MAIZE • PROGRAM • SPECIAL • REPORT

International Testing: Evaluating and Distributing Maize Germplasm Products

R. N. Wedderburn,
Technical Editor

CIMMYT

M A I Z E   P R O G R A M

Special Report

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C I M M Y T

CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO
Apartado Postal 6-641, C.P. 06600, México, D.F., México

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: Originally developed to provide background information for participants in a 1992 external review of maize international testing at CIMMYT, this publication describes CIMMYT's clients, international and regional testing of maize germplasm by the Center and national program cooperators, and the role of such testing in germplasm improvement and distribution. Appended material summarizes major conclusions and recommendations of recent internal reviews of maize international testing at CIMMYT and provides an overview of the Center's Maize Program.

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Foreword

This document was originally developed to provide background information for participants in an internally coordinated external review of maize international testing at CIMMYT in 1992. Such reviews are now a regular feature of our operations. They help to provide guidance in establishing priorities, to monitor progress toward objectives, and to account to our stakeholders on Center efforts. Each is conducted by a panel comprising internationally recognized experts in the area to be evaluated.

The decision to review international testing stemmed from the expansion in germplasm development activities over the last ten years. We continue to provide general purpose, broadly adapted populations of interest to our principal clients—national maize research systems throughout the developing world. Chapter 1 portrays the tremendous diversity of research capabilities and germplasm needs in those systems. However, we now seek to meet certain of their requirements by developing, testing and distributing a variety of special purpose materials. These include maize with resistance or tolerance to key constraints, such as drought, insect pests, or regionally important limiting factors, such as acid soils.

Our interest in improved targeting of the germplasm has also led to a strategy of more decentralized crop improvement research. Whereas breeding activities were initially concentrated in Mexico, the crop's center of genetic diversity, we now post scientists in key maize producing regions to focus on prevalent maize types or stresses. Chapters 4-6 describe their research and the regional trials they conduct, as well as discussing issues relating to the optimal coordination and flow of germplasm between regional and international testing.

Added to the decentralization of breeding activities and our expanded array of germplasm products (Chapter 7), several elements have significant implications for the way we conduct international trials, as is evident in Chapters 3, 8, and 9. These include new breeding methodologies, the availability of improved experimental designs, and new technology for storing, analyzing, and presenting data. A particularly important development in the latter regard is a collaborative project recently undertaken by the Maize Program with Michigan State University to design a PC-based data management software system.

While these issues have received attention in staff meetings, planning exercises, and various other Maize Program fora in recent years, they came under more formal consideration in an internal review of international testing conducted in December 1991. As a prelude, senior national program scientists and research managers participating in an advanced maize crop improvement course at CIMMYT headquarters were invited to provide feedback on maize international testing. The one-and-a-half-day event was judged a success by all who took part, and outcomes of the discussions are summarized in Appendix 1. The subsequent internal review, which involved outreach and headquarters staff, current directors, and two former directors of the Program, dealt with issues raised in the feedback session and identified additional themes of importance (see Appendices 2 and 3). The former director of the Maize Program, Ripusudan L. Paliwal, played a crucial role in ensuring the effectiveness of the evaluation process.

All these concerns and several others were addressed in the external review and the review panels' report, a final draft of which reached CIMMYT in November 1992. The Maize Program is now implementing the major recommendations from the review, which include:

- Identifying "key" sites—locations from which reliable data are normally obtained—and using data from those locations to make decisions about breeding
- Improving coordination between headquarters and regional programs in germplasm development and testing
- Accommodating hybrids in international testing
- Clustering populations by heterotic groups
- Establishing an integrated system for managing trial data
- Including "special trait" materials

We hope these changes improve our effectiveness in meeting clients' needs. As an added measure toward that end, we intend to provide increased technical information on Maize Program research. This publication is the first in a series with that aim. Called "special reports," they are designed to inform cooperators in a timely and cost effective manner about major research priorities and products from specific areas of CIMMYT's Maize Program. Please feel free to address comments or requests for additional information to the authors or the Director's Office of the Maize Program.

