoculations are not successful in Tlaltizapán, a winter nursery could not be used. Instead, these populations were grown in the summer in El Batán where innoculations are usually successful. Reciprocal full-sibs and S_1 and S_2 progenies were developed. The best full-sibs in the cold Toluca environment were selfed, and some years full-sibs and/or S_1s were tested in Pakistan in the summer season. The best full-sibs were used for recombination and experimental variety formation, and the best S_1s advanced to S_2.

Four populations (901, 920, 940, and 960) were developed for deep planting (20cm) in highland areas. These early white, early yellow, late white, and late yellow populations were composited using improved populations (for better agronomic type) and gene pools (for ability to emerge from deep plantings). Reciprocal full-sibs were made among plants that emerged from deep planting, were disease resistant, and had good agronomic character. Three cycles of selection were completed.

Cycles-of-selection trials were carried out at El Batán in 1991 and 1992 in populations 85, 86, and 845 (Tables 5-7). All cycles of all populations yielded more than the checks. The most outstanding deficiencies of the local check varieties based on Cónico and Cónico-Chalqueño germplasm were their extreme susceptibility to root lodging and high incidence of basal tillering. All populations showed a trend toward higher grain yield and earlier maturity, with almost no tillering and good resistance to ear rots and stalk lodging. They have not yet achieved the high shelling percentage of the local checks (88%), but the most important population, 85, has a shelling percentage of 85%.

Heterosis

We have been slow to exploit heterosis in highland maize because landrace varieties are notoriously sensitive to inbreeding depression. Still, by Januarly 1993 we were able to make eight highland inbred lines available to cooperators. These lines had been selfed for five to eight generations. They were developed from populations with about 40% exotic germplasm (principally temperate). Even in such populations selfing is still difficult beyond S_2.

The development of heterotic populations from source populations of mixed or undefined heterotic groups requires populations that tolerate inbreeding fairly well and lots of resources for testing. It is important for CIMMYT to develop its own heterotic groups as well as to collaborate with national programs in identifying heterotic combinations between their lines and ours.

Since almost half the world's highland maize is grown in Mexico, we have tried to work with the Mexican national program on heterosis (work is also in progress in Guatemala and Kenya). In 1989 collaborative research was initiated to explore heterosis between our lines and theirs. Three-way hybrids using Mexican single crosses as females and CIMMYT lines as males were formed in 1989 and tested in 1990 and 1991 (Table 8). Thirty-eight percent of the experimental hybrids yielded more than the single cross check. The experimental hybrids also tended to be earlier, shorter, less tillered, and more resistant to lodging than the check.

Encouraged by the results of the hybrids formed in 1989, CIMMYT and the Mexican national program developed more hybrids for testing in 1991. In these hybrids, the female was a CIMMYT single cross and the male a Mexican partially inbred line. The logic was that at some future date it would be easier to use the shorter, more uniform CIMMYT single cross in seed production. Data from 1992 (Table 9) show that 98% of the hybrids yielded better than the check hybrid, which root lodged badly. Some hybrids yielded as much as 12.7 t/ha.

The results of a trial grown the same year at the same location testing only hybrids made among CIMMYT lines (Table 10), show the need to improve heterosis among our lines. Although the yields were quite respectable (average 7.2 t/ha) and the agronomic type and earliness excellent, the maximum yield was only 9.9 t/ha.

Breeding Methodology: Multi-stage Selection

This has been the key technique by which CIMMYT has completely changed the architecture of the highland maize plant without losing its cold tolerance features or the required grain quality. First, every envelope of shelled grain is examined and selected for proper grain quality. Poor quality seeds are discarded or recycled (if the problem is minor). Second, before anthesis all families with unacceptable levels of tillering, diseases, genetic spotting, and lodging are eliminated. Third, at anthesis there is strict selection for floral syncrony. Fourth, two-thirds of the way through the grain filling stage, pollination bags are ripped off plants that have succumbed to disease or lodging, and the bags of the remaining plants are opened to check for husk cover and ear proliferation at the same node. Finally, at harvest clean ears with apparently good grain quality are selected from plants that resist lodging.

Future Plans

Research on highland maize at CIMMYT headquarters has resulted in an array of populations (Table 2) targeted to various mega-environments. These populations were developed to serve the highest priority areas where hard grain types are needed. A smaller effort will continue to develop certain populations for lower priority zones. White and yellow hard grain populations with intermediate maturity for tropical highland transition zones are being increased for testing, targeted principally for the "mid-hills" of the Himalayas but also showing promise in Guatemala's transition zone. The super early tropical highland population is also well advanced.

Inbred lines will continue to be developed from all populations that tolerate inbreeding. We will make available to cooperators only those lines that perform well *per se* and have good general combining ability. Although CIMMYT may detect some good specific combinations for Mexican environments, it will be the task of the local programs (public or private) to develop specific hybrid combinations for their target zone. CIMMYT can use the best lines it develops to form open pollinated source materials in the form of synthetics from which cooperators may draw high yield potential, cold tolerance, purple stalks, stiff stalks, short plant type, disease resistance, insect resistance, good grain quality, etc. All materials should tolerate inbreeding fairly well, so as to serve for developing either hybrids or open-pollinated varieties.

We will continue to use full-sib recurrent selection to improve certain populations for which the development of heterotic groups is not yet contemplated. We have already begun to develop heterotic groups within CIMMYT germplasm for the most important class of highland maize, the tropical highland early white semi-dents. We began by making line-by-tester crosses and by crossing genetically diverse S_3 lines of the same maturity in a modification of Eberhart's scheme for reciprocal full-sib interpopulation recurrent selection. These hybrids were yield tested in 1993. We will be very pragmatic in choosing a method to separate our germplasm into heterotic groups.

Since G x E and grain quality are so important in the highlands, CIMMYT should consider not only the heterosis among its own populations but also between CIMMYT populations and inbreds and local populations and lines. For example, there is excellent heterosis between CIMMYT inbreds and partially inbred Mexican lines derived from Cónico and Chalqueño landraces. The resulting hybrids are high yielding, with an intermediate plant and grain type that makes them more acceptable to traditional Mexican highland farmers than many hybrids from CIMMYT lines alone.

Since the Andean floury and *morocho* grain types are hyper-susceptible to *Fusarium* ear rots in Mexican highland environments, directly improving them here is out of the question. However, collaborative efforts involving backcross breeding should allow Andean breeders to convert some of the best hard grain source materials (inbreds, synthetics, etc.) to required grain types. Our entomologist has improved the corn earworm resistance of several types of highland maize, and some backcrossing and selection will be necessary before these materials are directly usable, especially in the Andean zone. The maize pathologist is similarly assisting to improve the *Fusarium* resistance of highland materials.

Table 11 shows the steps taken in the 1992-93 winter nursery plantings at Tlaltizapán to begin to develop heterotic groups within highland, early, white semi-dent germplasm. The most successful scheme for generating experimental hybrids was our modification of the Eberhart reciprocal full-sib recurrent selection. The line-by-tester scheme was not very successful in this hot environment, which is very stressful for highland germplasm.

The hybrids generated using these two schemes were yield tested in several Mexican highland environments in 1993. Many of them look excellent, and we expect to obtain enough good data to develop the initial cycle of heterotic groups A and B in this germplasm class. We plan to modify scheme #2 (Table 12) and routinely cross all good new S_3 lines to two testers (representing heterotic groups A and B) each summer at El Batán. Testers may be single crosses or inbreds. The Eberhart scheme may be used with a long-term back-up population if resources permit.

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Table 1. Major highland maize producing regions.

Region	Country	Area (ha)	Grain type
Mexico and C. America	Mexico	2,940,000	Semi-dent (98%) Floury (2%)
	Guatemala	150,000	Semi-dent (100%)
S. America	Colombia	177,000	Floury (49%) Semi-dent (33%) Morocho (18%)
	Ecuador	151,000	Floury (49%) Morocho (26%) Semi-dent (25%)
	Peru	137,000	Floury (64%) Morocho (27%) Other (12%)
	Bolivia	127,000	Morocho (56%) Floury (32%) Other (12%)
Africa	Kenya	589,000	Semi-dent (100%)
	Malawi	284,000	"
	Tanzania	240,000	"
	Ethiopia	217,000	"
	Burundi	70,000	"
	Uganda	59,000	"
	Angola	55,000	"
	Rwanda	42,000	"
	Cameroon	35,000	"
	Lesotho	26,000	"
	Madagascar	22,000	"
	Mozambique	20,000	"
	Morocco	13,000	"
	Zaire	4,000	"
Asia	China	420,000	"
	India	290,000	"
	Pakistan	187,000	"
	Nepal	60,000	"
Estimated world total		**6,315,000**	

Source: 1990 data from Miguel López-Pereira, CIMMYT Economics Program

Table 2. CIMMYT headquarters populations for highland tropical and highland temperate areas.

Population	Code	Description	Primary target area
Highland early white semi-dent	Pop. 85	60% highland, 20% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1]
Highland early yellow semi-dent	Pop. 86	55% highland, 25% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1]
Highland late white semi-dent	Pop. 87	55% highland, 25% temperate, 20% subtropical/tropical Germplasm.	Warmer highland areas[1]
Highland late yellow semi-dent	Pop. 88	55% highland, 25% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1]
Highland early white floury	Pop. 89	90% Cacahuacintle, 10% Andean races	Highland areas[2]
Highland early white semi-dent for very cold zones	Pop. 900	Diverse highland germplasm	Colder highland areas[2]
Tepoztoctoc-1[3]	Pop. 901	Selections from Pool 10A and Pop 85	Mexican highland areas[1]
Tepoztoctoc-2[3]	Pop. 920	Selections from Pool 11A, Pop 86 and New Zealand hybrids	Mexican highland areas[1]
Tepoztoctoc-3[3]	Pop. 940	Selections from Pool 12A and Pop 87	Mexican highland areas[1]
Tepoztoctoc-4[3]	Pop. 960	Selections from Pool 13A and Pop 88	Mexican highland areas[1]
Temperate highland early white semi-dent	Pop. 800	Selections from Pops 85,86,87 and 88, New Zealand hybrids, elite Corn Belt Dent and northern European germplasm	Himalayan region[4]
Temperate highland early yellow semi-dent	Pop. 845	Selections from Pops 86 and 88, New Zealand hybrids, elite Corn Belt Dent and northern European germplasm	Himalayan region[4]
Tropical highland transition zone late white semi-dent	Pool 9A	Selections from Kitale synthetics, Ecuador 573, SR52, Tuxpeño de Altura	Eastern and Southern Africa, Nepal, Americas.
Tropical highland transition zone late yellow semi-dent	Pool 9B	Same as Pool 9A plus Montaña from Colombia and Guatemala altiplano central selections	Americas, Himalayan Region

[1] Mean growing season temperatures of 15-17°C.
[2] Mean growing season temperatures of 12.5-15°C.
[3] For sowing up to 0.2 m deep.
[4] Mean growing season temperatures of 15-20°C.

Table 3. Breeding scheme for Populations 85-88, CIMMYT, Mexico.

Winter Nursery (Oct.-Mar.), Tlaltizapán (940 m)		Highland plantings (Apr.-Oct.), El Batán (2249 m) and Toluca (2550 m); other areas, different planting dates
	Plant best materials from the breeding nursery and pools.	
Plant remnant seed of best FS identified in highland yield trials the previous season.	Simultaneous recombination and formation of new FS progenies.	Test FS progenies in replicated yield trials in 2-6 highland locations.
Form experimental varieties by diallel crossing of best 6-10 FS families with similar maturity, ear height, plant height.	Self to produce S_1 progenies.	Evaluate S_1s in the highlands; pass remnant seed of the best to the hybrid program.
		Increase each experimental variety; test EVs in replicated yield trials.

Table 4. Breeding scheme for Populations 800 and 845, CIMMYT Mexico.

Mexican highlands (May-Oct.) El Batán (2249 m)	Mexican highlands (May-Oct.) Toluca (2550 m)	Himalaya zone (Apr.-Oct.) temperate highlands
Plant remnant seed of best FS identified in Himalaya zone yield trials the previous season.	Plant seed of reciprocal FS and self.	Plant seed of reciprocal FS and occasionally S_1 for yield and adaptation tests.
Form EVs by diallel crossing of best 6-10 FS with similar maturity, ear height, and plant height.		Test experimental varieties in larger plots, more locations.
Increase experimental varieties formed the previous year.		
Plant seed of reciprocal FS and S_1 lines made previous season; innoculate with *E. turcicum;* make reciprocal FS among unrelated families and make selfs; plant best S_2 lines from the previous year in the regular selfing nursery.		

Table 5. Population 85, cycles of selection trials, El Batán 1991, 1992.

Entry	Yield (t/ha)	Days to silk	Yield (kg/ha/d)	% ear rot	% root lodging	Tillers/ plant	% shell
Pop. 85 C_0	6.7	82	82	2.9	0.0	0.02	84
Pop. 85 C_1	6.5	77	84	4.6	5.8	0.08	87
Pop. 85 C_2	7.1	78	91	3.1	3.1	0.02	86
Pop. 85 C_3	7.1	78	92	5.0	4.2	0.07	85
Significance	NS	NS	NS	NS	NS	NS	NS
Checks grown in adjacent yield trials							
H-32							
(DC hybrid)	4.0	80	50	11.6	64	1.4	88
V-23 (OPV)	3.8	84	45	8.3	56	1.1	89

Table 6. Population 86 cycles of selection trials, El Batán 1991, 1992.

Entry	Yield (t/ha)	Days to silk	Yield (kg/ha/d)	% ear rot	% root lodging	Tillers/ plant	% shell
Pop. 86 C_0	6.8	82	83	6.0	4.5	0.03	83
Pop. 86 C_1	6.4	78	82	6.5	6.8	0.05	83
Pop. 86 C_2	7.3	79	92	5.2	2.9	0.06	84
Pop. 86 C_3	6.6	80	82	8.8	4.5	0.02	84
Significance	*	NS	**	NS	NS	NS	NS
Checks grown in adjacent yield trials							
H-32							
(DC hybrid)	4.0	80	50	11.6	64	1.4	88
V-23 (OPV)	3.8	84	45	8.3	56	1.1	89

Table 7. Population 845 Cycles of Selection Trials, El Batán 1991, 1992.

Entry	Yield (t/ha)	Days to silk	Yield (kg/ha/d)	% ear rot	% root lodging	Tillers/ plant	% shell
Pop. 845 C_0	4.5	93	48	6.2	11.1	0.02	82
Pop. 845 C_1	7.0	83	85	9.9	5.8	0.05	83
Pop. 845 C_2	6.0	76	79	7.4	2.1	0.06	84
Pop. 845 C_3	6.7	78	85	8.5	3.1	0.03	83
Significance	NS	*	NS	NS	*	NS	NS
Checks grown in adjacent yield trials							
H-32							
(DC hybrid)	4.0	80	50	11.6	63.9	1.4	88
V-23 (OPV)	3.8	84	45	8.3	56.3	1.1	89

Table 8. Three-way, highland maize hybrids formed in 1989.

Female: INIFAP single crosses of partially inbred lines
Male: CIMMYT partially inbred lines
Locations: El Batán 1990, 1991, Tlaxcala,1990, 1991

	Yield (t/ha)	Days to silk	Plant height (cm)	Ear height (cm)
Trial mean	8.6	81	240	123
Hybrid check (H-34)	8.8	86	259	155
Experimental hybrids	6.6-11.3	77-86	224-259	109-138
Best exp. hybrid	11.3	83	247	134

17/45 = 38% of the experimental hybrids yielded more than the check hybrid

Table 9. Three-way, highland maize hybrids formed in 1991.

Female: CIMMYT single crosses of nearly inbred lines
Male: INIFAP partially-to-nearly inbred lines
Locations: El Batán 1992

	Yield (t/ha)	Days to silk	% ear rot	% root lodging	Plant height (cm)	Ear height (cm)
Trial Mean	9.0	78	6.1	5	239	127
Hybrid Check H-30	5.8	92	0.0	43	273	150
Experimental Hybrids	5.2-12.7	69-85	0-31	0-56	183-270	110-153
Best Exp. Hybrid	12.7	77	6	6	228	128

157/160 = 98% of the experimental hybrids yielded more than the check hybrid

Table 10. CIMMYT early white highland maize hybrids, El Batán, 1992.

	Yield (t/ha)	Days to silk	% ear rot	% root lodging	Plant height (cm)	Ear height (cm)
Trial Mean	7.2	82	9	1	218	107
Hybrid check H-34	8	91	5	35	270	165
Experimental hybrids	3.4-9.9	71-91	0-35	0-3	178-245	78-133
Best exp. hybrid	9.9	82	0	0	240	125

12/36 = 33% of the experimental hybrids yielded more than the check hybrid

Table 11. Initial steps to develop heterotic groups within highland, early-white semident maize.

Winter nursery (Nov.-Mar.), Tlaltizapán (940 m)	Highland plantings (May-Oct.), El Batán (2249 m) and other locations
Scheme 1	
(Reciprocal FS recurrent selection) Plant 144 pairs of S_3 or greater inbreeding lines based on maturity and genetic diversity. Make S_3 x S_3 reciprocal crosses.	Yield test 108 hybrids, divided into 3 maturities, at El Batán and 4 other sites; standard density (66,000 plants/ha); grow 1 rep at El Batán with 98,000 plants/ha and no irrigation.
Scheme 2	
(Lines X Testers) Plant all 288 S_3 or greater inbreds and cross to 2 inbred testers identified in earlier diallels.	Due to problems with pollen production in one tester and other difficulties, only 119 line x tester hybrids are being evaluated; evaluate only at El Batán, 1 rep at 66,000 and 1 at 98,000 plants/ha with no irrigation.

Observations

- Heat and adaptation effects were more pronounced in the winter nursery, Scheme 2.
- 75% of planned crosses were achieved in Scheme 1.
- 21% of planned crosses were achieved in Scheme 2.
- Germination was poor in some Scheme 2 crosses.

Table 12. Plans for developing heterotic groups of highland maize.

Scheme 1: Eberhart reciprocal FS recurrent selection	Scheme 2: Lines x testers
Year 1, Season A - Make S_2 X S_2 crosses between 2 heterotic populations (began with S_3 X S_3).	Modify Scheme 2 as follows: • Make line x tester crosses in the highlands. • Test lines at the S3 stage and use single-cross testers representing each heterotic group.
Year 1, Season B - Test the S_2 x S_2 crosses in several highland environments.	
Year 2, Season A - First recombination best lines identified in heterotic groups A and B.	
Year 2, Season B - Second recombination.	
Year 3, Season A - Make S_1s.	
Year 3, Season B - Make S_2s.	

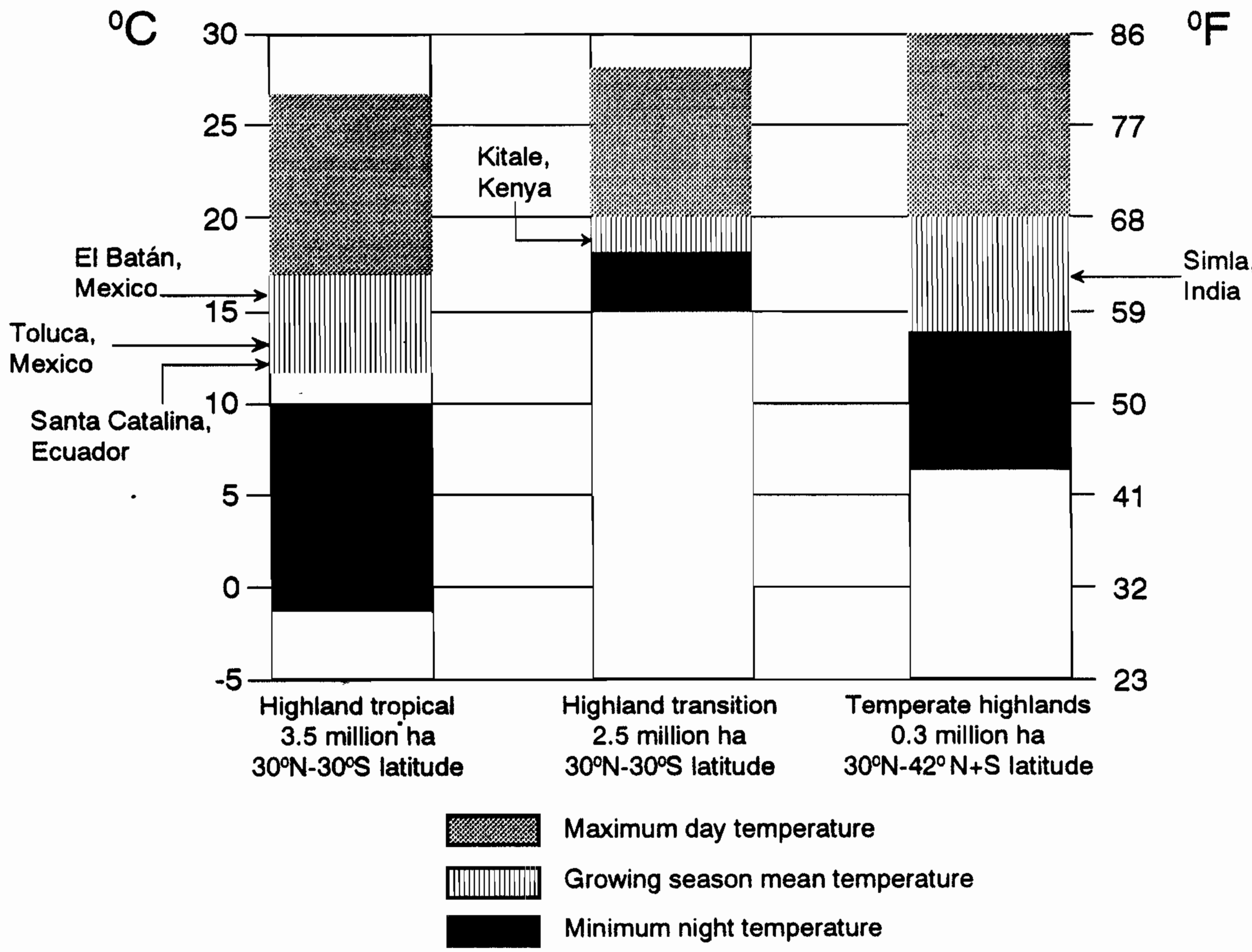

Figure 1. Mega-environments and temperature adaptation of highland maize. (Arrows indicate growing season mean temperatures of representative sites within each mega-environment.)

3

Chapter

Research on Cold Tolerance in Highland Maize

C. Giauffret and J.E. Lothrop *

Cold tolerance is an important trait in both tropical highland environments and some temperate areas (Northern Europe, Canada, New Zealand, etc.). Some developing countries are now interested in hybrid maize production for highland areas, while temperate breeding programs are trying to introduce cold tolerant highland tropical germplasm in their material. Thus combining-ability studies may be of mutual interest.

Five tropical highland inbred lines, selected in CIMMYT's experiment stations at El Batán, Mexico (2,250 m above sea level) or Toluca, Mexico (2,550 m above sea level) were chosen for a diallel, along with five inbreds representing different heterotic groups from the USA or Europe (Table 1).

The diallel crosses were made in 1992, at CIMMYT's station in El Batán, Mexico and the stations of the French National Institute of Agricultural Research (INRA) at Estrees-Mons or Saint-Martin de Hinx, France. In 1993, the crosses were being evaluated in five environments: El Batán, Mexico; Toluca, Mexico; Estrees-Mons, France; Montpellier, France; and Lusignan, France.

To limit competition due to differences in height and adaptation, the material was grouped in sets: 1) temperate x temperate, 2) temperate x highland tropical, and 3) highland tropical x highland tropical. The experiment used a three-block design with sets randomized within blocks. At least three checks (DEA, early temperate hybrid; ANJOU37, late temperate hybrid and H33, highland tropical hybrid) were included in every set at each location to determine the environmental effect between sets.

The inbred lines were tested in four environments (El Batán, Toluca, Estrees-Mons, and Montpellier), and the reciprocal crosses for the temperate x temperate and highland tropical x highland tropical sets in two environments (El Batán and Estrees-Mons).

At El Batán, Toluca, and Montpellier, four-row plots were used. Data up to flowering time was taken on one of the central rows and harvest will be done on the two central rows. At Estrees-Mons, six-row plots were used to take data up to flowering time and permit both silage and grain harvests on two different central rows. At Lusignan, two-row plots were used and were harvested for silage. One of the rows was used to take notes.

* Physiologist, CIMMYT-INRA (France) Collaborative Project; breeder, highland maize.

Data were recorded for the following traits:

- Rate of emergence, emergence duration, emergence percentage
- Leaf appearance rate
- Early vigor: visual scale at the 4/5 visible leaves stage, visual scale at the 7/8 visible leaves stage, plant height at the 7/8 visible leaves stage
- Chlorophyll content of the last fully expanded leaf at the 8/10 leaves stage, only in Mexico's environments
- Leaf area of the 6th and 8th fully expanded leaves
- Leaf area of the ear leaf
- Total number of leaves
- Flowering dates (silking and tasseling)
- Ear and plant height
- Dry matter weight and percentage at harvest time
- Grain yield

The results are being analyzed according to Griffing's method 4 (fixed model) to determine general combining ability (GCA) and specific combining ability (SCA) effects. Gardner and Eberhart's method will be used to interpret the results in terms of heterosis. Dudley's approach will be used to determine the best tropical parent to introduce into temperate material. Further on, the results will also allow us to determine the best cross from which to derive recombinant lines and to look for quantitative trait loci (QTLs) for cold tolerance.

Table 1. Materials used in a diallel-cross experiment to assess combining ability in highland and temperate maize genotypes.

Temperate lines	Highland tropical CIMMYT lines
F2 (France)	C1=CML 242 (Batán adaptation)
F252 (France)	C2=CML 246 (Batán adaptation)
F564 (France)	C3=CML 245 (Batán adaptation)
W117 (USA)	C4=HTBA89 136-5-1-B (Toluca adaptation)
MBS 847 (USA)	C5=Pop. 900 C0 HC 6-1-1-B (Toluca adaptation)

4

Chapter

Research on Maize for Midaltitude Regions

K.Pixley, D.Jewell, and S.Waddington *

The CIMMYT midaltitude research station was established in 1985 near Harare, Zimbabwe. Research activities target tropical maize grown at elevations roughly between 900 and 1,700 masl. This encompasses some 6.5 million hectares in eastern and southern Africa with a regional average yield for maize of 1.3 t/ha (CIMMYT 1992). The primary production constraints for maize in this region are drought, maize streak virus (MSV), *E. turcicum* leaf blight, and low soil fertility. The mandate of the Maize Program and of the midaltitude maize research station is to assist in raising the productivity of resources committed to maize by farmers in developing countries.

The objectives of the midaltitude research program can be summarized as follows. First, to develop parental materials (populations, synthetics, or inbred lines) for the region. By virtue of its apolitical nature, CIMMYT may have a comparative advantage over national programs or private seed companies for introducing and facilitating distribution of new germplasm. Relative stability in staffing and funding also allow the center to address technically challenging or long-term breeding objectives, such as resistance to MSV, drought tolerance, low soil fertility, acid soils, *Striga*, etc. Secondly, we strive to assist national programs in any appropriate way (e.g. provide germplasm, informal consultancies, services such as screening for resistance to MSV). Third, we participate in and assist networks that focus on regional issues relating to maize based farming. Fourth, we provide training opportunities of various types, including organizing and contributing to scientific meetings, advising and supervising on thesis projects, hosting visiting scientists, and sponsoring "internships" for university students.

Although our objectives have not changed since our program was initiated in 1985, the products of our research and the definition of our clients have gradually evolved. In 1985 we described our activities as providing national programs with improved germplasm, assistance in breeding methods, training, and some material needs (Gelaw 1986). Improved germplasm was defined in terms of stability when challenged by drought, diseases, insects, and other hazards; yield responsiveness; and maturity. Germplasm products were improved, broad-based populations and open-pollinated varieties (OPVs). By 1987, partially inbred lines (S_3 bulks) with information about their combining ability were added to the list of products from the midaltitude research program (Ward 1988). MSV-resistant conversions of existing elite midaltitude germplasm, narrow and broad-based populations, S_4 lines, greater emphasis on developing populations to fit heterotic groupings, identification of appropriate testers, and initiation of drought-tolerance work were emphasized by 1989 (Wedderburn et al. 1990). By 1991, much of the effort of the

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midaltitude station was aimed at hybrid-oriented products, in addition to OPVs. Several new populations were being improved by testcross or reciprocal recurrent selection methods. Increasing attention was also being given to evaluation of midaltitude germplasm for stress environments (drought, low soil N). Finally, inbred lines were added to the list of available products from the midaltitude research program (CIMMYT 1992 unpublished, second announcement of CIMMYT inbred maize lines), and private seed companies had become important clients.

In 1993 the midaltitude maize research program reached a juncture which gave us the opportunity to rethink research priorities and activities for the coming years. There had been a complete turnover in the maize breeding staff. A review by the University of Zimbabwe resulted in several suggestions for change (see section *Results of Review by the University of Zimbabwe*). The following information describes our activities, plans, and the state of development of germplasm from our research.

Germplasm Enhancement

Populations undergoing recurrent selection

Twelve populations are currently being improved as closed populations using recurrent selection (Table 1). Each population targets a germplasm maturity class and heterotic pattern. Two exceptions are ZM609, which targets improved yield potential under low N fertilizer input, and [MSRxPool9A], which is intended for upper midaltitude or transition zone environments. Traits of interest for all populations are maturity, standability, and grain yield. Selection for resistance to MSV is practiced for all populations, although intensity of selection is lowest in drought and N-use-efficiency materials. A selection index is commonly used to select families for recombination to form new cycles of each population.

INT-A and INT-B -- Of intermediate maturity, dent/flint texture, and white grain, these heterotically complementary populations were formed following the N3 and SC heterotic pattern. The populations have been improved using N3 as tester for S_1 lines of INT-B, and SC as tester for S_1 lines of INT-A. We are currently forming test-crosses of S_1 lines using the opposite or complementary population (F_2 bulk from previous cycle) as a tester. We are considering implementing a more hybrid-oriented methodology for future cycles of improvement. In the proposed method, S_4 lines from the four most outstanding S_1 lines of the preceding cycle of the complementary population would be used as testers for sub-sets of the new S_1 or S_2 lines. Evaluation of the hybrids would identify families for recombination and formation of the new cycle for each population, as well as superior hybrids.

LAT-A and LAT-B -- Late maturity, dent/flint texture, white grain, heterotically complementary populations. Similar to INT-A and INT-B, these late maturity populations were also based on the N3 and SC heterotic pattern and improvement was initially based on test crosses to these two lines. This winter we are forming test crosses using the complementary populations as testers for S_1 lines.

DR-A and DR-B -- Intermediate maturity, dent/flint texture, white grain, heterotically complementary populations with emphasis on selection for yield potential in drought environments. These populations were formed from a broad array of stress tolerant germplasm which was grouped primarily based on pedigree. Heat-stress-tolerant sister lines of N3 and SC were used as males in the initial recombination to form the populations. A first cycle of improvement was accomplished by S_1 per se evaluations at a drought-stressed location in Zimbabwe. Two modifications to the initial methodology are being implemented: 1) lines will be evaluated in testcrosses to reinforce and improve heterotic response between the two complementary populations, and 2) evaluation of S_1 lines and testcross hybrids will be expanded to include high yield potential sites as well as drought stressed sites.

ZM601{DR} and ZM601{DEN} -- Late maturity, dent/flint texture, white grain populations being improved for tolerance to drought and high plant density, respectively. Both populations were developed from the cross between EV7992 (a Tuxpeno-type variety developed in Tanzania) and an MSV-resistant conversion of an experimental variety from La Posta (CIMMYT Population 43). Thus, both populations are of the "A", N3 or Tuxpeno heterotic type. ZM601{DR} has been improved through S_1 per se evaluation in a shuttle program between the maize physiology unit in Mexico and our program in Harare. This shuttling of germplasm may no longer be useful because we now have access to a well-managed, reliable, drought-stressed site within Zimbabwe. It has also been observed that rank correlation is low for performance of genotypes evaluated under drought stress in Mexico and Zimbabwe (G. Edmeades, personal communication), so the shuttling may actually be counter-productive. ZM601{DEN} is being improved via S_1 per se evaluation at high plant density (106,000 plants per hectare). The intent is to compare performance in stress environments for material emerging from ZM601{DEN} with that from ZM601{DR}.

ZM605 -- Intermediate maturity, dent/flint texture, white grain population. This population was formed with experimental varieties from Population 42 (Eto Illinois), a streak conversion from Population 49 (Tuxpeño), and Pool 9A (highland late white dent). This population has been improved using an S_1 x tester approach, where selection emphases have been for resistance to MSV and foliar diseases followed by general combining ability. The tester has been ZS107, a local commercial single cross hybrid with high yield potential.

ZM607 -- Intermediate/late maturity, white dent population. Components that formed this population were EV7992 and EVPOP44-SRBC3. The population is thus of Tuxpeno or "A" heterotic type. Improvement has been by S_1 per se evaluation using two plant densities. In addition to grain yield, selection emphases have included resistance to MSV and foliar diseases. One of the original objectives of this population was to compare progress from selection by S_1 per se to selection by S_1 x tester (e.g. ZM605). We propose to modify the methodology to incorporate testing of combining ability, even though the aforementioned comparison of gains from different selection methods would no longer be possible. Topcross evaluation would enhance heterotic definition of the population and may identify useful hybrids. Another reason for discontinuing S_1 recurrent selection is that this method has been found to result in declining gains after only few cycles of selection.

ZM609 -- Intermediate maturity, white dent population. This is a Tuxpeño type population ("A" group) composed of EV7992 and EV8449-SR. Improvement is by S_1 per se evaluation at normal and low N fertilizer conditions. Selection for resistance to MSV and foliar diseases is also being practiced. This population, and related work on nitrogen use efficiency (NUE) is discussed later on in this chapter in the section *Special Research Projects In Eastern and Southern Africa.*

[MSR/POOL9A] -- Late maturity, dent/flint, white population for upper midaltitude or transition zones. This population has been improved by S_1 per se evaluation. Currently the population has been shelved while we appraise whether continued work is merited. One important question is whether we have access to appropriate testing sites; Zimbabwe has no significant maize growing area within the target elevation for this population.

Line development

Each cycle of recurrent selection also involves the identification of superior lines within our populations. Inbreeding of the most elite fraction of lines is routinely continued, and tests of general and specific combining ability begin mostly at the S_3 level. Small numbers of elite lines from the program are made available to cooperators at more or less frequent intervals: 22 midaltitude and 22 lowland tropical inbred lines were made available in 1992.

An important additional objective of this research is to develop suitable testers for use in our program and by interested cooperators. With this aim, a diallel was formed in summer 1993 among 11 key lines, including two from the subtropical program at headquarters, three of regional importance, and six recently made available to cooperators. The trial was evaluated at Tlaltizapán, Mexico, in 1993 and will be tested at several sites in Zimbabwe in 1994.

Increasing effort will be devoted to pedigree breeding. Particularly as we develop inbreds with tolerance to various stresses, we will want to mate these with other elite materials and extract improved lines. This process of pedigree breeding is not limited to crosses among inbred lines, but also includes topcrosses of inbred x variety or selection from narrow based synthetics.

Early maturing germplasm

There is a conspicuous absence of early maturing populations among those undergoing recurrent selection in our program. This trait was once assigned a low priority because of the relatively small maize growing area within midaltitude eastern and southern Africa which, based on duration of rainy season, clearly requires early maturing maize. There are, however, numerous factors, such as lack of draft power, seasonal labor shortages, late onset of rains, increasing interest in growing winter crops, and risk avoidance strategies, that combine to create a substantial demand for midaltitude maize of earlier maturity than most currently available cultivars.

Work is in progress to form a new set of heterotically complementary, early maturing populations that may be subjected to some form of reciprocal recurrent selection. Twenty-one early and intermediate maturity populations have been formed and are currently being advanced to the F_2 generation. These populations include germplasm from CIMMYT pools and experimental varieties from the subtropical and highland programs, successful cultivars from eastern and southern Africa, and crosses to selected commercial hybrids. The 21 populations are being evaluated in yield trials during 1993-94 main season and the best will be considered to form two new populations.

Germplasm Evaluation

During summer (main) season, nurseries of inbred lines and all crossing blocks are grown at our midaltitude research station, located on the University of Zimbabwe farm at 1,500 masl. In addition, we have tentative plans to enter an agreement with a local private seed company to supply leafhoppers for use in MSV evaluations in exchange for use of nursery space at a site near Harare where the climate facilitates selection for resistance to *E. turcicum* leaf blight. We also have access to 5.2 ha of winter nursery facilities at Mzarabani, 200 km north of Harare at an elevation of 400 masl.

Yield trials are conducted primarily at three sites in a high yielding maize area near Harare. The first is the CIMMYT midaltitude research station. The second is the Rattray-Arnold farm of the Seed Co-op Company of Zimbabwe, at 1,300 masl. A third site is near Glendale, on a privately owned farm at an elevation of 1,200 masl. Additional yield testing of materials being improved for drought tolerance is conducted at Department of Research and Specialist Services (DR & SS) station at Makoholi, an area of marginal productivity with sandy soil and an elevation of 1,200 masl.