Delbert C. Hess
Director

Richard Wedderburn
Associate Director

The CIMMYT Maize Program

List of Acronyms

AICMIP	All India Coordinated Maize Improvement Project
AMMI	Additive main effects and multiplicative interaction
ANOVA	Analysis of variance
ARMP	Asian Regional Maize Program (of CIMMYT)
ASE	Acid soil environment
ASI	Anthesis-silking interval
AST	Asian stress trial
ASTP	Acid soil tolerant population
ATT	Aluminum tolerance trial
CD-ROM	Compact disc, read-only memory
CGIAR or CG	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency
CMR	Crop management research
CSRS	Cooperative State Research Service of the USDA
DDN	Drought development network
DEVT	Drought experimental variety trial
DIPT	Drought international progeny trial
DMR	Downy mildew resistant
DTN	Drought testing network
DTP	Drought tolerant population
EACRMVT	East Africa Cooperative Regional Maize Variety Trial
EE	Extra early
ELVT	Elite variety trial
ENSAT	Lowland trials for acid soil tolerance
ERSAT	Lowland trials for normal maize
ERVEZAS	Highland maize variety trials
EV	Experimental variety
EVT	Experimental variety trial
FS	Full sib
GE or G x E	Genotype-by-environment interaction
HS	Half sib
IANR	Institute of Agriculture and Natural Resources, UNL
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IICA	Instituto Interamericano de Cooperación para la Agricultura
IITA	International Institute of Tropical Agriculture
IPTT	International Progeny Testing Trial
IRDN	Insect resistance development network
IRPT	Insect resistance progeny trial
IRTN	Insect resistance testing network
KARI	Kenya Agricultural Research Institute
LAMP	Latin American Maize Evaluation Project
LET	Line evaluation trial
MBR	Multiple-borer-resistant population
MIRT	Multiple-insect-resistant tropical population
MRRS	Modified reciprocal recurrent selection
MSTAT	Microcomputer program for the design, management, and analysis of agronomic experiments (developed at MSU)
MSU	Michigan State University
MSV	Maize streak virus
NARS	National agricultural research systems
NGO	Non-government organization
NUE	Nitrogen use efficiency
OPVs	Open pollinated varieties
PET	Preliminary evaluation trial
PROCIANDINO	Programa Cooperativo de Investigación Agrícola para la Subregión Andina
PROCISUR	Programa Cooperativo de Investigación Agrícola para la Región Sur
QPM	Quality protein maize
RCB	Randomized complete block
RFLP	Restriction fragment length polymorphism
RFS	Reciprocal full-sib selection
RRS	Reciprocal recurrent selection
SAS	Statistical analysis system
SASS	Scottish Agricultural Statistics Service
SHMM	Shift multiplicative model
TAC	Technical advisory committee of the CGIAR
TZT	Transition zone trial
UNL	University of Nebraska at Lincoln
USAID	United States Agency of International Development
USDA	United States Department of Agriculture
USMARC	University of Southern Mindanao Agricultural Research Center
VC	Varietal cross

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CHAPTER

Our Clients, Their Research Capacities, and Germplasm Needs

D. Beck and S.K. Vasal

CIMMYT's Clients

CIMMYT's ultimate goal is to help developing world farmers improve their livelihood through the adoption of better agricultural technologies particularly improved varieties. We recognize that the national agricultural research systems (NARS) are the key intermediaries in this technology transfer process. The NARS, therefore are CIMMYT's primary clients.

No simple definition of the NARS in the developing world can be given, as they are a diverse and constantly evolving group of research organizations. However, the NARS generally include publicly funded national maize research programs, universities engaged in agricultural research, the private sector, and non-government organizations (NGOs). The publicly funded national maize research programs and universities have historically conducted much of the maize research in developing countries. Consequently, throughout much of CIMMYT's history they have been the main focus of our cooperative research efforts. However, we have recently witnessed a rapidly expanding role for the private sector and NGOs. Overall, CIMMYT views this as a positive and necessary trend, although one that deserves careful analysis and coordination.

Just who are the players in the private sector and of what significance are their maize research efforts? The private sector often includes local seed cooperatives or associations, local private seed companies, and multi-national seed companies. As indicated by our definitions, the private sector at present emphasizes seed production and distribution, although some of these—particularly larger ones—are involved in maize breeding research. The rapidly expanding role of the private sector was highlighted in a recent survey of maize seed enterprises in 46 developing countries (CIMMYT, 1992a), the results of which show that 67% are private companies. Only in sub-Saharan Africa did the number of government seed companies exceed that of the private sector. The report noted that in all four regions surveyed (sub-Saharan Africa; West Asia and North Africa; South, East, and Southeast Asia; and Latin America), the number of domestically-owned private companies was equal to or greater than that of internationally-owned private companies. Although we expect that private firms will increasingly add to the availability of maize hybrids for higher input environments in developing countries, we foresee minimal contributions in open-pollinated varieties and marginal environments.