Twenty-four yield trials were grown at 2-4 sites in Zimbabwe during the 1992-1993 major season (Table 2). These trials can be classified into four types: 1) test-crosses of lines resistant to stem borers; 2) test-crosses of preliminary, advanced, or elite inbred lines; 3) evaluation of drought tolerant hybrids or populations; and 4) evaluation of new populations.

Probably the greatest strength of the germplasm from the CIMMYT midaltitude program in Zimbabwe is its resistance to MSV (Table 3). The tester used for the CIMMYT lines was 'SC,' an MSV-susceptible line. It is important to note, therefore, that one parent can confer acceptable resistance to MSV in a single-cross hybrid. The two commercial hybrid check entries, ZS206 and SC601, yielded less than 1 t/ha when MSV was severe, but they were the highest yielding entries at sites where MSV was not important.

Another trial of special interest included variety crosses among populations being improved with a specific heterotic pattern in mind (Table 4). Results from 4 sites do not indicate much heterosis among partner populations (e.g. DR-A x DR-B, INT-A x INT-B, LAT-A x LAT-B). This is disappointing, but does not negate the fact that excellent inbred lines are arising from these populations. We intend to change the testers used for increasing heterosis between populations. Instead of using N3 and SC as testers for "B" and "A" populations, respectively, we plan to use either selected inbreds from the previous cycle of the complementary population or a narrow-based synthetic of such inbreds.

Testcross hybrids of lines arising from our program are competitive with commercial hybrid checks (Tables 5, 6, 7, 8, 9, and 10). Research is in progress to identify inbreds from our program for use as testers in place of public lines we are currently using for testcross evaluations. The new testers may be inbreds themselves or single-crosses among inbreds of similar heterotic behavior.

Preliminary evaluation trials (PETs), which to date have consisted primarily of populations and synthetics, are sent to interested cooperators throughout the region. With increasing interest in hybrid development, we are considering initiating PET trials with hybrid entries. There would be a start-up delay of at least one more year for such trials, as we believe hybrids should be tested within our research sites for a minimum of two years before entering regional trials. Another means to offer more hybrid trials to interested cooperators in the region, while at the same time providing us with better testing of our germplasm, would be to form small networks of cooperators to evaluate testcross trials for populations in recurrent selection. Such cooperators would receive S_2 bulks for lines which performed outstandingly in testcross trials, thus allowing researchers to form hybrids between CIMMYT S_2 lines and their own testers.

Resistance to Maize Streak Virus

A screenhouse facility at the CIMMYT midaltitude station allows us to conduct an ambitious program of screening and improving germplasm for resistance to MSV. Our 720 m^2 screenhouse produced sufficient leafhoppers (*Cicadulina mbila*) to infest 7,300 nursery rows during the past main season and 4,000 nursery rows in our current winter nursery. The leafhopper rearing and field infestation techniques are now well proven and we consider these to be a routine and important part of our breeding program.

Consultancies

Any scientific research program benefits from the input of professional colleagues that share common interests and objectives. In this spirit, staff of the CIMMYT midaltitude research station frequently travel to annual planning sessions and visit research facilities of national programs in the region. We also invite scientists from the region to visit our facilities and view germplasm that may be useful to their programs. Thus, consultancies take the form of an exchange of ideas regarding methodologies and strategic planning, technological assistance (such as screening germplasm for streak virus resistance), and supplying germplasm. One example of this activity has been CIMMYT cooperation with the Department of Agricultural Research of Malawi in drafting a maize improvement and production research action plan for 1989-1999 (Zambezi 1992).

Products Available

1. Source populations of well defined heterotic composition.
2. Partially inbred lines of defined heterotic orientation.
3. Narrow-base synthetics.
4. Source populations for stress tolerance.
5. 44 inbred lines with information on combining ability.

Results of Review by the University of Zimbabwe

The following is a point summary of recommendations resulting from a review of the status and impact of CIMMYT maize midaltitude station conducted by the University of Zimbabwe in 1993:

1. The role of the station's team leader needs to be more clearly defined. To be effective the leader should be given functional administrative and technical leadership responsibilities, in addition to his role as a breeder.

2. The breeders should report to the team leader on both technical and administrative issues and not directly to CIMMYT Mexico. The team leader should be an effective link between the station, national agricultural research systems (NARSs) of the region, and CIMMYT headquarters in Mexico.

3. The station's staff structure should be rationalized and include regional scientists at the professional level in order to ensure continuity. This could also serve as a useful training mechanism.

4. The breeding effort of the midaltitude station is currently geared towards developing germplasm for high yielding environments, which puts it in competition with NARSs and private seed companies. The station's efforts should be targeted towards the needs of the resource poor small-scale farmers located in marginal areas. Drought resistance and nitrogen use efficiency MUST receive greater emphasis and selecting for resistance to maize streak virus should be done as a matter of routine rather than as the main objective.

5. A Regional Steering Committee made up of breeders, agronomists, physiologists and economists from East and Southern Africa should be established. The Committee would set out regional priorities and evaluate the station's technical activities on a regular basis. There is also need for annual reports on station activities for circulation in the region. Screening and testing of germplasm should be vigorously extended to the more marginal rainfall locations.

6. More in-service training activities should be conducted at CIMMYT, Harare. Emphasis should also be put on attachments of NARS scientists to the station for specific in-service training.

Proposed Changes

Changes to the midaltitude breeding program will not be made hastily, given that the new staff has had little time to become acquainted with the work in progress and with regional research needs. We are also aware of (and hope to minimize) the large costs associated with lack of continuity in breeding work. Several changes, though, could be implemented immediately to enhance the present program:*

1) Increase efforts to develop maize germplasm for marginal environments. This would not necessarily involve increased breeding in marginal environments, but increased testing of germplasm under less favorable conditions seems essential. To do this, one or more sites (in addition to Makoholi) must be secured.

2) Decrease use of S_1 x tester, increase use of S_2 x tester recurrent selection. This will allow increasing selection intensity, will increase the quality of lines which reach testcross evaluation, may decrease the number of lines test-crossed (decreasing resources for testing), and may attract participation of national programs in the testing scheme.

3) Increase efforts relating to early maturity germplasm. The need for this category of germplasm is apparent, and we propose to form and reciprocally improve a pair of heterotically complementary populations.

4) Combine LAT-A with INT-A, and LAT-B with INT-B. If emphasis is placed on maintaining variability for maturity, it should be possible to develop lines, synthetics, and variety crosses for either maturity category from just one pair of populations.

5) Discontinue work with population ZM601{DEN}. The maize physiology program at CIMMYT headquarters have studied the relationship between tolerance to high density and drought tolerance at flowering and have concluded there is little value in selecting for drought tolerance indirectly by screening for tolerance to high density (G. Edmeades, personal

* Some of these have already been implemented or contemplated by our predecesors.

communication). Incidentally, there are other benefits from selecting for tolerance to high density. Drought tolerant lines from population ZM601{DEN} will be merged into ZM601{DR}.

6) Increase efforts in screening for leaf blight (*E. turcicum*). We are presently modifying inoculation techniques developed at CIMMYT headquarters. During the 1993/1994 season we will screen lines at a new site (Mazoe, Zimbabwe) to determine the feasibility of routinely screening our germplasm for resistance to *turcicum* leaf blight.

7) Prepare and broadly circulate annual reports on research activities at the midaltitude station.

In the near future we will consider the following issues relating to the research priorities and directions of the CIMMYT research station in Zimbabwe:

- The relative emphasis on high-potential versus marginal environments and refining our definition of these environments.
- Attracting more potential users to our germplasm, possibly through increasing collaboration with non-government organizations (NGOs), such as Sasakawa Global 2000 and World Vision.

Special Research Projects In Eastern and Southern Africa

The following research projects are described separately from the mainstream work of the Harare midaltitude research program either because they are preliminary efforts (i.e., we are still deciding whether a long-term effort is warranted or technically feasible) or because they are complementary to our primary breeding program. We will briefly outline four such efforts: 1) developing germplasm that performs better than unimproved maize when N fertility is limiting, 2) assessing genotypic differences in tolerance to *Striga hermonthica*, 3) screening germplasm for yield potential under weed infested conditions, and 4) developing maize for southern and eastern Africa that possesses multiple insect resistance, particularly to first generation corn borers. Our work to develop drought tolerant maize will not be discussed because it has become part of core breeding and because the methodologies are described in detail in Chapter 8.

Maize improvement for nitrogen use efficiency

There is widespread interest in developing maize cultivars that perform well under reduced N fertilizer inputs. Reasons for this interest include a concern by CIMMYT (CIMMYT mission statement) for farmers in marginal or resource-poor areas where practical constraints of access to chemical fertilizer, credit, or appropriate technology limit the use of N fertilizer. Low and Waddington (1989) found that the average amount of N fertilizer applied to each hectare of smallholder maize land in southern Africa is between 4 and 25 kg per year. Large numbers of farmers apply no N fertilizer at all. Low N status of soils is regarded as a primary maize production constraint within the southern African region (Southern Africa Development

Community, 1993, unpublished report, "Status of Crop Production, Constraints and Research/Development Priorities in SADC Countries").

An S_1 recurrent selection program was initiated at the Harare midaltitude station in 1989 to improve nitrogen use efficiency (NUE) of population ZM609 (Short and Edmeades 1991). Population ZM609 is a late maturity, dent/flint, white grain, Tuxpeño type population with maize streak virus resistance, good yield potential, resistance to *E. turcicum* and *P. sorghi* foliar diseases, and short, semi-prolific plant type. The population has now undergone two cycles of selection following the scheme outlined in Table 11.

Nitrogen-use-efficient (NE) lines have high grain yield at both high and low N, whereas nitrogen-use-inefficient (NI) lines yield well at high N but much less under low N (Short and Edmeades 1991).

In addition to the population improvement scheme and inbreeding of best lines, testcross hybrids were formed for the best NE and NI S_2 lines from ZM609c1. The testers used were N3 and SC, the inbred parents of the high yielding commercial hybrid, SR52. The nature of the correlation between inbred NUE per se and in hybrid combinations is unclear. Evaluation of these testcross hybrids was a failure due to drought at most of the seven trial locations in the summer of 1991-1992, but one trial was completed at Mzarabani this winter (1993) and others are proposed for 1994.

Joseph DeVries, a graduate student from Cornell University, has joined our team at the midaltitude research station to conduct his doctoral thesis research on NUE in maize in Zimbabwe and Mozambique. This research is funded by the Rockefeller Foundation for a period of 18 months, and will use NE and NI lines, as well as synthetics developed from population ZM609. Specifically, projects will be conducted to study the inheritance of various traits used to quantify nitrogen use efficiency and the relationship between inbred NUE per se and in hybrid combinations. We anticipate that results from this research will enable us to determine whether continuation of NUE work is merited and/or technically feasible (i.e. are we achieving or likely to achieve an acceptable gain from our efforts?). Researchers at CIMMYT headquarters are also developing selection techniques for improved performance under low nitrogen conditions. Results from both efforts will determine future directions of this project.

Genotypic differences in tolerance to *Striga hermonthica*

Striga hermonthica affects sugar cane, finger millet, Napier grass, sorghum and maize in large areas of Africa, apparently below 1500 masl. CIMMYT's initial research on *Striga* resistance has been based in Kenya. It is estimated that 10 percent of Kenya's maize area is affected by *Striga* at a level severe enough to reduce yields by 5 percent or more. The Kenyan National Research Centre for sugar, based at Kibos, has been named the national centre for *Striga* research. Preliminary research has concentrated on evaluation of different germplasm for tolerance to *Striga* infestation and on differences in attachment and emergence of this parasitic weed in maize plots.

A high correlation between days to silking and *Striga* numbers has been observed (Ransom and Odhiambo 1991), and further research is studying implications of this relationship.

Questions arising from this research relate to problems in establishing uniform *Striga* populations in field tests and hence to the considerable variation present when screening progenies. Joel Ransom, CIMMYT agronomist in Kenya, will continue agronomic research and screening in germplasm for resistance, while attempting to obtain increased precision of the screening techniques. The use of genetically engineered glyphosate resistant maize (perhaps even maize that produces glyphosate) could be considered, whether or not genetic resistance is isolated within the crop.

Tolerance to weed infestation

Timely weeding of maize crops is often not accomplished by smallholder farmers in high yield potential as well as in marginal-productivity areas. This may be due to conflicting demands on household labor from planting or weeding other crops, high cost and unprofitability of hiring off-farm labor, or various other constraints. It is usually not cost-effective for farmers in marginal areas to utilize chemical herbicides and many in potentially higher production areas find herbicide use impracticable.

A preliminary study was initiated during summer 1989-1990 to assess whether significant differences occur among genotypes for performance under weed infestation. Twenty maize cultivars, including four commercial hybrids, one local variety, and 15 CIMMYT populations and synthetics, were evaluated under well-weeded and late-weeded conditions. Natural weed infestation was supplemented with a mixture of *Amaranthus hybridus* and *Eleusine indica* applied mixed with sand to soil surface at planting. This trial, with minor modifications, has now been repeated for a third time during summer 1992-1993.

Although these trials have proven somewhat difficult to manage, differences have been observed and several CIMMYT materials have shown greater vigor and growth with weeds than the check materials (Waddington 1992, unpublished data). 'Tuxpeño Sequía' and population ZM609 (NUE) are among the best CIMMYT materials for performance with weed infestation. And 'R201', a commercial hybrid recommended for marginal environments, may be the best among the checks. These results, although tentative, suggest that materials improved for tolerance to abiotic stresses may also have a competitive advantage under weed infestation. To further explore this hypothesis, the trial was planted at a second site in 1992-1993 with high and low N fertilizer input. Problems associated with these trials have been inconsistency in level of weed infestation and its effect upon yield between years, as well as the confounding effects of maize streak virus at Harare midaltitude station.

We do not envision that this research will lead to special breeding projects. It would be useful, however, if traits can be identified which confer relative advantage to maize genotypes in weed infested environments (for example seedling vigor). It would be both interesting and useful to note any relationship between tolerance to abiotic stresses receiving attention in our breeding program and tolerance to weed infestation. A modest (in terms of allocated resources) evaluation effort might assist in making germplasm recommendations for marginal-productivity maize crops.

Resistance to corn borers

The full extent of losses in production in southern and eastern Africa associated with corn borer infestations is unknown, although borers are listed as a serious problem for maize production in many countries in the region (CIMMYT 1988). Researchers at CIMMYT headquarters have successfully isolated host plant resistance to first generation attack by multiple borer species. Some of the germplasm from this program has been evaluated for resistance to corn borer species present in Africa, and resistance has been found. CIMMYT's applied biotechnology laboratories are working with the Maize Program to locate the genome segments associated with resistance to corn borers and thus facilitate incorporating this trait into a range of useful germplasm. A backcross program has been initiated to introduce borer resistance to inbred lines developed at Harare. A small effort will continue for screening and developing germplasm with suitable adaptation and insect resistance for southern and eastern Africa. In particular, we will concentrate on isolating resistance in germplasm with white endosperm, streak resistance, and suitable foliar disease resistance.

Conclusion

Special research projects will undoubtedly continue to arise as new issues are identified that merit attention. Communication with staff at headquarters is essential to ensure timely input of ideas and to avoid duplication of efforts, but efforts at Harare should reflect regional needs as well as those identified as significant at CIMMYT headquarters. Careful consideration must be given when deciding which research projects should be "promoted" into our core program.

We would like to see more special projects handled by visiting scientists or graduate students. Funding for such positions is an important consideration and donors will be approached in southern and eastern Africa. Special research projects also provide excellent training for regional scientists. A research problem of particular interest to a scientist within a national program could lead to a bilateral project that will have spill-over benefits for other countries within the region, as well as providing training and possibly a thesis topic for the scientist.

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Table 1. Improvement methodology for population ZM609.

Season	Procedure	Outcome
Winter 1	Self pollinate within F_2	500 S_1 lines
Summer 1	Yield trials of 500 S_1s: 2 locations, 3 reps at 0 N and 2 reps at 120 kg/ha N	Identify NE* and NI* lines
Winter 2	1. Recombine best 26 lines 2. Recombine best 13 NE lines 3. Recombine best 13 NI lines 4. Self-pollinate best lines	Form cycle n+1 F_1. Form NE synthetic Form NI synthetic S_2 NE and NI lines
Summer 2	1. Advance F_1s to F_2s 2. Evaluate S_2s, self	Pop. F_2, Syn. F_2s S_3 NE and NI lines
Winter	Repeat winter 1 and continue inbreeding of lines	

* NE = N-use efficient; NI = N-use inefficient.

Table 2. Summary of yield trials, CIMMYT regional program, Harare, Zimbabwe, 1992-1993.

Trials	Description	Entries	Number of locations
2	Elite early line TC	52	3
7	Borer line TC	210	2
3	Preliminary line TC	134	2
2	Advanced line TC	103	2
5	Elite line TC	201	3
1	Elite hybrid (MSV)	30	3
1	Drought S_1 lines	225	3
1	Drought population and hybrid	32	4
1	Population diallel	64	4
1	New populations	30	2

Table 3. Performance of hybrids evaluated under maize streak virus (1 site) and non-infested conditions (2 sites), Zimbabwe, 1993 (30 entries).

Entry	Yield, MSV site (t/ha)	Yield, non-MSV site (t/ha)	MSV score (1-5)
MSR-129-S6/SC	2.6	11.1	3.0
MSR-308-S6/SC	5.1	10.0	3.0
MSR-76-S6/SC	5.8	10.5	3.0
7794-S11/SC	5.3	9.3	2.0
ZM607-S7/SC	5.1	10.0	4.0
EV7992-S7/SC	6.1	11.4	3.0
EV8443-SR-S8/SC	6.1	9.0	3.0
MSR:121-S6/SC	4.6	12.0	3.0
ZSR923-S8/SC	4.8	11.9	4.0
ZS206	0.2	12.4	5.0
SC601	0.7	12.5	5.0
LSD (0.05)	2.7	1.4	0.5

Table 4. Populations diallel: means across 4 sites (Harare, Glendale, Rattray Arnold, and Makoholi), Zimbabwe, 1993.

		DR-B	INT-B	LAT-B	WFE1	WEDETO	SNSYNF2 [SC/ETO]		
		7.07	6.60	7.35	4.90	6.32	7.30		
DR-A	6.77	7.17	6.59	7.68	7.15	7.07	6.97	7.11	0.09
INT-A	5.73	7.09	6.79	7.16	7.14	6.97	7.38	7.09	0.07
LAT-A	7.72	7.42	7.15	6.53	6.98	7.24	7.08	7.07	0.05
ZM607	7.07	7.68	6.77	6.70	6.86	6.83	6.39	6.87	-0.15
ZM609	5.53	7.39	6.44	6.84	7.48	6.15	6.28	6.76	-0.25
MLWS1	7.18	7.21	6.93	7.37	6.67	6.85	7.19	7.04	0.02
WEDTUX	7.24	7.13	6.93	7.47	7.12	6.93	6.61	7.03	0.01
SNSYNF2[N3/TUX]	6.07	7.69	7.55	6.94	7.07	7.05	6.76	7.18	0.16
Mean	7.35	6.89	7.09	7.06	6.89	6.83	7.02		
GCA	0.33	-0.12	0.07	0.04	-0.13	-0.19			

C.V. = 11.6%, LSD(0.05) = 1.13

Table 5. Results of trials with a CIMMYT borer resistant maize line testcross, Zimbabwe, 1993 (2 sites, 32 entries).

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Lodging (%)	Husk cover (%)	Ear rot (%)
MIRT[FAW]-S5/N3	10.8	81	136	25	18	4
MIRT[SCB]-S5/N3	9.7	77	125	23	54	3
MBRST/TMH-S5/N3	9.3	79	126	52	27	12
R201	8.3	74	105	40	23	22
ZS206	9.5	81	126	22	41	25
LSD (0.05)	2	2	16	39	20	14

Table 6. Results of trials with a CIMMYT borer resistant maize line testcross, Zimbabwe, 1993 (2 sites, 38 entries).

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Lodging (%)	Husk cover (%)	Ear rot (%)
MIRT[FAW]-S5/P32	11.5	79	138	7	9	4
MBRST/TCHILO-S6/P32	10.1	73	118	36	46	12
MIRT[SCB]-S5/P32	9.9	75	128	8	59	3
ZS225	9.9	72	114	15	40	21
ZS206	9.3	80	121	19	31	11
LSD (0.05)	1.9	3	15	16	23	NS

Table 7. Results of trials with a CIMMYT elite early/intermediate line testcross, 1993, Zimbabwe, (3 sites, 20 entries).

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Lodging (%)	Husk cover (%)	Ear rot (%)
EV8744-SR-S6/Mo17	10.3	69	118	17	8	5
TZI4001-S2/B73	8.9	72	134	13	14	4
EV8232-SR-S6/Mo17	8.6	68	114	22	11	13
R201	7.5	68	120	19	29	16
ZS225	8	71	126	12	26	10
LSD (0.05)	1.4	2	12	11	14	7.0

Table 8. Trials with CIMMYT drought tolerant populations and hybrids under dry and well - watered conditions, 1993 (4 sites, 32 entries).

Entry	Dry (1)	Well-watered (3)	Days to silk
K64R/TUXPEÑO SEQUIA C6	3.6	6.7	71
TUXPEÑO SEQUIA/SC501	4.0	7.9	73
R201/SYN[SC/ETO]	3.1	11.1	75
R201/SYN[N3/TUX]	4.0	10.3	74
M162W/SYN[SC/ETO]	3.7	9.3	75
M162W/SYN[N3/TUX]	2.9	10.3	71
ZM609{NE}-106-S5/K64R	3.5	8.6	71
ZM609{NE}-306-S5/K64R	3.6	9.0	70
ZM609{NE}-89-S5/K64R	3.5	9.6	72
ZM609c1F2/TEMP.HIGHLAND	3.9	7.0	66
TUXPEÑO SEQUIA C6	3.7	8.0	75
R201	4.2	8.9	70
LSD (0.05)	NS	1.1	2.3

Table 9. Results of trials with a CIMMYT advanced maize line testcross, Zimbabwe, 1993 (2 sites, 53 entries).

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Lodging (%)	Husk cover (%)	Ear rot (%)
ZM607-S4/N3	10.8	79	139	15	14	5
[EBN102/MSR:131-S4]-S2/N3	10.8	78	138	17	24	8
[EBN112/7794-S9]-S2/SC	10.5	78	149	25	19	7
ZM609{NE}-S5/N3	9.6	73	123	5	21	4
ZS206	11.5	78	148	4	22	9
SC601	10.5	77	143	5	23	15
LSD (0.05)	1.2	2	17	NS	13	9.0

Table 10. Results of trials with new CIMMYT populations, Zimbabwe, 1993 (2 sites, 30 entries).

Entry	Yield (t/ha)	Days to silk	Ear height (cm)	Lodging (%)	Husk cover (%)	Ear rot (%)
SNSYN[N3/TUX]/KITALEII	9.7	81	155	7	7	9
ECU573/SNSYN[SC/ETO]	9.6	80	168	7	17	11
Eto COMP/MSRXPL9A	9.1	80	147	10	10	5
ZS206	11.4	79	153	3	16	10
SC601	10.6	77	144	7	14	17
LSD (0.05)	1.2	7	13	NS	8	6.0

Table 11. Populations undergoing recurrent selection, CIMMYT-Harare regional program.

Population	Research target	Breeding method
INT-A	A heterotic group	S_1 x tester
INT-B	B heterotic group	S_1 x tester
LAT-A	A heterotic group	S_1 x tester
LAT-B	B heterotic group	S_1 x tester
DR-A	A group - drought	S_1 per se and S_1 x tester
DR-B	B group - drought	S_1 per se and S_1 x tester
ZM601{DR}	A group - drought	S_1 per se
ZM601{DEN}	A group - density	S_1 per se
ZM605	A/B heterotic group	S_1 x tester
ZM607	A heterotic group	S_1 x tester
ZM609	N use efficiency	S_1 per se
[MSR/Pool 9A]	Transition zone	S_1 per se

"A group" = Tuxpeño, N3, BSS, Kitale; "B group" = Eto, SC, Lancaster, Ecuador.

5

Chapter

Maize Pathology Research for the Subtropics and Highlands

D. Jeffers *

One of the major activities of the maize pathology unit is providing assistance in developing maize with host plant resistance to pathogens. To prioritize pathology activities in this area, information assembled in the 1988 mega-environments study was used to quantify the importance of diseases in the subtropical, midaltitude, transition zone, and highland maize ecologies. This information confirmed priorities previously set in the pathology program. Depending on the ability to work effectively with the diseases of concern, disease screening procedures were evaluated and the most effective methods used to screen germplasm for disease resistance. This chapter presents information on 1) the distribution and importance of the major maize diseases for the subtropical, midaltitude, transition zone, and highland maize ecologies; 2) our ability to work with the pathogens for disease resistance screening activities; 3) the levels of disease resistance available in our advanced germplasm; and 4) collaborative activities presently underway for the development and incorporation of disease resistance in CIMMYT germplasm.

Important Maize Diseases

The major diseases covered in our research on maize for the subtropical, midaltitude, transition zone, and highland maize ecologies are: the foliar diseases turcicum leaf blight, and common rust; fusarium and gibberella stalk and ear rots, and the regional diseases of maize streak virus (MSV) in Africa and the tarspot disease complex in Latin America. Other diseases occur and can cause significant local losses, but most will not be discussed in this chapter.

Turcicum leaf blight caused by *Exserohilum turcicum* (*Helminthosporium turcicum*) is distributed worldwide, and can cause yield losses of more than 60% in susceptible germplasm (Raymundo 1981). In the 1988 mega-environment data, approximately 13.5 million hectares or 59% of maize production in subtropical, midaltitude, transition zone, and highland maize ecologies were reported to experience economic losses due to this disease. In highland maize ecologies, disease development is limited by cool temperatures.

Common rust caused by *Puccinia sorghi* is found worldwide and has been reported to cause economic losses on some 7.8 million hectares or 34% of the maize in subtropical-through-

* Pathologist.

highland maize ecologies. In contrast to turcicum leaf blight, this disease is influenced less by cool temperatures and can develop in environments not favorable for turcicum blight development.

Stalk and ear rots can cause significant losses in yield, but data from the developing countries on actual losses is lacking. Several of these fungi produce potent mycotoxins which reduce grain quality and cause mycotoxicoses in both humans and livestock that consume infected grain. The most important pathogens associated with ear and stalk rots worldwide in the maize ecologies being discussed are *Fusarium moniliforme* (*Gibberella fujikuroi*), *F. subglutinans*, and *G. zeae* (*F. graminearum*), with *G. zeae* being more important in the cooler environments. In areas of Africa and Latin America, *Diplodia* spp. can also cause significant losses. Mega-environment data reported economic losses in 56 and 32% of the maize, respectively, for ear and stalk rots in subtropical-through-highland maize ecologies. MSV is important in areas of sub-Saharan Africa. CIMMYT research in breeding for resistance to this disease is discussed in detail in Chapter 4.

The tarspot disease complex, which includes *Phyllachora maydis* and the associated fungi *Monographella maydis* and *Coniothyrium phyllachorae,* is most important in the midaltitude and transition zone ecologies throughout Latin America but also occurs in cool tropical lowland conditions. Work on the disease complex and epidemiological studies were part of the doctoral research of Jens Hock and masters research of Ursula Dittrich carried out here at CIMMYT. Among other things, their work describes the sequence of events in the development of the disease (Hock et al. 1992), optimum conditions for the germination and infection by the fungi involved in the complex (Dittrich et al. 1991), its the distribution in Mexico, and the excessive leaf burning associated with *M. maydis* infection of the *P. maydis* ascocarp (Hock et al. 1989). A paper on the epidemiology of this disease complex is currently in preparation. The work mentioned above is the only information available on this disease complex besides the initial description.

Disease Resistance Screening Activities

In disease resistance screening there are two groups of pathogens with which we work. The first comprises "aggressive" pathogens which, under favorable environmental conditions for infection and disease development, allow easy screening for resistance. This group is represented by *E. turcicum, P. sorghi,* the tarspot disease complex fungi, and Diplodia ear rots under our conditions. The second group are "weak" pathogens whose development is strongly affected by environmental or biotic stresses on the maize crop. This group is represented by Fusarium and Gibberella ear and stalk rots as well as many other fungi associated with ear and stalk rots including *Aspergillus* spp. Results of disease resistance evaluations for such pathogens tend to exhibit more variability and, thus, progress in breeding for resistance has been slower than for aggressive pathogens.

Since the early 1980's there has been a major emphasis on the improvement of subtropical, midaltitude, transition zone, and highland maize for resistance to turcicum leaf blight and common rust. Working at El Batán in the summer cycle and Poza Rica in the winter, we have established artificial inoculations with E. *turcicum* to provide sufficient disease pressure for selecting turcicum resistant germplasm. Additional sites in the states of Irapuato and Jalisco were used for turcicum screening during 1986-1990. At the subtropical research station in Tlaltizapán, even with supplemental canopy moisture provided by sprinklers, turcicum leaf blight development is extremely limited in both winter and summer cycles.

Artificial inoculations are used to generate epidemics of turcicum leaf blight for disease resistance evaluations. Inoculum is grown on a sterilized substrate--partially filled oat grain, prior to 1992. Beginning in 1992, we switched to low tannin sorghum grain to improve the efficiency and uniformity of inoculations. We use a dispenser for application of inoculum. Cultures of *E. turcicum* are grown on the sorghum grain which is then air dried, sieved to get uniform particle size, and applied in the whorl of maize plants at the V5-V6 growth stage. Disease evaluations are made prior to flowering and again prior to senescence.

Common rust evaluations are carried out at El Batán where Oxalis provides abundant aeciospores for high levels of natural infection and the easy identification of susceptible plants.

Artificial inoculations have been used to eliminate germplasm that is highly susceptible to stalk and ear rots caused by *F. moniliforme* and *G. zeae*. The research is conducted at El Batán in the summer cycle, Poza Rica in the winter cycle, and Tlaltizapán in both cycles. El Batán is the most conducive for *G. zeae* resistance evaluations. An evaluation of different ear and stalk rot inoculation techniques for *F. moniliforme* has been published by Drepper et al. (1990). His work showed an improvement in infection levels using the nail punch/sponge inoculation technique over the technique previously used with the injection of inoculum into the silk channel. Work has continued to develop methods that provide higher levels of disease pressure with *F. moniliforme* ear rot inoculations. Using highly inbred materials, we are examining inoculation techniques for their effectiveness in improving ear rot development across a broad range of germplasm.

Highland grain types specific to the Andean region cannot be handled effectively in the highland maize environments of Mexico. Losses due to ear rots are quite severe, and selection for Fusarium and Gibberella ear rot resistance in this germplasm is coordinated through our South American regional office.

Stalk rot evaluations for *F. moniliforme* and *G. zeae* are carried out by placing a colonized toothpick through the first expanded internode of the stalk seven days after flowering. The stalk is split at the time of harvest to determine the extent of colonization. This technique has provided adequate levels of colonization, but bypasses the root system through which the stalk rot pathogens normally enter the plant.

Ear and stalk rot evaluations for *Diplodia maydis* and *D. macrospora* are carried out by inoculating the shank of the ear with a colonized toothpick 7-14 days after flowering and the stalks using techniques similar to those for Fusarium stalk rot. Ear rot evaluations for Diplodia can often be too severe for locating sources of resistance, and we are examining different inoculation techniques for varying the level of disease pressure. The technique described above has resulted in intermediate levels of infection.

Disease resistance screening to the tarspot disease complex has taken place at Poza Rica during the winter cycle, and from 1988-1990 at the transition zone site of Xicotepec, Puebla, during the summer cycle. Evaluations are based on natural inoculum, which provides moderate-to-severe disease pressure depending on the year.

Disease Resistance in Advanced CIMMYT Germplasm

Here I will describe the general levels of disease resistance attained in CIMMYT maize germplasm for the different ecologies. Detailed presentations on levels of disease resistance in specific germplasm are provided in other chapters.

For turcicum leaf blight and common rust, significant gains in disease resistance have been achieved since the mid-1980s, and for the subtropical pools results have been presented at meetings and in scientific articles (Smith et al. 1987; Ceballos et al. 1991). In the pathology program, eight experimental varieties were derived from pools 27-34. The varieties possess good disease resistance to turcicum leaf blight and common rust, as well as good agronomic characteristics. In the entomology program, crosses of these experimental varieties with multiple-borer-resistant materials have produced borer resistant germplasm that also possesses good levels of disease resistance. CIMMYT physiologists have worked within their semi-prolific midaltitude tropical (SPMAT) and drought tolerant (DTP2) populations to improve resistance to these two diseases (see Chapter 6). Work in subtropical advanced populations since the mid-1980s has improved their resistance to these diseases as well (1990 CIMMYT annual report), but populations differ in their potential for improvement of different characteristics. In transition zone and highland maize, several materials possess good levels of resistance to one or both diseases.

We have generally emphasized polygenic resistance. Ht genes for resistance were incorporated into several CIMMYT pools, but there has been selection against the chlorosis reaction associated with Ht1, Ht2, and Ht3 resistance genes throughout the late 1980s. We have observed reduced lesion number associated with the resistance, but have not tried to quantify any possible reduction in lesion size. Under severe disease pressure in Uganda, Population 42 was found to possess high levels of rate reducing resistance characteristic of polygenic resistance to Race O of *E. turcicum.* The population showed the same reaction to Race 1 of the fungus in trials in the USA (Adipala et al. 1992). For common rust, we have selected for both rate reducing resistance as well as reduced pustule formation. By having the alternate host for common rust in El Batán and often severe disease pressure, we have been able to develop good levels of common rust resistance.

For the tarspot disease complex, pool 9A TSR has good levels of resistance. CIMMYT research suggests that resistance to the complex is simply inherited (Ceballos et al. 1992). Tropical lowland germplasm that also possesses good resistance to tarspot can be moved into some lower elevation environments where the disease is important. We have selected over two cycles for resistance to turcicum and common rust in four tropical populations that also possess tarspot resistance. These populations now show some resistance to turcicum and limited resistance to common rust.

Improvements in resistance to Fusarium and Gibberella ear and stalk rot are more difficult to observe than is the case for foliar diseases. Through inoculations and selection for improved agronomic characteristics, we have improved resistance to ear rots over cycles of selection in some populations, while others show little if any change. With improvements in stalk quality and through artificial inoculations, resistance to stalk rot has improved. We are working to identify resistance to both ear and stalk rots in inbred materials for use as source germplasm.

All work on resistance to Diplodia ear rot has involved tropical materials, with a Diplodia population now entering its third cycle of selection by CIMMYT stress breeders. When high enough levels of resistance are attained and confirmed at test sites under high natural disease pressure, the resistance may be transferred into germplasm adapted for other ecologies.

Current Pathology Activities and Future Directions

Collaborative projects

In the highland subprogram, we are in the second year of evaluating S_2 lines from Population 85 for resistance to *F. moniliforme* ear rot at El Batán. The goal is to identify the best families for ear rot resistance and use them as source material to improve the population.

There are two projects in progress with the subtropical subprogram. Beginning in 1993A, 453 inbred lines were evaluated for resistance to *F. moniliforme* ear and stalk rot. Some 30% of these were evaluated for stalk rot under both normal density and high density conditions. During the 1993B cycle these lines were evaluated at El Batán, Tlaltizapán, and a site in Jalisco state operated by the Mexican National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) and characterized by high levels of natural stalk rot. The lines will also be evaluated at El Batán for turcicum and common rust resistance. Inbred lines from Populations 33, 44, and 45 are also under disease evaluation at Tlaltizapán and El Batán. The goal here is to locate sources of resistance, confirm their resistance through several cycles of testing, and utilize the lines as sources of resistance in population improvement and hybrid development. This cycle we have also initiated a study to look for differences in resistance to *Aspergillus flavus* ear rot in 212 inbred lines, and at the same time we will be examining different inoculation techniques for this ear rot pathogen.

In CIMMYT's East African regional program there is a collaborative project with the University of Hohenheim, Germany, and Bar-Ilan University, Israel to examine the genetics of resistance to turcicum leaf blight.

Future directions

There is a need for the continual evaluation of advanced CIMMYT germplasm in key disease hot spots, especially for stalk and ear rots. Disease pressure at our stations for *F. moniliforme* ear rot varies from cycle to cycle depending on environmental factors. There are collaborator locations characterized by high natural disease pressure. With stalk rots, our inoculation techniques bypass several barriers to natural infection. Under high natural disease pressure one could get a better evaluation of performance under natural conditions. For foliar diseases, evaluation of our materials under high natural disease pressure would allow the breeder and the pathologist to know if levels of disease resistance are sufficient. This would be very useful if there are significant differences in the aggressiveness and/or virulence of fungal isolates from different locations. At present we receive data on our materials mainly through international testing. We do not choose planting sites for the trials and rely solely on data taken and returned by the collaborator. Collaboration with selected national programs at a few key sites would improve the efficiency of this research for both national programs and CIMMYT.