An increasingly important client for CIMMYT's products—especially materials more suitable for marginal environments—are the NGOs. Although generally small, NGOs are extremely influential because of their large number. A US government publication of last decade listed 184 non-profit organizations involved in food production and agricultural development assistance programs abroad (TAICH, 1981). Carroll (1992) describes the often misunderstood and yet rapidly expanding role of NGOs in agricultural development.

CIMMYT's strategic plan presents summary results of a survey on the strength of NARS (CIMMYT, 1989). The survey was conducted by experienced CIMMYT regional staff and augmented with results from a similar survey among national program representatives. Research programs were ranked according to present capabilities and those expected on through the year 2000. The results for maize germplasm improvement capabilities are briefly outlined here. The scale used to assess the strengths of NARS was as follows:

1) A full-fledged program capable of developing quality varieties from the crossing-block onward. Staff and support are adequate.

2) Can deliver some varieties from the crossing-block onward, but not on a continuing basis for all major environments.

3) Capable of developing useful varieties from resource germplasm provided by CIMMYT or other suppliers.

4) Able to select near finished materials from variety trials.

A summary of important characteristics of different ranks of maize programs is presented in Table 1.

The survey showed that developing countries with stronger national maize research programs also tended to produce most of the developing world's maize, use more maize on a per capita basis, produce higher maize yields, and have higher overall per capita incomes. Conversely, the countries with lower ranked maize programs tended to be poorer, with lower per capita incomes, and lower maize production.

Implications for CIMMYT are that we must offer a range of products and services to meet the needs of our varying NARS clients. Quoting from the strategic plan:

> *We believe that national programs will continue to improve in their ability to conduct research and to provide certain types of training for themselves and, eventually, for others. We do not expect, however, that national programs will progress uniformly during the next 12 years.... For both maize and wheat, the majority of national programs are small and poorly developed, and represent a relatively small portion of the crop. We seek an appropriate balance between the attention we give to the majority of the crop (for the most part through larger, more advanced programs) and the attention we give to the majority of programs (even though they affect a minority of the crop).*

The last sentence has important implications for the germplasm needs of our clients. These will be elaborated on in the final section of the chapter.

External Factors Affecting CIMMYT's Clients

The physical environment

Population pressure—Many longer term changes expected in the physical environment will result directly from increasing population pressure, particularly in the developing world. By mid-1990 the world's population is expected to exceed 5 billion, an increase of 75% since 1960 (World Resources Institute, 1990). At projected growth rates, the population will approach 8.5 billion by the year 2025—a 60% increase over 1990 and nearly triple the 1960 population. Unfortunately, the highest rates of growth are found in developing regions including Africa (3.0%), South America (2.1%), Central America (2.0%), and Asia (1.9%). This increasing population pressure will lead directly to greater land pressure as the demand for food rises and as land is required for other uses.

Cropping intensification—From 1950 to 1975 the global average area of cropland per person fell from 0.24 ha to 0.18 ha and is expected to drop to 0.13 ha by the year 2000. This will intensify the use of land already under production and promote the expansion of agriculture into less favored and more fragile environments.

Loss of Arable land—Yearly estimates of cropland rendered unproductive due to waterlogging and salinity range from 1.0-1.5 million hectares. Erosion is responsible for a net annual loss of 26 billion tons of topsoil. Desertification is removing an additional 6 million hectares of agricultural land per year. The spread of urban areas is also significantly reducing cultivable area. These figures suggest that farming will increasingly take place on marginal lands.

Environmental degradation—Industry, domestic use, and agriculture have all been blamed for the deterioration of our environment. Depletion of the ozone layer, contamination of air and water resources, removal of tropical rain forests, and extinction of numerous plant and animal species are now common problems facing mankind. The consequences of this on agricultural production remains a source of debate. However, we can be assured that the NARS and International centers will be under increased pressure to develop agricultural technologies that preserve the environment and are sustainable.

Weather patterns and global warming—Analysis of climactic change in the major maize producing areas of the world (particularly the U.S.) show that extremely favorable weather patterns for maize production were experienced during the period from 1958-1982. In light of the cyclical nature of weather patterns, a period of drought and high temperatures is predicted for the early 1990's. This, along with probable global warming due to higher atmospheric carbon dioxide levels, give reason for concern. In the USA there are indications that maize yields would decrease under a warmer climate, although this may be compensated for by the direct fertilizing effect of higher carbon dioxide. Overall, precipitation levels are predicted to decrease in important temperate maize production areas (World Resources Institute, 1990). Production decreases in these areas would have an important effect on global maize prices.