There are several other diseases of worldwide economic importance with which we have not worked. For example head smut, caused by the fungus *Sphacelotheca reiliana,* affects maize production in the ecologies under discussion here. CIMMYT does not have research station where materials can be evaluated, but through collaborative efforts at locations where the pathogen is endemic, we could examine germplasm to locate sources of resistance. Common smut, caused by the fungus *Ustilago maydis,* is another disease found on maize worldwide but for which we have no information regarding possible sources of resistance.

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6
Chapter

Research on Tolerance to Abiotic Stresses in Maize for Subtropical, Midaltitude, and Highland Ecologies

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Crop physiology research in the Maize Program has among its objectives:

- Prioritizing abiotic stresses faced by maize in tropical and subtropical maize growing areas.
- Developing methodologies that will increase the efficiency of selection for abiotic stress tolerance.
- Developing source germplasm that possesses abiotic stress tolerance and which could be used to transfer tolerance to specific maize cultivars through introgression procedures.

Abiotic Stresses of Subtropical, Midaltitude and Highland Environments

We have used several methods to determine the relative importance of production constraints. The first is a survey conducted by CIMMYT on maize mega-environments, in which respondents were asked to list the biotic and abiotic challenges encountered by maize crops according to adaptation zone, maturity class, grain color and grain texture classes (CIMMYT 1988). While this approach was useful for determining the relative importance of diseases and insect pests in terms of area affected and severity of crop losses, it was much less useful for abiotic stresses. Respondents were asked to consider only the frequency and severity of drought, and the questionnaire did not attempt to assess the importance of other abiotic constraints.

The alternative method to assessing relative importance of stresses relies on the accumulated experience of breeders and agronomists from CIMMYT and from the NARS, and from various estimates of stresses in the literature. Our current ranking of the relative importance of abiotic stresses is based on our estimates of percentage loss of potential yield associated with each abiotic stress (Table 1). This suggests that the largest causes of yield loss in farmers' fields are low fertility (principally N deficiency) followed by drought and varying plant competition caused by low planting densities, weeds and by intercrops. Accordingly, CIMMYT has focused on four major areas in selecting for abiotic stress tolerance: drought, low nitrogen, soil aluminum/acidity, and offsetting the effects of variable competition. Selection for tolerance to soil aluminum is conducted by breeders based at Cali, Colombia, and is not reported here.

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Since the largest proportion of CIMMYT's target maize growing area is in the lowland tropics, about 80% of our research has been concentrated on lowland tropical germplasm and 20% on subtropical/midaltitude germplasm. We have not commenced selection for abiotic stress tolerance in highland-adapted materials, though these have been studied quite extensively from the viewpoint of adaptation to temperature and to photoperiod. Selection for low N tolerance at CIMMYT's Harare station in midaltitude germplasm is considered elsewhere in this report, but that conducted at CIMMYT, Mexico, has been largely with lowland tropical germplasm, and is not considered here. This chapter will focus on tolerance to drought and to varying plant densities, where subtropical germplasm has been used in some of the studies.

CIMMYT Research on Drought Tolerance in Elite Populations

Drought is a common phenomenon in the less developed world, where it ranks second to soil infertility as the most severe limitation to maize production. Annual yield losses due to drought are thought to average 17% per year (Table 2), but in specific locations they can be far greater. During 1991-92 southern Africa experienced its worst drought this century, with maize grain production declining in Zimbabwe by 77%, Malawi by 62%, South Africa by 60%, and by 60% for the region as a whole (Rosen and Scott 1992).

Breeding for drought tolerance requires knowledge of the target environment. A typical tropical maize crop season follows a well-defined dry period. Mean rainfalls often appear adequate for production, but rainfall distribution is characterized by high variability, both within and between years. Yield is often reduced by an uncertain start to the rains, when crop stand may be severely affected. As mentioned in Chapter 2, CIMMYT has selected in highland maize for the ability to emerge from depths of 20 cm through dry soil, but selection has only recently begun in lowland germplasm for improved establishment in dry soil from normal sowing depths. Further yield reductions result from intermittent dry spells that can occur throughout the season, but these are unpredictable, and a drought-tolerant variety, if it is to gain farmer acceptance, must also perform well in the estimated 40% of years when rainfall is adequate. A breeding objective, then, is to improve grain yields under drought at no cost to yields under well watered conditions.

Maize grain yield and drought stress

Grain yield under stress is normally more highly correlated with kernel number per plant than with individual grain weight. Although we recognize the importance of maintaining functional leaf area during terminal drought stress, our major focus has been on events which occur during the flowering period, when ears per plant and grains per ear are determined. Maize is unusually susceptible to drought stress at flowering. In part this is because male and female flowers are separated by 30-100 cm, because silks must extend by up to 30 cm to escape the husk, and because pollination demands that delicate stigmatic tissue and pollen grains are exposed to a desiccating environment. A characteristic of maize under environmental stress is an increase in the anthesis-silking interval (ASI).

Recent evidence from temperate hybrids suggests that direct effects of pollen supply on grain number per plant can be expected only when pollen production is reduced by 80%, or when ASI exceeds 8 d (Westgate and Bassetti 1990). In open-pollinated varieties with greater variation in flowering date, an ASI of 10-12 d could probably be tolerated before pollen supply would limit grain set. Pollen viability is normally little affected by plant water status, but is significantly reduced by temperatures greater than 38-40°C. Tassel blasting (failure to extrude anthers) is also observed in the field at these temperatures when the atmosphere is dry.

Severe water stress prior to flowering can result in the failure of the developing ovule. Silk growth is very sensitive to turgor and follows leaf water status quite closely. In some circumstances slow-emerging silks may enter a senescent phase and abscise from the ovule prior to fertilization, though this is not thought to be a major source of yield loss under drought (Westgate and Bassetti 1990). When late-emerging silks on drought stressed plants are pollinated, fertilization can be shown to have taken place, but grain development is arrested shortly afterwards (Grant et al. 1989), giving rise to patchy grain formation, bare ear tips or complete barrenness. The greatest reduction in grain numbers per plant under drought occurs within the first 2 wk after pollination (Grant et al. 1989). The reserves of labile carbohydrate in the maize plant at silking are comparatively small, and the capacity of newly-fertilized ovules to attract these reserves is limited. Thus Boyle et al. (1991) were able to offset most of the effects of drought stress at flowering by infusing the stems of stressed plants with a sucrose-rich solution. We conclude that the continuing development of fertilized ovules is related to the *flux* of assimilates from current photosynthesis (Schussler and Westgate 1991) rather than to the concentration of carbohydrates in the stem or even in the developing kernel (Westgate and Boyer 1985). The problem of reduced grain number per plant under drought thus seems more chemical than physical in nature (Boyer 1992), and silk delay may rather be a symptom of reduced assimilate flux than the direct cause of barrenness.

Recurrent selection for drought tolerance in 'Tuxpeño Sequía'

Although Tuxpeño Sequía is adapted to the tropical lowlands, progress in breeding for drought tolerance in this population has provided the justification for continued selection under drought in a wider range of germplasm. For this reason selection methods and results are briefly considered here.

The population 'Tuxpeño Crema I' C_{11} underwent eight cycles of recurrent full-sib selection in the cool, virtually rain-free winter crop season at Tlaltizapán (19 °N, 940 masl), México, where timing and intensity of stress can be managed by irrigation. Each of 250 families was grown in single-row plots under three regimes of increasing drought intensity: well-watered (WW); intermediate stress (IS), where water was withdrawn during late flowering and throughout grain filling; and severe stress (SS), where no water was applied from approximately 3 wk before silking to maturity. Yields under each regime were approximately 100%, 65% and 25% of well-watered potential. In addition to grain yield, we measured the relative extension of leaf and stem under WW and SS regimes, ASI, canopy temperature, and scored for lower leaf senescence. We attempted to maintain anthesis dates constant in the selected fraction to avoid selecting early-flowering "escapes". The best 80 families for recombination at a lowland site, Poza Rica, were identified using an index of traits thought to describe a plant which could access a greater volume of soil water.

Selection resulted in a significant increase in grain yield (108 kg ha^{-1} $cycle^{-1}$) at yield levels ranging from 1 to 8 t ha^{-1}, with no significant interaction between rate of gain and yield level (Bolaños and Edmeades 1993). At a yield level of 2 t ha^{-1} this represents a gain of 6.3% $cycle^{-1}$, compared with 2.3% $cycle^{-1}$ at a yield level of 6 t ha^{-1}. These data suggest that selection has resulted in a 20-40% increase in yield for a farmer whose yields have been reduced from 6 to 2 t ha^{-1} by drought occurring near flowering and during grain filling.

Improvement of drought tolerant germplasm for midaltitude environments

Encouraged by these results, CIMMYT commenced selection for drought tolerance in five additional elite tropical maize populations, four of which are adapted to the lowland tropics. The fifth population is ZM601, a midaltitude tropical white dent derived from a cross of Population 92 from East Africa and La Posta. This streak resistant population is being handled out of CIMMYT, Harare; we provide two drought stress environments for S_1 families in Tlaltizapán in the winter.

A recurrent S_1 selection scheme is used, in which a large number (600-1,500) of S_1 families are prescreened under summer drought and heat stress in the Sonoran Desert near Ciudad Obregón, northern Mexico. The superior 200-250 families are grown in Tlaltizapán during winter from remnant seed under two water stress regimes (intermediate and severe stress), and also in Zimbabwe at two locations, one moist and one dry. The best 50 families are recombined in Mexico to form the subsequent cycle of selection. Canopy temperature and relative leaf and stem extension rate were replaced as secondary selection traits by upright unrolled leaves, small tassels, and lodging resistance, while grain yield, ASI and "staygreen" under stress were retained as the principal traits on which selection was based.

Selection environments -- Each of the managed selection environments used has a specific purpose. The dry heat of Obregon (temperatures often exceed 37°C) exposes lines susceptible to upper leaf firing and tassel blasting. At Tlaltizapán the IS regime exposes genetic variability for lower leaf senescence and for grain yield. Under the SS regime, observed variability for grain yield is small, but this stress exposes variability for ears per plant and ASI. There is little variation from 1.0 in ears per plant in these predominantly single-eared populations until stress applied at flowering becomes severe. Plots managed in this way are not attractive in appearance, but the method provides an unique opportunity to expose genetic variation for partitioning of current assimilate to the ear at flowering. The nurseries in Zimbabwe allow the maintenance of yield potential and adaptation to the target environment, especially in terms of disease resistances.

Selection criteria -- The evaluation of S_1 families in replicated yield trials has allowed us to examine broad-sense heritabilities for various traits at different yield levels. We found that heritability for grain yield remained in the range of 0.5-0.6 until yields were reduced by drought to below 20% of the well-watered control. At these low yield levels the genetic correlation between grain yield and ASI approached -0.80, and that for grain yield and ears per plant increased to 0.90, indicating that ASI and ears per plant were good surrogates for grain yield in these environments. In fact, the heritability of ears per plant, unlike that for grain yield or ASI, increased with declining yield levels.

Preliminary unpublished data suggest that realized heritabilities of leaf extension rate, canopy temperature, and leaf chlorophyll concentration are low, and that those for leaf erectness, tassel size, senescence scores and ASI are relatively high. Of these, only reduced ASI and occasionally small tassel size appear to have significant adaptive value under drought. Delayed senescence during grain filling, cool canopy temperatures and upright leaves we also consider worth including in an ideotype of a stress-tolerant water-efficient tropical maize plant growing in a competitive situation.

On the basis of these results, superior families are those which maintain yield in all environments, and have well synchronized flowering, delayed senescence, small tassels, and appropriate disease resistances. These traits are combined with the maintenance of maturity and desirable agronomic characteristics.

Evaluations of progress -- No evaluations have taken place in ZM601, since only two selection cycles have been completed. During the severe regional drought of 1992, however, ZM601 drought selection was the highest yielder in variety trials conducted at the severely stressed site of Makaholi (K. Short, pers. comm.).

Development of Source Populations for Drought Tolerance

Research thus far described has been directed to elite populations in the belief that "drought adaptive alleles exist at relatively high frequencies in common breeding populations" (Blum 1983). In order to sample a wider array of alleles we have screened over 200 landraces collected from areas in Latin America with less than 500 mm of rainfall and from elevations of less than 1000 m. The best of these were compared with hybrids and populations having reputed drought tolerance from the US, South Africa, Zimbabwe, Kenya, Thailand and Nigeria. On the basis of superior performance under drought at Tlaltizapán, we recombined 13 sources to make the Drought Tolerant Population-1 (DTP1) in 1987. After several cycles of half-sib selection, and further screening, 25 additional elite sources were introgressed into DTP1 in 1990 to form DTP2. Only 5 landraces are represented in the parentage of DTP2, contributing a total of 13% of the germplasm. Both DTP1 and DTP2 are intermediate in maturity, mixed in grain type and color, and are, respectively, targeted for the drought-prone areas in the lowland tropics and subtropics.

The composition of DTP2 by ecological class is as follows:

1. DTP1 (various cycles)	58%
2. Lowland tropical	27%
3. Subtropical	7%
4. Temperate	8%

Combining the adaptation of DTP1, which contributed 58% of the germplasm forming DTP2, gives the following adaptation breakdown for DTP2:

Lowland tropical	65%
Subtropical	15%
Temperate	20%

These drought tolerant populations will ultimately provide lines and varieties which may occasionally be used directly, but in most cases will be crossed with locally-adapted materials. At the outset it was considered unlikely that such a population would ever be used for direct release. Reasons for this relate to the almost impossible task of delivering in "final product" form an array of traits which a specific environment may require. This is particularly true for disease resistance. In trials, Populations DTP1 and 2 flowered 4-5 days earlier than late lowland tropical entries, but nonetheless are fully competitive with them for yield under a wide range of moisture stresses. At present DTP1 is being improved internationally through a network of collaborators, and white and yellow versions are being formed. S_1 families have been formed in DTP2 C_4 for testing in subtropical environments. These families are also being screened for drought and heat tolerance in Obregon, and for resistance to *E. turcicum* and *P. polysora* in El Batán.

Drought testing network for the improvement of source populations

CIMMYT has established a network of national program collaborators. It is made up of individuals in national programs (mostly public) who share an interest in developing drought tolerant maize germplasm. The network is coordinated by CIMMYT, under the auspices of the UNDP Maize Stress Project, and provides a vehicle through which information and methodologies can also be shared.

We have identified two types of network cooperator. The first and larger group comprises researchers who are primarily interested in testing synthetics and varieties that are being developed within the network. Generally they will conduct such tests in the normal rainy season and will contribute locally adapted drought tolerant varieties for testing across a wider range of sites by other collaborators. We refer to these as **testing cooperators**. A second smaller group of cooperators will concentrate on the development of drought tolerant germplasm through a recurrent testing scheme of S_1 (or full-sib) families under conditions of carefully controlled drought. The development of population(s) will be coordinated from CIMMYT with national program help. Populations are open-ended, and introgressions of superior germplasm will take place from time to time as appropriate. We refer to this group as **development cooperators.**

Participants are currently testing the second cycle of S_1 families of DTP1 and the elite selections from each of the drought tolerant populations as synthetics, under their local conditions of drought. CIMMYT provides collaborators with remnant S_1 seed and seed of cultivars on request, and forms site-specific synthetics for subsequent testing by national programs. Outstanding local check cultivars identified through this testing procedure will be incorporated into the DTPs during the next round of introgression.

Subtropical and midaltitude sites used in testing included:
1990: Harare, Zimbabwe; Golden Valley, Zambia; Tucuman, Argentina; Tlaltizapán, Mexico (winter; 3 moisture regimes)
1993: Makaholi, Zimbabwe; Golden Valley, Zambia; Katumani, Kenya; Awassa, Ethiopia; Tlaltizapán, Mexico (winter; 3 moisture regimes); Giza, Egypt

Training course on selecting for drought tolerance
From March 8 through April 2, 1993, 19 network participants from 15 countries attended a short course that consisted of lectures on the physiology of drought stress, sources of germplasm, field management of water stress, selection indices, incomplete block designs and their analysis, soils and soil management to reduce stress levels. Lectures were supplemented with hands-on training in computer techniques and five days of field work in nurseries subjected to drought.

Developing Germplasm that Tolerates Variable Levels of Competition

While plant densities are well-controlled and quite uniform in the US and in Europe, this is not so in the developing world. It is common to find plant densities ranging from 20,000 plants/ha in Africa, where intercrops are common and plant establishment sometimes poor, through to >100,000 plants/ha in Asia, where the crop may serve both as a source of fodder (from thinnings) and of grain. One means of stabilizing grain yields across a wide range of densities is to introduce flexibility into the yield structure of maize. For this reason we have formed three semiproplific populations which are simultaneously selected for prolificacy and yield at low densities, and for yield and resistance to barrenness and lodging at high plant densities. These are:

Semiprolific Early (SPE): lowland tropical intermediate white flint/dent, with average ears per plant of 1.7 at normal densities.
Semiprolific Late (SPL): lowland tropical late white flint/dent, with average ears per plant of 1.6 at normal plant densities.
Semiprolific midaltitude tropical (SPMAT): subtropical, late mixed grain color and type, average ears per plant 1.6 at normal plant densities.

We define prolificacy as the tendency to have more than one ear per plant at normal plant densities. Prolific genotypes tend to be more stable across density levels and in response to a range of stresses (Russell 1968; Prior and Russell 1975; Motto and Moll 1983; Coors and Mardones 1989). Prolificacy has increased in US germplasm over the years, probably because of the consistent use of high plant densities in breeding nurseries (Duvick 1984). In developing countries the trait is not without its problems: increased work at harvest, saving the largest ears for seed quickly returns to single-eared types, prolific plants are often tall, and two-eared plants often lodge. In this writeup, we will concentrate on SPMAT.

Population formation -- The original families comprising SPMAT were selected in 1985, on the basis of their observed prolific tendencies. The population was formed from lowland tropical yellow families (54%) and midaltitude tropical whites and yellows (46%) from a total of 44 separate components. Those which provided the largest contribution were the subtropical Population 45 (14%) and Population 44 (13%), and the lowland Population 26 (9%). An additional subtropical sub-population was handled separately for four cycles. It was originally a cross between B73 and a US *Tripsacum* source backcrossed to lowland tropical germplasm. This population has now been introgressed into SPMAT.

Breeding methodology -- Components were mixed by planting each family (230-450 in total) in two densities in the field; a 5-m low density (LD; 35-40,000 pl/ha) plot and a high density plot (HD; 106,000 pl/ha) in a half-sib recombination block. Data were passed through a selection index which identified families that show:

- Many second ears at LD
- Many ears per plant at HD and good standability
- High grain yield at HD
- A short interval between first and second ear silking at LD
- Low lodging at HD
- Average plant and ear height, especially at HD
- Disease resistance

After 4 cycles of mixing and selecting in this manner, an evaluation of progress against elite checks was conducted at three densities and in three environments (Table 3). The results showed that considerable progress had been made in increasing grain yields of second ears, at some cost to first ear yields. Associated with this was a slight increase in lodging at high plant density. The optimum density for grain yield did not increase, nor did the grain yield at that optimum, or yield at high plant densities. Ears per plant at low density increased in SPMAT but not in the maize x *Tripsacum* population. There was a reduction in the interval between first and second ear silking dates. Thus from the very mild selection applied to these materials during recombination, no changes in stress tolerance occurred but there was a considerable increase in prolificacy.

Following recombination, the breeding methodology was changed to a recurrent S_1 scheme in which 500 S_1 families are sown for observation purposes in a unreplicated nursery, and the next cycle the best 144-200 S_1 families (selected for disease resistance and prolificacy) are sown at HD and LD in paired plots at 40,000 and 106,000 pl/ha. ASI, silk synchronization, lodging, tassel branch number, yields and yield components of first and second ears at high and low density are recorded. We use an alpha (0,1) lattice design in two replications for these trials.

An evaluation of progress following two complete cycles of recurrent S_1 selection is planned. SPMAT has shown value as a source of yield potential in the subtropical breeding program, where it is performing well in crosses. It has shown good *per se* performance also, coming in fourth out of more than 40 entries in the 1991 Preliminary Evaluation Trials. For this germplasm to be directly useful, additional disease resistance will be required, especially to *E. turcicum* and *P. sorghi.* The population SPL has found a use in the low plant density intercropping environments of the Guinea savannah of West Africa, and the International Institute of Tropical Agriculture (IITA) has requested permission to convert it to streak resistance, as SPL-SR.

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Table 1. The relative importance of abiotic stresses experienced by maize in farmers' fields, by ecology. Numbers are percentage annual yield losses compared with an unstressed condition. Total losses represent average decline in yield from the potential yield of improved germplasm grown in the specific ecology.

Constraint	**Lowland tropical**	**Midaltitude and subtropical**	**Highland tropical**
		Percentage loss	
Drought	15	15	19
establishment	4	6	8
mid-season	7	7	3
terminal	4	2	8
N deficiency	16	13	13
P deficiency	4	5	6
Soil acidity/Al	4	4	2
Variable density	4	3	3
Competition (weeds, intercrops)	10	8	8
Cold temperatures	2	4	4
Heat	3	3	3
Waterlogging	5	3	3
Salinity	1	2	2
Total abiotic	**64**	**60**	**63**
Biotic stresses	*15*	*17*	*20*
Total all stresses	**79**	**77**	**83**

Table 2. Estimated annual loss of maize grain yield due to drought in the less developed world (excludes central and northern China). Sources: CIMMYT 1988; CIMMYT 1992.

	Area	**Yield loss due to drought**	
	(000 ha)	**(%)**	**(000 t)**
Highland tropical	3,273	28	2,199
Transition[a]	2,301	7	435
Subtropical[b]	16,632	15	7,734
Lowland tropical	32,720	15	8,834
Temperate	5,186	23	4,890
Developing world	**60,561**	**17**	**24,092**

[a] Transition area lying between mid-altitude tropical and highland tropical ecologies
[b] Includes mid-altitude tropical ecology

Table 3. Changes in grain yield and other traits between Cycle 0 and Cycle 3 of two subtropical populations undergoing half-sib recurrent selection for prolificacy, when evaluated at three locations and three plant densities in three environments in Mexico, 1988.

Entry	Grain yield Low density — (kg/ha) —	Grain yield Opt. dens.[a]	Opt. dens. (pl/m^2)	Days to 50% anthesis[b] — (d) —	S2-S1[c]	Lodging Root — (%) —	Lodging Stem	Ears per plant, low density	Yield of second ear, low density (kg/ha)
Semi-prolific mid-altitude tropical (SPMAT)									
C_0	3,923	5,249	7.22	81.0	47.2	6.2	9.1	1.31	367
C_1	4,352	5,518	6.98	80.7	43.7	5.7	7.3	1.45	626
C_2	4,110	5,235	6.66	83.7	28.8	7.8	4.5	1.49	678
C_3	3,961	5,200	6.82	82.6	29.0	8.7	10.6	1.68	801
Maize x *Tripsacum population*									
C_0	3,663	5,087	7.81	80.9	35.4	6.0	7.2	1.72	815
C_1	3,866	5,030	6.96	80.3	27.4	6.7	8.2	1.62	853
C_2	3,760	5,082	7.58	80.5	41.5	5.1	7.3	1.51	801
C_3	3,474	4,993	7.77	80.2	30.2	3.9	6.6	1.60	829
Checks									
Across 7845 (RE)	3,438	4,470	6.73	80.6	58.2	6.4	5.6	1.10	46
FS 854[d]	3,738	5,395	9.75	82.5	24.4	1.9	11.6	1.39	292
LSD (0.05)	723	611	1.93	1.00	22.8	4.0	4.0	0.21	319

[a] Optimum density for grain yield and grain yield at optimum density calculated by method of Duncan (1958) using data collected at three plant densities: low (2.7 plants m^{-2}), intermediate (5.3-6.7 plants m^{-2}), and high (10.6-13.3 plants m^{-2}).

[b] Days to 50% anthesis, recorded at two sites only, average across all densities.

[c] Interval between 50% silking of the first and second ears at two sites only.

[d] A Corn Belt hybrid.

7

Chapter

An Overview of Applied Biotechnology Research at CIMMYT

D. Hoisington and D. González de León *

With the completion of the applied biotechnology building in 1989, CIMMYT's efforts in biotechnology were enhanced to include the use of molecular marker technology for locating and manipulating the genes involved in traits of agronomic importance. These efforts are the focus of the applied molecular genetics laboratory (AMGL). More recently, the applied genetic engineering laboratory (AGEL) was established to take advantage of recent advances in maize and wheat transformation. All activities in biotechnology have the general mandate of enhancing the success of the breeding programs, either through more efficient selection techniques or through enhanced germplasm. Technology evaluation and adaptation for use at CIMMYT and in its client countries, training and technology transfer, and collaborative research all play a part in helping reach the goals of the group. Already, the group has provided both short- and long-term training to scientists in Mexico as well as several other developing countries in the areas of molecular marker technology and tissue culture. More formal course offerings are anticipated during the coming years.

Achievements

The AMGL has concentrated in the last two years on establishing efficient protocols for the use of marker technologies in wheat and maize. Among other things, we have made significant progress in four aspects of protocol development:

- Use of non-radioactive DNA hybridization techniques to provide a safer working environment
- Adaptation of RFLP and other marker techniques for large-scale analyses
- Optimization of cost-effective experimental strategies
- Development of software for fingerprinting databases, molecular data capture and verification and cost analysis

Current collaborative research in maize includes the evaluation of genetic diversity of tropical, subtropical, highland and African germplasm. The database contains molecular fingerprints for over one hundred lines. This information has improved CIMMYT breeders' understanding of the heterotic groupings and allowed them to develop more appropriate testers for germplasm

* Head, applied biotechnology; head, applied molecular genetics.

improvement. Another major study involves the genetic base of resistance to multiple corn borers using RFLP genotyping and field evaluations of several populations segregating for resistance. Results to date indicate that the resistance is polygenic and primarily additive in gene action. It is expected that RFLP markers can be used to facilitate the incorporation of resistance into elite germplasm, thereby increasing efficiency and reducing costs. A third project focuses on tagging the genes associated with anthesis-silking interval (ASI), given the relationship that CIMMYT research has established between drought tolerance at flowering and a reduced ASI under drought stress. Molecular markers will probably become routine breeding tools at CIMMYT within the next two years; requiring a "service-oriented" laboratory to handle the volume of requests expected for molecular analyses.

The AGEL ultimately seeks to enhance the resistance of tropical maize to major insect pests through transformation technology. Initially, several major tropical, subtropical, highland and African CIMMYT lines are being evaluated for embryogenic callus formation and regeneration potential. In the last two years, the program has identified several lines from each environment with high regeneration capacity which can be used in transformation experiments.

The laboratory has also been conducting insect bioassays of partially-purified toxins from *Bacillus thuringiensis* (Bt) strains collected in Latin America in collaboration with the Mexican plant molecular biology institute, CINVESTAV. Four of the most important Lepidopteran insect species in the tropics are being used in the bioassay. A similar collaboration is underway with the maize breeding station of EMBRAPA in Sete Lagoas, Brazil using insect species of importance to Brazil as well as Bt strains collected from the South American continent. Collaborations are also being sought to screen toxins coded for by cloned Cry II and III genes.

Efforts in maize transformation as well as collaboration in several developing and developed country institutions will be enhanced this year with the recent approval of a special project under UNDP funding. It is expected that transformation will provide the breeders with another method for enhancing the genetic composition of their germplasm.

Challenges for the Future

The main challenge faced by the biotechnology group is identifying and prioritizing the topics it should address. Priority setting with the Maize and Wheat programs plays an extremely important role in making sure that the group is focused on the highest needs of the programs. Periodic discussions with the breeders are also important in deciding future needs and providing the breeders with progress reports.

To date, the Maize Program has "shortlisted" thirteen breeding objectives in order of importance, for continuining and developing specific projects in collaboration with the Applied Biotechnology Laboratories. These include the work mentioned above on insect resistance and ASI, as well as research on resistance to maize streak virus (MSV), downy mildew, and various other biotic and abiotic stresses.

Biotechnology is one the most rapidly evolving areas of science in CIMMYT. Keeping abreast of current achievements and approaches in molecular biology and transformation technology is one the challenges faced by CIMMYT scientists. Ensuring that these new technologies are effectively applied to improving breeding methodologies will probably be our most demanding challenge. CIMMYT will continue to maintain its applied approach to biotechnology. If more basic research is necessary for application at CIMMYT, collaborative projects will be developed with other institutes.

Continuous reassessment of the prospects and progress in biotechnology will be necessary in order to make sure that CIMMYT's activities are appropriate and adequate to meet the demands of the breeders.

8

Chapter

The Use of Geographic Information Systems to Characterize Target Environments

J.D. Corbett *

Agroclimatological evaluation and geographic information systems (GISs) offer tools which greatly improve the targeting of germplasm products and provide information to help prioritize breeding efforts.

The map on page 86 highlights midaltitude tropical and transition zones in Mexico. These zones were identified from interpolated climate variables and offer a first look at the spatial distribution of germplasm-specific adaptation zones.

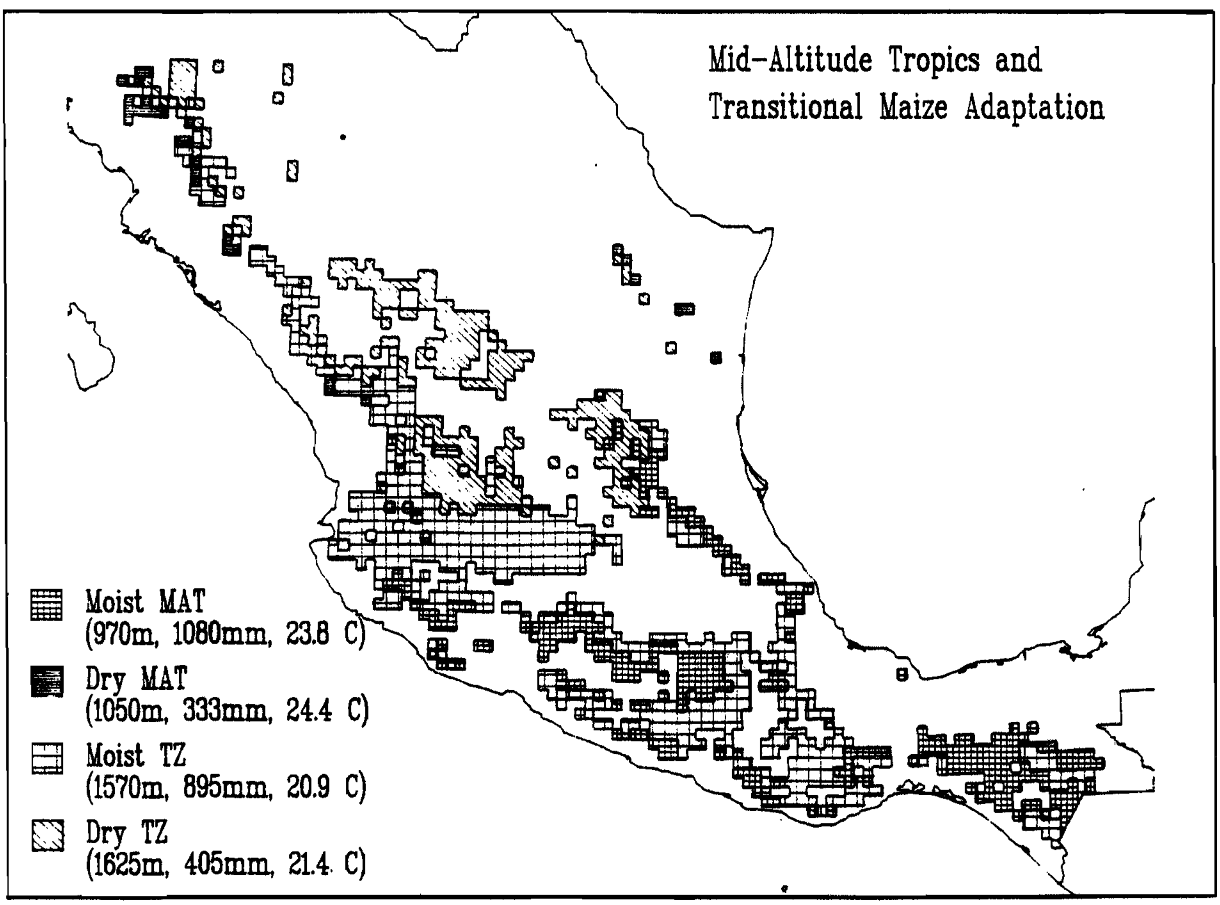
A GIS provides the mechanism (software) to link databases which are arranged by latitude, longitude, and elevation (or "geo-referenced"). Perhaps the database of most obvious importance to the Maize Program would be the spatial distribution of maize production areas. For targeting germplasm, a classification of production zones by maize adaptation is the next step; e.g., transitional vs midaltitude tropical. Linked to actual production data (for Mexico, 1989 area planted by development district), the relative importance of each adaption zone can be ascertained. Combined with an evaluation of abiotic and biotic stresses and tied to production system and economic data (resource access, population, etc.), it is possible to devise a weighting system by which the activities of each subprogram can be more accurately assessed.

These spatial databases assist with the priority setting from an administrative view point, but they also allow the identification of like areas for subsequent adoption of improved technology. For example, an improved variety is characterized by a set of traits which reflect specific selection goals, from pathogen resistance to grain color/texture and maturity. The extent of areas where such selection goals are applicable can be precisely identified and an improved variety can thus be developed for a well defined environment.

Finally, such databases contribute to the characterization of trial sites. Locations may be selected based on the efficiency they provide in screening for specific traits; i.e., sites are quantifiably representative of a target production environment.

* Agroclimatologist.

The midaltitude tropics are characterized by broad temperature requirements (22-24°C mean season temperature), whereas the transition zone (from midaltitude tropical to highland tropical) has cooler temperatures, though noticeably warmer than the tropical highlands. An agroclimatological investigation using GIS tools will allow the construction of additional databases. Armed with such databases, plant breeders, agronomists, and physiologists can easily access a range of geo-referenced information, including daylength, temperature, precipitation, radiation, and humidity. By analyzing growing period, researchers can build more spatially related databases (growing degree days to a physiological stage, warming/cooling, moist and drying trends). Simulation models offer a breadth of potentially useful, geo-referenced information (abiotic and biotic stress risk, yield potential). Finally, ties to the Maize Program's trial database (the location of the trial sites provides the link) means that the full featured spatial dataset is linked directly to a wealth of trial data. In this manner, the yield of a given EVT can be viewed in relation to the same EVT in a different location while tied to climate and stress databases. The information offered by these tools enhances both the generation of improved germplasm and the administration of CIMMYT's research resources.



9

Chapter

International Testing and the Adoption of Subtropical, Midaltitude, and Highland Germplasm

G. Srinivasan *

Over 40% of the total maize area in the developing world (excluding temperate China and Argentina) comprises subtropical, midaltitude, or highland ecologies. The subtropical environments are generally served by relatively strong national programs and are also the focus of several private and multinational seed companies. The interest shown by the private sector in recent years reflects the demand for more hybrid-oriented products in the subtropical ecologies. However, there is also an increased demand for early maturing subtropical materials, particularly from the public sector for use in marginal areas.

Highland environments with more than 100,000 hectares are found in at least a dozen developing countries. As mentioned in Chapter 2, these ecologies are characterized by large G x E interactions and low adoption of improved varieties by farmers. However, the trend is changing in certain countries like Mexico, where several private seed companies are starting to develop improved varieties and hybrids for the highlands, especially using CIMMYT's improved germplasm.

The CIMMYT Maize Program has developed and improved several pools and populations in the last two decades to suit subtropical and highland environments. Work on midaltitude germplasm is concentrated at CIMMYT's regional research station at Harare, Zimbabwe.

The Role of International Testing in Germplasm Improvement and Dissemination

International testing of CIMMYT maize germplasm has three basic functions:

1. It serves as a mechanism for breeders to test the progenies from a population through the network of International Progeny Testing Trials (IPTTs) in varied environments and identify superior performing families for selection and further population improvement.
2. It helps breeders to form open-pollinated products such as experimental varieties and synthetics based on the IPTT results and to evaluate their performance in

* Head, maize international testing.

Experimental Varietal Trials (EVTs) and Elite Variety Trials (ELVTs) in a large number of diverse environments. The superior germplasm thus identified is used by national programs in breeding work or released directly to farmers.

3. For many national programs, international trials serve as a demonstration/advertisement of CIMMYT's improved and most recent maize germplasm. This is especially important for cooperators who are evaluating CIMMYT germplasm for the first time.

International Testing of Subtropical Populations

The CIMMYT Maize Program put together several gene pools and populations in the late 60s and early 70s for different ecologies. Realizing the importance of systematic testing to refine and disseminate this improved germplasm, CIMMYT began global testing of its maize products in 1974. During the first year, progeny trials from 28 populations were sent out. These were given trial numbers 21 to 48--the first 20 numbers were reserved for experimental varietal trials, trials from the bank, etc. Eight of the progeny testing trials comprised subtropical populations. Over time, trial number became synonymous with population number; for example, "Trial 33" was later known as "Population 33." Some of the populations have been removed from the international testing and population improvement system for reasons such as lack of demand, slowing down of genetic gain per cycle, etc. Population 33 and 48 were removed after 1988. Currently six subtropical populations are undergoing improvement through IPTT. They are Populations 34, 42, 44 and 47 of white grain type and Populations 45 and 46 of yellow grain type. (Table 3, Chapter 1, and Table 2, Chapter 2, list populations that are currently in the international testing system.)