Various predictions of global warming effects on tropical areas suggest that precipitation will increase and become more erratic. Resulting flooding, waterlogging, and soil erosion could prove detrimental to agricultural (Schlesinger and Mitchell, 1985; Schneider and Rosenberg, 1989).

Although many questions remain about future weather patterns and global warming effects on maize growing regions, we believe NARS will feel increasingly constrained to develop more stress tolerant maize germplasm. Of particular relevance to this discussion would be materials tolerant to both drought and waterlogging, germplasm more efficient in nutrient uptake, and earlier maturing varieties.

The economic environment

The World Economy—One shudders to hear that the world's major economic powers, including Japan, Germany, and the USA, are either in recession or economic decline. The picture for developing countries is generally worse. Annual average change in real GNP from 1977-1987 in the developing world fluctuated greatly. Growth in Central America only approached 1.0%, and was actually negative for South America (World Resources Institute, 1990). Although the growth rate in GNP exceeded 2% in Africa, one must examine the low base levels and the increasing problem of national debt in this and many other developing regions. Total external debt for 111 developing countries totaled over US$1 trillion in 1987 and is growing (World Resources Institute, 1990). Many countries, particularly in Latin America, are paying more each year to service existing debt than they borrow. Preliminary 1988 figures show that the Developing countries borrowed US$92 billion and paid out US$142 billion in interest and principal on old loans. The overall consequences for agriculture is that the NARS (particularly publicly funded research and universities) will be increasing strapped for research funds.

Maize markets—Annual global demand for maize is forecasted to increase at a rate of 2.6% (FAO, 1987). For developing countries, growth rates are estimated at 3.5% per year. In most developing countries, growth in demand for maize will be driven by both population growth and the increasing use of maize for animal feed. (Projected demand growth for feed equals 4.9% per year, compared to 1.6% for food, in the developing world.) Overall, world production of maize is expected to outpace demand slightly, according to FAO estimates. However, production increases in developing countries are not expected to keep up with demand.

Although supply and demand projections are notoriously subject to a large margin of error, we hope and expect that maize prices will remain relatively stable, allowing the weaker NARS to continue to import maize without significantly increasing their cash outlays. However, we expect that the forecasted rapid growth in demand for maize in developing countries will put significant pressure on even the strongest of our NARS clients.

The scientific environment

The environment of science is filled with exciting new possibilities including, among others, new information technology and biotechnology tools. However, to what extent they are available and will benefit CIMMYT and our clients is a matter of discussion. Serious concerns exist regarding the cost, complexity, and intellectual ownership of both information and genetic materials.

Biotechnology—While our knowledge of genetic and biochemical processes in plants will no doubt grow considerably due to biotechnology research, major near—term payoffs for applied plant breeding are less certain. We are convinced that current breeding techniques will remain the most important methods of maize improvement and genetic manipulation over the next decade. Our expectation is that biotechnology research will provide important new techniques that increase the efficiency of selection (particularly for traits that do not respond well to conventional breeding procedures) and add to the genetic variability upon which breeders can draw.

Biotechnology research is expensive and demanding in terms of trained personnel, the timely supply of reagents, and the maintenance of expensive and delicate equipment. By implication we expect that such research will be increasingly concentrated in developed countries. With some exceptions, developing countries generally will remain importers and modifiers of advanced technology.

Overall, we expect a significant increase in use of these new biotechnology tools by our stronger NARS clients, with limited or no use by the weaker NARS. Unfortunately, adoption of these techniques may come at the expense of research in applied plant breeding (as is being experienced in many developing countries). We at CIMMYT hope to assist our NARS clients in making most efficient application of these technologies by providing expertise in its application to plant breeding, training others in the skills needed to apply it, and making cost- and time-saving techniques widely available.

Intellectual property—The direction of research and access to results will be increasingly affected by issues of public and private ownership of intellectual property. Access to the results of certain classes of research will become more restricted. For example, if research funded by the private sector succeeds in transferring highly effective alien genes for stress tolerance to maize and inducing their expression, it is unlikely that the techniques or the germplasm will be freely available to CIMMYT or its clients in a reproducible form. International legal sparring over private ownership of germplasm is expected to continue throughout the next decade. On the positive side, however, it appears likely that the private sector will assume some public sector functions in maize research related to more favored areas in advanced developing countries.

Information technology—Improvements in computing and data management technology will vastly augment our ability to store, access, distribute, and process large quantities of information at a low cost, and could significantly accelerate the rate of technological change in many countries. Powerful microcomputers with simplified operating environments will become more common in national programs during the next decade. Major developments are expected in expert systems, particularly those that deal with statistical analysis. These tools will enhance the capacity and efficiency of researchers to design and analyze experiments.

To obtain benefits from these new technologies, our NARS clients may require assistance in the purchase of hardware and software, as well as training in its use and service.

Germplasm Needs of CIMMYT's Clients

Maize is distributed more widely than any other cereal crop. Its genetic diversity and plasticity allow it to grow in many diverse environments. It is cultivated in the lowland tropics year round, in subtropical and temperate regions during the summer, in the tropical highlands up to elevations of 3,300 m, and in irrigated deserts under very high temperatures. Its diversity has been stratified into thousands of land races, improved varieties, and hybrids used in myriad ways for human food, animal feed, and industry (Inglett, 1970). The broad spectrum of maize germplasm types, uses, and production environments is reflected in the germplasm needs of our NARS clients.

Major production environments

The lowland tropics—Lowland tropical environments constitute approximately 59% of the developing world's total non-temperate maize area of 56 million hectares (Table 2). Traditionally, CIMMYT's maize program has given highest priority to germplasm development for tropical environments. We expect this emphasis to continue, since the weaker NARS tend to be located in tropical regions and because of the complex array of biotic and abiotic stresses limiting maize production in these regions.

CIMMYT's impact study showed that nearly seven-tenths of the improved maize varieties released in developing countries were of tropical adaptation (CIMMYT, 1992b). The majority of these materials are Tuxpeño-based and of intermediate-to-late maturity. We expect the already large demand for early maturing types (Table 3) to grow. NARS requirements for various maturities of maize is discussed below.

The subtropics and midaltitude zones—Of the 17 million hectares of maize cultivated in subtropical environments in the developing world, about 10 million are sown in lowland areas in subtropical latitudes, and 7 million are grown at midaltitudes (900-1700 m above sea level) within the tropics. The subtropical environments are served by generally strong national programs and are the focus of intensive efforts by both local and transnational private seed companies. In this context, we expect demand for more hybrid oriented germplasm to grow significantly in subtropical regions. However, this must be balanced with the increased demand expected for early maturing subtropical materials, particularly for use by the public sector in marginal areas.

Highlands—Although not as widespread as tropical and subtropical maize types, highland germplasm covers an area of about 6 million hectares worldwide, is grown extensively in certain areas, and occupies 100,000 hectares or more in at least a dozen developing countries. Farmers adoption of improved varieties are generally low in this ecology, due largely to the lack of improved varieties, poorly developed seed industries, and severe limitations in farmer resources. Accordingly, adoption of CIMMYT materials has been low (CIMMYT, 1992b), reflecting perhaps a lower commitment of staff and resources relative to other maize types.

One of the primary challenges in developing broadly adapted, improved maize for highland areas is that small changes in elevation cause large genotype x environment interactions, and elevation may vary greatly within a reduced geographical area in the highlands. Such difficulties, together with the limited use of hybrids in these regions, have resulted in an unwillingness on the part of the public and private sector to invest in research on maize for the highlands. In this context, we expect that CIMMYT will increasingly be called upon to provide suitable maize germplasm for highland regions.

Germplasm product environment

A cross-pollinated crop such as maize provides breeders with the opportunity to develop a multitude of germplasm products to meet farmers' needs. Among the most important products are populations, open-pollinated varieties (OPVs), synthetics, and conventional and non-conventional hybrids (Vasal and Srinivasan, 1991).

OPVs are being used extensively in maize producing regions in the developing world (Pandey et al. 1991). They are preferred over hybrids in many developing country areas because of nonsignificant differences between OPVs and hybrids under high-stress and low-yielding farming conditions, limited financial resources for purchase of farm inputs, and lack of effective seed production and distribution systems (Paliwal and Sprague, 1981; CIMMYT, 1987). Historically, CIMMYT has strongly supported the NARS in developing OPVs. A recent survey shows that 70% of the OPVs released in developing countries contain CIMMYT germplasm (CIMMYT, 1992b). Although we expect continued strong interest by our NARS clients in OPV development, hybrid varieties are becoming increasing important in various areas.

Mangelsdorf (1974) probably was right when he stated that "....hybrid corn is the most far-reaching development in applied biology in this quarter century." Dramatic maize yield increases have been achieved, particularly in the developed world, due to "hybrid vigor." These results have aroused great interest in developing countries, where maize hybrids are being used with varying degrees of success. Recent estimates summarized by CIMMYT economists show that 39% of the maize area in the developing world is sown to hybrids (CIMMYT, 1990). Eliminating Argentina, Brazil, and China, however, alters the picture considerably, reducing the area planted to hybrids to only 16%. Nevertheless, demand for hybrids in many client countries is expected to grow. Private sector companies will meet much of the increased demand for seed, especially in the more favored production areas. Public sector NARS will contribute relatively more to research than to seed production. CIMMYT expects increasing requests from both our public and private cooperators for hybrid oriented germplasm and information.