During the first two years of international testing, populations were evaluated each year as they were formed by recombining the best full-sib families based on international testing data. Starting in 1976, a modified full-sib recurrent selection procedure was implemented, requiring four cropping seasons--or two years--to complete one cycle. These populations have undergone several cycles of improvement through the international testing system with emphasis on yield, stability, disease resistance and other characters.

In the mid-1980s a USAID/USDA funded project involving maize breeders from US universities and CIMMYT looked critically at international testing data to evaluate progress in population improvement. The team found no evidence of reduced genetic variability in the populations, despite their having undergone several cycles of improvement (Gardner et al. 1990). They attributed this to the broad genetic base and considerable genetic variability of CIMMYT populations. They also noted that the populations had become more broadly adapted as a result of international testing and that yield increases observed were due mainly to the elimination of deleterious genes, reductions in plant height, and increases in harvest index.

Progress from full-sib recurrent selection in four subtropical maize populations was reported by Eaton et al. (1990). Gains in grain yield ranged from 3.8 to 4.6% per cycle for the different populations. Three of the four populations had reduced stalk lodging and improved resistance to the foliar pathogens.

Experimental Variety Trials (EVTs) and Elite Variety Trials (ELVTs)

Yield and agronomic data from each IPTT site are used to identify the best 10 full-sib families for formation of experimental varieties (EVs), which are used as entries in EVTs. These are developed by making plant-to-plant crosses among the selected families in all possible combinations, and advancing to the F_2 stage by bulk pollination. EVs are assigned a name that indicates the year and location in which the IPTT was grown, as well as the number of the population. The EV "Tlaltizapán 8844," for example, was developed from the 10 best families of IPTT 44 tested at Tlaltizapán, Mexico in 1988. In addition, a site-specific EV can be formed upon request from the cooperators who have found certain families to be superior, based on field observations of characteristics of importance to them. In this case a number is inserted in parentheses after the name of the test location, as in TakFa (1) 8742. For each IPTT one experimental variety, termed an "Across EV" is formed on the basis of combined data from all sites reporting results. An example is Across 8842, which was developed on the basis of 1988 IPTT 42 results from six sites.

EVTs are organized according to ecological adaptation (tropical, subtropical, highland), maturity, and grain color. EVs derived from subtropical populations are included in two different types of EVTs. EVT 16A includes varieties derived from subtropical populations with yellow grain color, whereas EVT 16B includes varieties derived from subtropical populations with white grain color. After international evaluation of the EVT, the best (elite) entries from these two EVTs are further tested in ELVT 20. Varieties derived from highland populations are tested in EVT 17. These trials typically include 10-to-20 new EVs, 2 stable high yielding EVs from previous years (termed reference entries), and 2 local checks supplied by the national programs. Distribution of EVTs began in 1975 and in any year each EVT/ELVT will be tested at 30-60 sites, depending on the demand from cooperators. In recent years, we have tried to include promising special purpose materials and stress-tolerant germplasm in these trials.

The distribution of subtropical and highland EVTs and ELVTs is represented in Figure 1. There was unusually high demand during 1988 for both EVTs and ELVTs due to increased participation of South American countries. In approximately 60% of the subtropical and highland variety trials, CIMMYT varieties performed equal to or better than the local check (Fig. 2). This is slightly lower than the corresponding figure for tropical EVTs. This is mostly due to the fact that in many of the subtropical ecologies, hybrids are becoming more popular and usually the local checks included are the best hybrids available in the market.

Stability for Yield in Subtropical Experimental Varieties

CIMMYT devotes considerable effort to producing stable, high-yielding varieties that perform well over a wide range of environments. The IPTT system used for population improvement was designed with this objective in mind. Several studies have shown that in both tropical and subtropical ecologies, CIMMYT's experimental varieties have shown considerable stability for yield performance.

Using principal coordinate analysis, Crossa et al. (1989) examined the yield stability of varieties from subtropical EVTs (EVT 16, EVT 16A, and EVT 16B) conducted during 1979-1983. Varieties from Blanco Subtropical (Population 34) were stable at low yielding sites, whereas Amarillo Bajio (Population 45) and Eto-Illinois (Population 42) produced a greater number of varieties that gave stable yields under both favorable and unfavorable conditions. Some selections based on multilocation data showed good stability across years in both low and high yielding sites. However, they noticed that across-site EVs were not always more stable than site-specific selections. Varieties formed at Tlaltizapán (Mexico) and Chuquisaca (Bolivia) were found to be more stable in many regions.

In another study, Crossa et al. (1990) utilized the Additive Main Effects and Multiplicative Interaction (AMMI) method to look at the G x E interactions in EVT 16A grown in 1984 in 36 environments. Results showed that AMMI increased the precision of yield estimates equivalent to increasing the number of replications by a factor of 4.30, and AMMI provided much insight into G x E interactions in these materials. This study also confirmed that varieties from Population 45 showed high yield response and were more stable across sites than varieties from other populations.

Adoption of CIMMYT's Subtropical Germplasm

Best performing EVs selected from the EVTs and ELVTs are utilized by national programs in various ways. They are sometimes released with little or no modification. In most cases, though, they are utilized in the breeding program for introgression, further testing and improvement or as parents in crosses. Upon request the cooperators are provided with sufficient quantity of nucleus seeds of the EVs for further seed increase and utilization.

In 1990, CIMMYT's Maize and Economics programs conducted a joint study to determine the adoption and impact of CIMMYT maize germplasm in developing countries. The survey showed that 133 varieties with subtropical / midaltitude or highland adaptation were released by the national programs during 1965-1990 based on CIMMYT germplasm. The origin of these releases are shown in Figure 3. A large number of releases (94) contained some CIMMYT germplasm, followed by 23 varieties selected from CIMMYT trials and 16 varieties which were direct releases of CIMMYT EVs. By region, the largest number of releases occurred in Asia (50), followed by West and North Africa (32) and South America (25) (Fig. 4).

The use of CIMMYT germplasm has steadily increased over the years; the most varieties containing CIMMYT contributions were released during the 1980s (Fig. 5). With the growing emphasis of the Maize Program on hybrid oriented products and inbred lines, we expect increased use of CIMMYT maize germplasm by both public and private sector entities in coming years (see Chapter 10).

Future Directions in International Testing

During 1991 and 1992, maize population improvement and international testing underwent a series of in-depth internal and external reviews. Several of the recommendations emanating from these reviews are being examined and will be implemented in the future:

One significant addition will be the introduction of hybrid trials in the international testing system starting from the 1994 growing season. Our breeders at headquarters and outreach have been testing several promising hybrids in limited multilocation testing during the current season and superior and stable performing hybrids will be included in the international hybrid trials. At least two subtropical and one highland hybrid trial are planned for distribution in 1994.

With the introduction of hybrid trials, we expect a higher demand for these trials at least in the initial years and a declining demand for EVTs. Nevertheless, EVTs will continue to be offered to our cooperators and we believe that there is a definite need for open-pollinated varieties in several of our client countries. The number of EVTs to be distributed will be limited to around 20 to accommodate the introduction of hybrid trials in the system.

Some of the recommendations with regard to EVTs were: reducing the plot size from four-row to two-row, and including only entries of similar maturity and plant type in the EVTs to avoid competition effects. These recommendations will be implemented. Reducing the number of replications from 4 to 3 is being critically examined and a decision will be made soon. When the new CIMMYT/MSU software system becomes operational, we will introduce alpha-lattices and other unbalanced designs to improve experimental efficiency.

The concept of key-site or target-site testing for population improvement was one of the major recommendations of the review. In consultation with subprogram coordinators and the GIS specialist and using historical data from international testing, we will identify key sites for each target mega-environment and will use them wherever possible.

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Fig. 1. Distribution of EVTs and ELVTs Subtropical and highland (1975-1992)

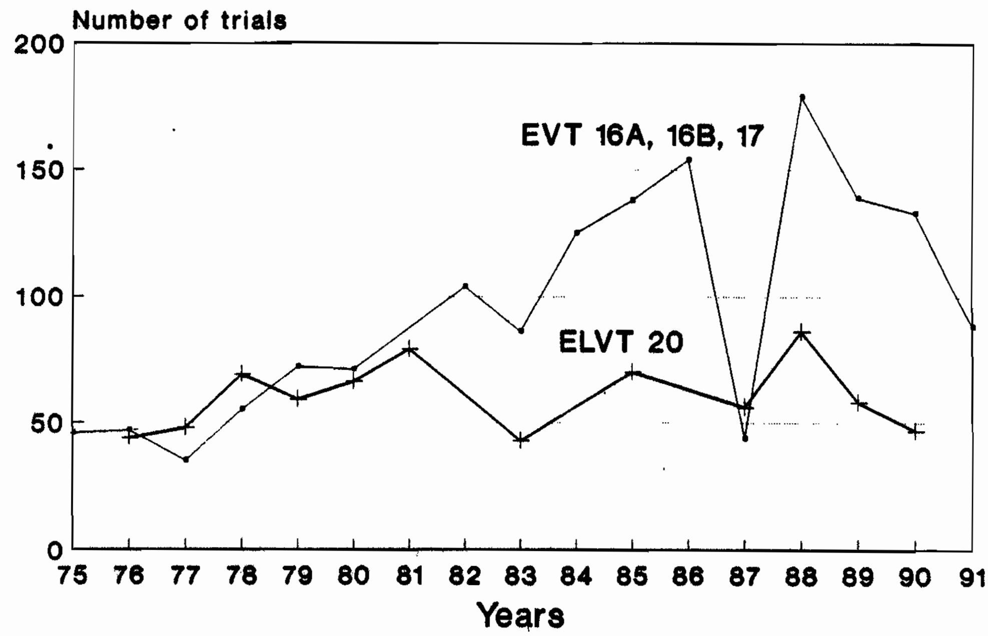


Fig. 2. Percentage of trials in which CIMMYT EV's yielded more than or equal to the best local check.

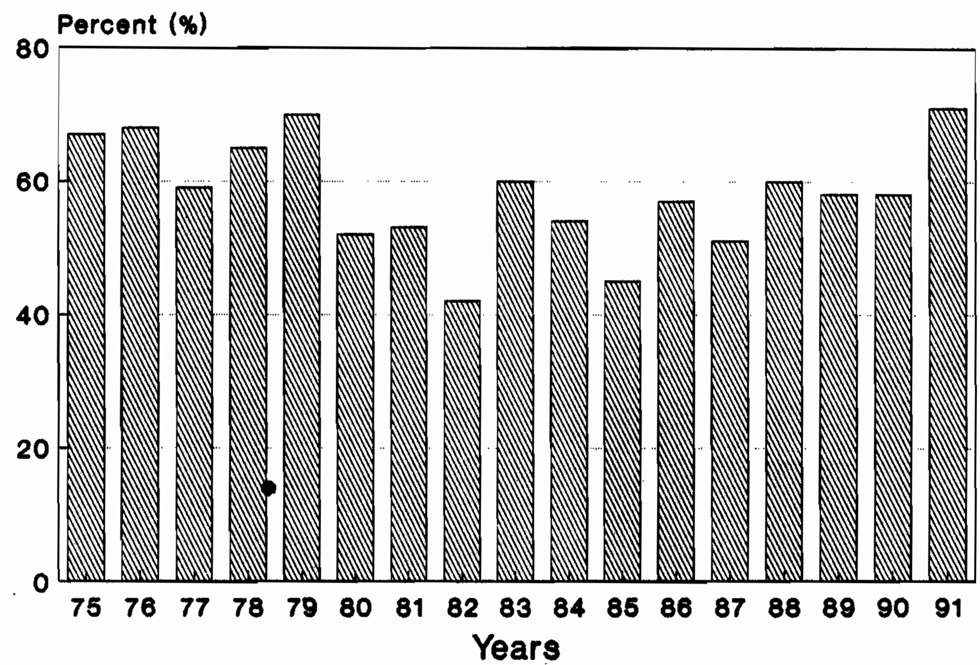
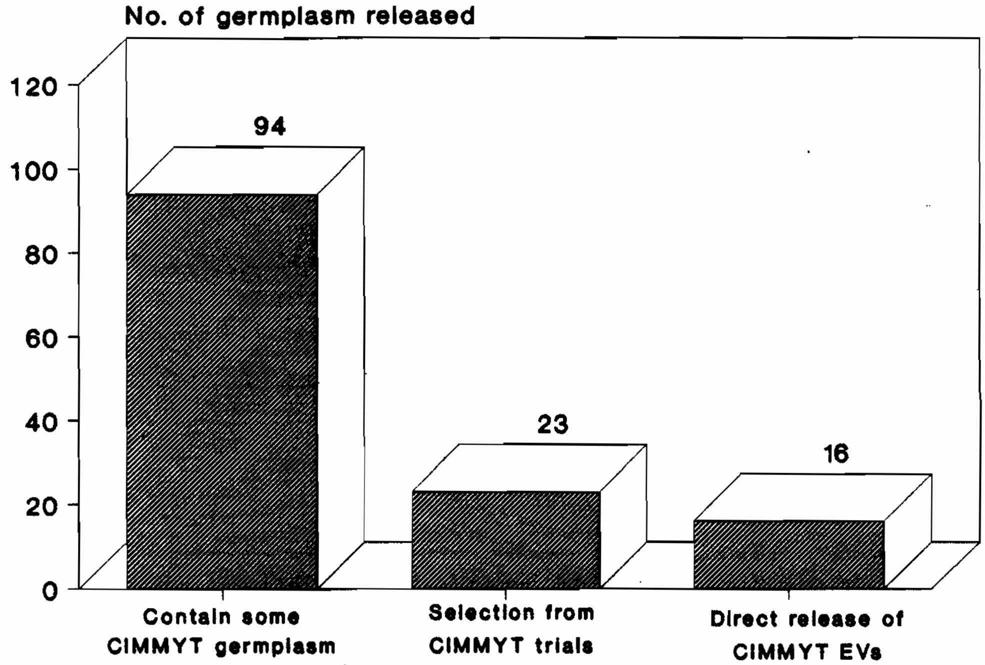
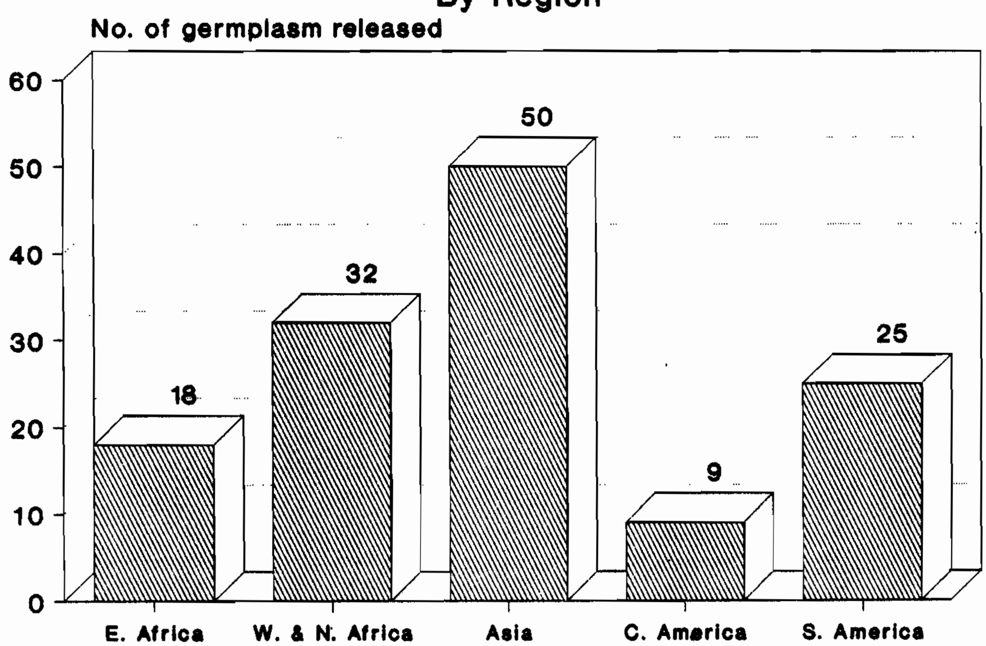


Fig. 3. Release of CIMMYT-based Maize Germplasm (Subtropical, mid-altitude and highland)



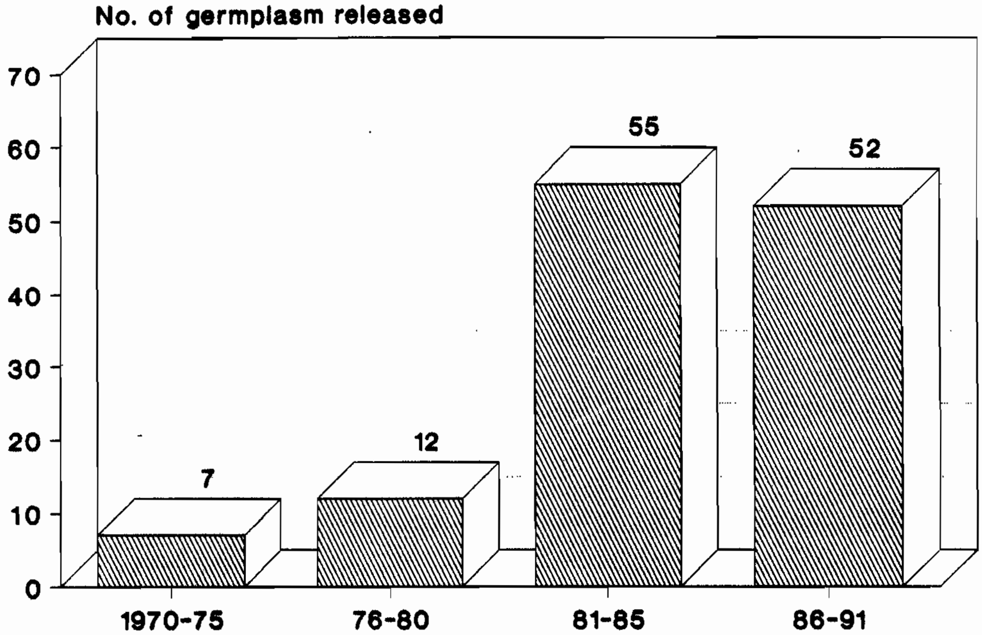
Source: CIMMYT Impact study (1990)

Fig. 4. Release of CIMMYT-based maize germplasm (Subtropical, mid-altitude and highland) By Region



Source: CIMMYT Impact study (1990)

Fig. 5. Release of CIMMYT-based maize germplasm (Subtropical, mid-altitude and highland) By Year of release



Source: CIMMYT Impact study (1990)

10
Chapter

Impacts of Research on Maize for Subtropical, Midaltitude, and Highland Regions and Prospects for the Future

M. A. López-Pereira *

Although most of the maize area in developing countries is found in ecologies classified as tropical lowland or temperate, there are important regions of the world with other ecologies where maize is produced, especially in subtropical, midaltitude, and highland (or ST/MA/HL) regions. In general, CIMMYT defines subtropical maize environments as those falling within 23° and 35° latitudes north and south; midaltitude environments as those areas within the tropics with altitudes between 900 and 1,800 masl; and highland maize environments as those areas within the tropics with altitudes above 1,800 masl. Of the approximately 81 million hectares of maize grown in developing countries, 20 million hectares are in temperate environments, [1] and approximately 61 million hectares in non-temperate environments (Table 1). Of this non-temperate maize area, maize grown in ST/MA/HL regions accounts for about 43%, or 26 million hectares. Maize growing environments classified as subtropical, midaltitude, and highland[2] are very important in some specific regions of the developing world (Table 2). Of the total highland maize area, Mexico accounts for about 50%, and the rest is spread in diverse regions such as East and South Asia, the Andes, and in East and Southern Africa. Most of the subtropical and midaltitude maize is located in East and Southern Africa, South and East Asia, and in Mexico and Brazil.