Given the complexity of hybrid development and seed production and distribution, we believe that nonconventional hybrids can play an important developmental role. These hybrids will find their greatest use and acceptance in countries with relatively poorly developed seed industries and where there is a transition from OPVs to hybrids. Breeders can often develop nonconventional hybrids more quickly than conventional ones. The major advantage of nonconventional hybrids is the use of a non-inbred parent, making F1 seed production easier and relatively less expensive. Use of nonconventional hybrids also facilitates targeting for commercial seed production and distribution.

General purpose vs. special purpose materials

Our 25 years of experience in maize breeding has amply demonstrated that broadly adapted, general purpose maize populations can be developed through careful selection at representative sites in Mexico, along with international testing. Population development and improvement was the principal activity in the first stage of CIMMYT's Maize Program (Paliwal, 1991). Our goal has been to develop a wide array of genotypes with high yields and resistance to stresses that are important globally and can be effectively handled in Mexico. These populations, and experimental varieties developed from them, have been used extensively throughout almost the entire range of major maize producing areas in the developing world (CIMMYT, 1992b). They still constitute the core of our germplasm offerings for our NARS clients.

Despite our success we realized that, to be more acceptable to some cooperators, our improved populations would require resistance to certain regional constraints. We also knew that breeding for such resistance would be less effective in Mexico than in areas where the target stress was naturally present. In view of these circumstances, the Maize Program established regional programs in Africa, Asia, and South America to develop improved maize with resistance or tolerance to key biotic and abiotic constraints of those regions (see Chapters 5-7 for greater detail).

Another area where we have modified our breeding program to better serve our NARS clients is in the development of special purpose populations with insect resistance. To date we have two—the multiple borer resistant (MBR) and the multiple insect resistant (MIRT) populations (see Chapter 7). In general, we have achieved satisfying levels of insect resistance in these materials, and are now working on other traits that will enhance their usefulness to clients. Our success with these special purpose populations has led us to apply a similar strategy for drought stress breeding.

Overall, we expect that our *general purpose* populations will remain popular, especially with the less advanced NARS, whereas demand for special purpose materials (insect resistant, drought and inbreeding tolerant), particularly by the stronger NARS, will grow. As stated previously, changes in climate may move us toward a greater emphasis on special purpose materials.

Maturity requirements
Although late maturing maize germplasm is preferred in many developing world regions because of its superior yield potential (Table 3), earlier maturing types have distinct advantages. They generally give farmers greater flexibility in time of planting, may permit the crop to escape abiotic and biotic stresses, often fit more easily into intensive multiple and intercropping systems, and can allow farmers to market their crop sooner, possibly at a higher price. In spite of these significant advantages, formidable challenges remain in the development of early maturing varieties. They tend to be more susceptible to biotic stresses than their later maturing counterparts, and as a consequence difficulties are commonly encountered in extracting useful inbred lines. Moreover, there is often a strong positive correlation between high yields and a longer growing cycle, so that early materials are frequently lacking in yield potential. Largely as a result of these difficulties, elite early maturing maize germplasm is relatively scarce worldwide. However, the significant advantages of early maturing varieties and the increasingly erratic weather patterns predicted for major maize regions should lead to a rise in demand for this product from all ecologies.

The weaker NARS will probably not invest in research on earlier maturing maize because of the difficulties and costs involved. Private sector NARS have shown only modest interest in early types because of their lower yield potential and their limited use for hybrids. All in all, we expect that CIMMYT will be asked more and more to supply suitable early maturing germplasm for the major maize producing areas of the developing world.

Grain color and texture requirements
Materials of white grain type predominate in Africa and less so in the Americas, whereas the yellows are preferred in Asia. Since white grain materials are traditionally used for human consumption in the poorer maize growing areas of the world, we expect that NARS demand for this type will remain high. Since feed use of maize is growing significantly, particularly in the more prosperous maize growing regions, we also expect NARS demand for yellow grain color to run high.

Grain texture preferences are especially important in regions where maize is used for human consumption. Many subsistence farmers who grow maize, particularly in highland regions, tend to be very particular as to grain type and other traits related to food preparation and may reject higher yielding genotypes strictly on that basis. Although, among white grain maize, dent types predominate in several major maize growing areas, the flints are popular in numerous regions and are especially favored because of their excellent grain storage qualities. With yellow maize, flint types tend to be more popular in most developing country regions. However, with the increased use of maize as animal feed, particularly yellow grain, we expect increased demand for dent types. Dent maize generally yields more than flint.

Conclusions

In summary, we perceive that CIMMYT's clients are a diverse, constantly evolving, and increasing complex group of research organizations. Added to this, CIMMYT and our clients are functioning in a constantly changing physical, economic, and scientific environment characterized by a physical environment under growing population pressure and environmental degradation, an economic environment presenting increased debt in developing countries and greater North-South tensions, and a scientific environment offering new technologies which may or may not be accessible to our NARS clients due to cost, complexity, and intellectual property restrictions. Additionally, our NARS clients are growing maize in a very diverse set of environments where the crop is confronted by a range of abiotic and biotic stresses. In general, work by our Program to classify maize production zones into "mega-environments" showed that a large diversity of materials are required to fit special ecologies. Now that we have gone ahead and developed many of these, we are looking at our international testing and distribution system to see how the materials can best be accommodated.

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Table 1. A profile of developing country maize research programs (CIMMYT, 1989).

	Program rank (germplasm improvement capacity)			
	1	2	3	4
Number of programs	4	17	19	14
% total maize production[a]	49.7	33.8	12.4	2.5
% total maize production[a] in...				
...low-income countries	16	44	31	100
...lower/middle-income countries	8	53	61	0
Per capita utilization[b] (kg/yr)	144	73	84	48
Yield (t/ha)[b]	1.9	2.2	1.2	0.9
Per capita income ($US)	1,462	606	694	235
Percentage labor force in agriculture	40	66	59	79

[a] Not including temperate maize.
[b] Including temperate maize.

Table 2. Maize area sown in the developing world's major ecologies (CIMMYT, 1988).

Ecology	Area (million ha)	% maize area
Lowland tropical	33	59
Subtropical	10	18
Midaltitude	7	13
Highland	6	11
Total	**56**	**101***

* Exceeds 100 due to rounding

Table 3. Maize area sown in the developing world to lowland tropical, and subtropical and midaltitude maize, by maturity (CIMMYT, 1988).

Category	Tropics	Subtropics and midaltitude
	(million ha)	
Extra-Early	2.5	0.0
Early	8.4	1.6
Intermediate	12.6	5.2
Late	11.9	9.4

Maize Improvement Through International Testing at CIMMYT

S. Pandey and K. Short

One of the most widely declared objectives of maize breeding programs in the tropics is development of cultivars with increased yield relative to available options and stable yield across environments. The best way to meet these objectives has been through the evaluation of genotypes over a wide range of environments during the breeding and post- breeding phases. Different genotypes do not respond similarly to a change in the environment. This differential response is due to genotype x environment interaction (GE). Baker (1988) defined GE as instances in which true means of genotypes change in rank from one environment to another. Numerous studies have indicated GE to be significant for most traits in maize (Gardner, 1963; Stuber and Moll, 1971; Pandey *et al.*, 1986, 1987, 1991).

How broad should the adaptation of the cultivar be? This is a question that haunts most breeders. Plant breeders can ignore, avoid, or exploit GE interactions. When GE is large, the first is not an option. The second option involves managing and/or reducing GE through grouping of genotypes and environments in the target areas. The third option requires determination of causes, nature, and magnitude of GE to be able to exploit it in a breeding program (Eisemann *et al.*, 1990). Large GE is undesirable for developing cultivars with wide adaptation but desirable for developing site-specific cultivars. It should be recognized, however, that a variety selected for a site on the basis of high GE may not stay desirable, when a change in the environmental conditions at the site occurs. The highest yielding variety during a season at a site must be further tested, as some undesirable characteristics can go undetected in a situation of minimum testing and express themselves under different environmental conditions. High and positive GE can be exploited but it's magnitude should be determined and recognized.

International testing in maize implies testing genotypes in more than one country and increases the range of environmental conditions sampled within a mega-environment over that possible through multilocation testing within a single country. The number of countries in which a group of genotypes should be tested depends on interest in the genotypes, the capacity of countries to conduct tests, seed quantities available, and the minimum number of environments necessary to meet the objectives of the trials.

Objectives of International Testing at CIMMYT

Germplasm improvement

Recurrent selection using full-sib families is an important component of the IT system. Selection of progenies for recombination is based on their superiority over a range of sites. The objective is to increase the mean performance and stability of the populations over cycles.