This brief analysis of maize area under different ecologies indicates the importance of the subtropical, midaltitude, and highland environments for maize production. As in the case of tropical lowland environments, the breeding needs for development of maize germplasm adapted to these environments are very different even within a given ecology, as different biotic and abiotic stresses are present according to altitude, latitude, and moisture regimes.

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* Economist.

1 CIMMYT's maize breeding research mandate excludes maize grown in temperate regions, defined as those above 35° north latitude and below 35° south. In the discussion that follows temperate maize regions are excluded. Tropical lowlands, the other major growing environment for CIMMYT's maize breeding activities, are defined as those areas within the Tropics of Cancer and Capricorn with altitudes below 900 masl.

2 Whenever possible, an effort is made to separate subtropical, midaltitude, and highland environments, but sometimes subtropical and midaltitude environments are lumped together and only the distinction between subtropical and highland maize can be made. The terms 'nontropical' and 'ST/MA/HL' are used interchangeably in this paper to refer to all three environments together, to distinguish them from the tropical lowland environments (see footnote 1 above).

This chapter provides a short overview of maize breeding research in national agricultural research systems (NARSs) in collaboration with CIMMYT to develop improved germplasm for the subtropical, midaltitude, and highland environments in developing countries. The discussion centers on the number and types of products developed and released for each environment and especially the distinction between open pollinated varieties (OPVs) and hybrids, the area planted to improved materials with and without CIMMYT germplasm, the prospects for future impacts of CIMMYT's germplasm products for these environments, and the possible implications of the changing roles of private and public sectors in seed industries for CIMMYT's long term breeding research priorities in these environments.

Germplasm Development for Nontropical Environments

The development of improved germplasm adapted to ST/MA/HL environments started very early in some developing countries. In fact, in the period up to 1965, the total number of NARSs maize varietal releases for these environments was higher than the number of releases for tropical lowland environments (Table 3)[3]. Many of these early subtropical and highland materials were released in Mexico, where a strong breeding program was established in 1943 with the collaboration of the Rockefeller Foundation. Starting in the mid-1960s, national programs substantially increased the pace of both tropical lowland and nontropical maize releases. During 1966-90, NARSs released 448 tropical lowland and 394 nontropical maize varieties and hybrids. Given the distribution of tropical lowland and nontropical maize area in developing countries, these figures indicate comparable rates of varietal releases per million hectares of maize for each type of environment; there have been 13 and 15 NARS releases per million hectares of maize in tropical lowland and nontropical environments, respectively, during 1966-90 (Tables 1 and 3).

Breeding for maize adapted to nontropical environments developed more slowly than for tropical lowland environments at CIMMYT. The challenges for improved germplasm development in the tropics seemed more formidable; thus, greater attention was devoted to these environments. At the beginning, breeding efforts concentrated almost exclusively on the tropical lowlands. Consequently, the release of varieties based on CIMMYT germplasm adapted to subtropical and midaltitude environments occurred later than for tropical lowland areas (Tables 4 and 5). Breeding for hybrid products adapted to highland environments began even later, and the first materials containing CIMMYT germplasm for this ecology were not released until the early 1990s. Nevertheless, the importance of CIMMYT's germplasm in NARS releases for ST/MA/HL environments is rapidly increasing with the faster pace at which improved germplasm is being made available to national programs. For example, 51% of the 91 nontropical maize varieties and hybrids

[3] It should be noted that our records of public maize varietal releases in developing countries for the period before 1966 are incomplete, as data collection efforts emphasized the 1966-90 period.

released by NARSs in 1986-90 included germplasm from CIMMYT, up from only 8% of the same type of materials released in 1971-75. Given the increasing importance of CIMMYT germplasm in public releases and the faster pace at which these releases are occurring, it is reasonable to expect a greater impact, in terms of area planted, from CIMMYT's germplasm adapted to the ST/MA/HL environments in the next five-to-ten years (see discussion below).

Type of Germplasm

Whereas the number of varietal releases was similar for tropical lowland and nontropical environments, the types of materials being released were different between environments. There was a heavy concentration of OPVs in the total number of tropical lowland releases, and a relatively small proportion of hybrids. During 1966-90, 72% of tropical lowland releases were OPVs and only 28% hybrids (Table 5). In contrast, hybrid releases for ST/MA/HL environments account for 44% of total releases in the same period (Table 5). In absolute numbers, hybrid releases for nontropical environments are 37% higher than hybrid releases for tropical lowland environments for the period (173 vs. 126), indicating a greater relative importance of hybrids in the nontropical environments.

It is also important to note that private sector releases (i.e., proprietary hybrids) are not included in this analysis. In some countries, the private sector has concentrated its efforts to develop materials for the subtropical and midaltitude environments. For example, most of the 'maize belt' in Brazil is classified as subtropical, and most of the maize area there is planted to hybrids from the private sector. In contrast, in the tropical lowland North and Northeast regions of Brazil very few improved maize varieties are used. A similar situation occurs in Mexico where, with agricultural policy reforms and privatization, most of the improved maize area outside of the tropics and highlands is also planted with private sector hybrids. The Mexican national agricultural research institute, INIFAP, has already released its own inbred lines adapted to highland environments, and is expected to release additional superior inbred lines as a result of a collaborative project with CIMMYT's highland breeding program. INIFAP's inbred lines and hybrids have the potential to become a new generation of high quality hybrid products for the highlands, as they have shown outstanding yield performance and are expected to be taken up by farmers rapidly through private sector seed production and distribution.

In Malawi, a country with approximately 0.9 million hectares of nontropical maize (out of a total of about 1.3 million hectares), two new flint hybrids adapted to midaltitude environments have been enthusiastically received by farmers due to their high yields relative to local varieties and cooking characteristics equivalent to those of the locals. As they replace old dent hybrids and local varieties, these hybrids, which include CIMMYT germplasm, are widely expected to revolutionize the maize sector in Malawi, and are already responsible for the dramatic increase in seed production and sales from about 1,000 tons in 1987 to 8,000 tons in 1993. More generally, throughout Eastern and Southern Africa where most of the maize is grown in nontropical environments, hybrid materials, many of them based on CIMMYT germplasm with resistance to streak virus, out-yield the local varieties by 40 - 50% even under very marginal conditions (Byerlee and Heisey 1993). This contradicts the common belief that hybrids need favorable conditions to show better yield performance relative to the locals. An important private sector presence, combined with relatively more successful and stronger breeding programs in countries with significant maize area under nontropical environments, are important factors indicating that it is reasonable to expect substantial increases in maize area planted to improved materials in these ecologies, especially hybrids for the subtropical and midaltitude regions.

Maize Area Under Improved Varieties in Nontropical Environments

Of the 26 million hectares of maize under ST/MA/HL environments in developing countries, 8.4 million hectares (or 32%) were planted in 1990 to improved varieties and hybrids developed by public research systems (Table 6). This compares with 38% of the total tropical lowland maize area planted to public releases the same year. The proportion would be even higher if we exclude highland regions, where very little improved maize seed is used, indicating that the area under improved maize corresponds mostly to subtropical and midaltitude environments. In this case, the proportion of subtropical and midaltitude maize area under improved materials is 42%, comparable with that in the lowland tropics. Of the 8.4 million hectares of maize under improved varieties in ST/MA/HL environments in 1990, 2.2 million hectares (or 26%) were under materials which had at least some CIMMYT germplasm. Given that the germplasm products from the subprogram started to appear consistently in public varietal releases in the 1980s, this shows an already important impact of CIMMYT's breeding effort for these environments. As discussed above, there are many recent releases still finding their way to farmers' fields, and the area under materials with CIMMYT germplasm should increase substantially in the medium term.

Two-thirds of the nontropical maize area under improved materials is planted to public hybrids (Table 7). This hybrid maize area of about 5.5 million hectares is in fact 22% greater than the area under public maize hybrids in the tropics (4.5 million hectares). Combined with the large nontropical maize areas under private sector hybrids (not included here), this confirms again the apparent 'specialization' of subtropical and midaltitude regions in hybrids and tropical lowland regions in improved OPVs. Of this total nontropical, public hybrid maize area, over 90% is in Eastern and Southern Africa and in Asia, where most of the strong national programs with maize in these environments are located. Brazil and Mexico, also with very strong national programs and large nontropical maize areas, have very active private seed sectors whose hybrids dominate these maize areas, especially in subtropical and midaltitude regions.

Prospects for the Future and Breeding Priorities for Nontropical Environments

The change in breeding priorities that occurred in the mid-1970s at CIMMYT--whereby strong emphasis was given to the development of OPVs over hybrid products--had a relatively moderate impact on national breeding programs working for ST/MA/HL environments, compared with its effects on maize breeding for tropical lowland environments. The pace of nontropical hybrid releases by the NARSs was maintained throughout 1966-90, in contrast to the tropical lowland environments, where hybrid releases did not pick up until the late 1980s and always at a slower pace than in the ST/MA/HL environments. With a renewed interest in hybrid products by the NARSs, the ST/MA/HL subprogram at CIMMYT may be poised to make an even more important contribution than in the past to the development of hybrid products for these environments. An important factor that will influence the types of products to be developed is the increasingly prevalent trend of agricultural policy reforms and agricultural sector liberalization in developing countries, allowing a more important participation by private sector organizations in all phases of the maize seed industries, but especially in seed production and distribution, including public sector releases of OPVs and hybrids.

As the direct presence and dominance of public sector seed companies diminishes, private sector organizations have more incentives to enter the market, especially those with the financial resources to establish breeding programs and invest in seed conditioning facilities. Seed companies with large capital reserves able to take advantage of these opportunities are most likely to be multinational corporations. This is especially the case in countries with large subtropical and midaltitude maize areas and with strong public sector breeding programs, which are making their germplasm available for use by the private sector (e.g., Zimbabwe, India, Brazil, Mexico). As they acquire this and other public germplasm such as CIMMYT's, and adapt their temperate germplasm from developed-country subsidiaries, these companies reduce substantially the time required to develop hybrid materials for the subtropics and midaltitudes. A good example of this benefit from public research is the Mexican highlands, where many private companies are increasing their interest in entering the market after INIFAP and CIMMYT developed outstanding inbred lines. These public-private sector interactions are especially important in these environments because the local varieties are usually high yielding, and the improved OPVs developed by the NARSs may not be able to clearly out-yield these local varieties, and the yield advantage provided through heterosis in hybrids may be the only way to provide farmers with a better product.

Summarizing, the subtropical, midaltitude and highland maize subprogram at CIMMYT seems to be in the enviable situation of having the products of its research making their way to farmers' fields as varieties and hybrids released by NARSs, and with the promise of much more impact in the near future. The relatively strong emphasis on hybrid products that has characterized their breeding research will allow both NARSs in nontropical maize regions and the ST/MA/HL maize subprogram at CIMMYT to adapt readily to policy reforms and agricultural sector restructuring in developing countries. Many NARSs seem to be actively redefining their role in the maize seed industries, evolving toward pure breeding research and providing elite materials with which to develop hybrid. As a parallel, they are conceding an increasing share of seed production and distribution to private organizations. In this regard, the CIMMYT ST/MA/HL maize subprogram may be able to strengthen its position as a key source of elite germplasm for both the national programs and for private national and multinational seed companies interested in strengthening or initiating nontropical maize breeding programs. These environments usually offer the potential for high maize yields, and the local varieties often compete effectively with improved OPVs. The development of outstanding hybrid products capable of offering substantial yield increases over these good local varieties is probably the best alternative for getting improved maize to nontropical farmers. The extensive experience with hybrids of both public and private sector organizations, as well as maize farmers, in ST/MA/HL environments should facilitate the development of the appropriate germplasm products. Such products will be important not only to increase producitivity but for the continued development of the maize economies in these environments.

Reference

Byerlee, D. and P. Heisey. 1993. Performance of hybrids under low-input conditions in eastern and southern Africa. Draft paper. Mexico, D.F. CIMMYT.

Table 1. Maize area in developing countries, by ecology, 1990.

Ecology	Total maize area (million hectares)	Percent of: Total	Percent of: Nontemperate
Lowland tropics	34.7	43	57
Subtropics	12.6	16	21
Mid altitude	7.6	9	12
Highlands	5.8	7	10
Temperate	20.0	25	-
Total	**80.7**	**100**	**100**

Source: CIMMYT Maize mega-environment database.

Table 2. Nontemperate maize area in developing countries by region and ecology, 1990.

Region	Maize area (million hectares) Tropical lowlands	Subtropical and midaltitude	Highlands	Total
East & Southern Africa	2.1	6.2	1.0	9.3
West & Central Africa	5.0	0.9	0.1	6.0
North Africa	0.0	1.2	0.0	1.2
West Asia	0.0	0.1	0.0	0.1
South Asia	3.4	3.5	0.5	7.4
South East Asia & Pacific	8.8	0.2	0.0	9.0
East Asia	1.3	2.5	0.4	4.3
Central America & Mexico	4.5	1.5	3.1	9.1
Andean Region, South America	1.4	0.3	0.6	2.3
Southern Cone, South America	8.3	3.8	0.0	12.1
Total	**34.7**	**20.2**	**5.8**	**60.7**

Source: CIMMYT Maize Mega-environment database. Note: Totals may not add due to rounding.

Table 3. Number of public maize materials released in developing countries, by period and ecology, 1941-90.

Period[a]	Number of tropical lowland materials released	Number of nontropical releases Sub-Tropical	Mid-altitude	Highland	Total
1941 - 65	48	28	5	45	78
1966 - 70	38	17	37	8	62
1971 - 75	60	26	42	18	86
1976 - 80	70	12	26	26	64
1981 - 85	142	36	36	19	91
1986 - 90	138	38	43	10	91
Totals					
1941-90	**496**	**157**	**189**	**126**	**472**
1966-90	**448**	**129**	**184**	**81**	**394**

[a] Information on public maize varietal releases before 1966 may be incomplete.
Source: CIMMYT maize varietal releases database.

Table 4. Public maize varietal releases adapted to subtropical, midaltitude and highland environments in developing countries, by type and origin, 1966-90.

Period	Number of releases for nontropical environments			Releases with CIMMYT germplasm (as % of total)		
	OPVs	Hybrids	Total	OPVs	Hybrids	Total
1966 - 70	34	28	62	12	0	7
1971 - 75	42	44	86	12	4	8
1976 - 80	39	25	64	28	4	19
1981 - 85	54	37	91	59	24	45
1986 - 90	52	39	91	71	23	51
Totals	**221**	**173**	**394**	**40**	**12**	**28**
(percent of total)	(56)	(44)	(100)			

Source: CIMMYT maize varietal releases database.

Table 5. Public maize varietal releases adapted to the lowland tropics in developing countries, by and type and origin, 1966-90.

Period	Number of releases for tropical lowland environments			Releases with CIMMYT germplasm (as % of total)		
	OPVs	Hybrids	Total	OPVs	Hybrids	Total
1966 - 70	24	14	38	54	64	58
1971 - 75	42	18	60	40	28	37
1976 - 80	57	13	70	64	39	59
1981 - 85	107	35	142	89	77	86
1986 - 90	92	46	138	95	89	93
Totals	**322**	**126**	**448**	**77**	**69**	**75**
(percent of total)	(72)	(28)	(100)			

Source: CIMMYT maize varietal releases database.

Table 6. Maize area under public improved maize varieties adapted to subtropical, midaltitude and highland environments in developing countries, by origin, 1990.

Region	Total nontropical maize area under improved varieties released by NARSs (1000 ha)	Maize area under public varieties containing CIMMYT germplasm	
		1000 ha	% of total
Sub-Saharan Africa	3,734	221	6
West Asia & North Africa	569	545	96
Asia	5,585	1,146	32
Latin America	490	258	53
Totals	**8,377**	**2,170**	**26**

Source: CIMMYT maize varietal releases database.

Table 7. Maize area under public improved maize varieties in developing countries, by niche and type, 1990.

	Area under releases for tropical lowland environments		Area under releases for nontropical environments	
	OPVs	Hybrids	OPVs	Hybrids
	(1000 ha)			
Sub-Saharan Africa	2,377	65	665	3,068
West Asia & North Africa	0	0	486	83
Asia	4,220	1,078	1,617	1,968
Latin America	2,283	3,362	100	389
Totals	**8,839**	**4,505**	**2,868**	**5,509**
(percent of total)	(66)	(34)	(34)	(66)

Source: CIMMYT maize varietal releases database.

List of Acronyms

AGEL	Applied genetic engineering laboratory
AMGL	Applied molecular genetics laboratory
DR & SS	Department of Research and Specialist Services, Zimbabwe
EUREKA	Pan-European funding organization
GCA	General combining ability
GIS	Geographic information system
IITA	The International Institute of Tropical Agriculture
INIFAP	The Mexican National Institute of Forestry, Agriculture, and Livestock Research
INRA	The French National Institute of Agricultural Research
IPTT	International progeny testing trial
MDR	Multiple disease resistant
MER	Modified ear-to-row selection
MSV	Maize streak virus
NGO	Non-government organization
NUE	Nitrogen use efficiency
OPV	Open pollinated variety
PET	Preliminary evaluation trial
QPM	Quality protein maize
QTLs	Quantitative trait loci
SCA	Specific combining ability
SEW	Subtropical early white
SEY	Subtropical early yellow
SIW	Subtropical intermediate white
SIY	Subtropical intermediate yellow
SLW	Subtropical late white
SLY	Subtropical late yellow
SPE	Semiprolific early
SPL	Semiprolific late
SPMAT	Semi-prolific midaltitude tropical population
SWCB	Southwestern corn borer

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