International testing helps determine GE of individual genotypes and provides information on relative GE of genotypes being evaluated. It enables us to identify sites that are similar in their influence on genotypes, information that can help reduce duplication in testing.

International testing permits screening for high yield and wide adaptability. Breeding for resistance to several diseases and pests and other special traits is possible at the same time, if nurseries are widely scattered. New diseases and pests can be spotted via international nurseries, which provide an "early warning" system. International testing contributes to institutional building, helps identify leaders among its clients, and helps train them with new materials and methodologies. It permits scientists from different parts of the globe to work together on common germplasm and problems, surmounting ideological, religious, ethnic, and language differences (Plucknett and Smith, 1984). It gives NARS scientists a sense of involvement in the development of the products they will be using, a feeling of partnership with CIMMYT, the satisfaction of helping colleagues worldwide whom they may never actually meet, and a sense of pride in the fact that they are providing data useful for improving germplasm that may someday serve their client farmers. Overall, since they must invest their own resources, time, and scientific abilities to help improve what they receive, they place a higher value on the product.

International testing can contribute to other important aspects of breeding research, among them: 1) documenting the prevalence of biotic and abiotic constraints that affect maize in the tropics, 2) establishing research priorities, and 3) monitoring changes in climatic and biological conditions. Appropriate and adequate reporting of the results helps NARS identify potential collaborators on specific issues.

Germplasm distribution

International testing is a systematic method for germplasm distribution. It gives NARS an opportunity to examine CIMMYT materials and their own in local environments and to identify additional germplasm that can enrich their research programs. To a new scientist who is unfamiliar with *what* to request and from *where*, international testing is particularly useful. The resulting reports permit scientists to identify environments from which additional germplasm could be requested and helps them locate potentially useful germplasm from CIMMYT and other NARS.

International trials can, in some cases, be quite large and inflexible, a particular problem for small, resource-poor collaborators. If the collaborator does not do a good job of conducting the trial, collecting data or providing it on time, the whole system falters and resources are wasted.

Genotype X Environment Interactions in CIMMYT Maize Populations

One question generally asked is whether international testing helps reduce GE. If conducted with scientific rigor and if results are used appropriately, then the answer is "yes." However, Gardner *et al.* (1990) did not find a reduction in GE different cycles of selection of several CIMMYT maize populations (Table 1). They used data from trials where the progenies were evaluated at varying number of sites and at different sites for cycles of selection. Genotype, GE, and error variance components of CIMMYT's 11 tropical maize populations were calculated. The broad genetic base of CIMMYT populations, low initial frequency of desirable alleles, low selection intensity, introgression of additional germplasm, and extremely diverse environments used during different selection cycles were cited as possible explanations for the results obtained. While the study is statistically valid, the questions may be more appropriately answered by randomly generating a number of progenies (say 50-100) from different cycles of several populations, evaluating them at the same 6-10 environments in replicated trials, and then examining GE variance components of different cycles.

Pandey *et al.* (1986, 1987, 1991) used the stability analysis of Eberhart and Russell (1966) to analyze the data from cycles of selection trials of late and medium maturity CIMMYT populations and from the trial of EVs derived from the original and the latter cycles of selection from most of the same populations. They found the mean yields and stability of the more advanced cycles of selection of populations as well as of varieties derived from them to be higher than for original cycles of the same populations. Improvement in such traits as maturity, plant height, and ear quality also occurred simultaneously (Tables 2, 3, and 4).

For late tropical populations, the deviations from regressions were generally nonsignificant. The *b* values for C4/C5 of the late materials were significantly lower than those for CO (Table 4). The advanced cycles of selection had lower *b* values than C0 in the case of six of the eight populations. The last cycles had higher yields across the environments as well. The advanced cycles of selection yielded higher than C0 in 15 out of 16 cases in low yielding environments and in 21 out of 32 cases in high yielding environments.

In the medium maturity materials, the *b* values decreased significantly from C0 to C2 and then increased again (Table 4). In two of the four populations, the advanced cycles of selection averaged higher yields and lower *b*'s than C0. In this study as well, the advanced cycles of selection yielded more than C0 in 11 of 12 cases in low yielding environments and 12 out of 16 cases in high yielding environments.

The regression values of Across EVs derived from C3/C4 were lower than those from Poza Rica and Across EVs derived from the C0 and Poza Rica EVs derived from the last cycle ($P<0.01$) (Table 3). The results indicate that EVs developed from advanced cycles of selection of populations undergoing recurrent selection yield more ($P<0.01$) and are more stable ($P<0.01$) than those developed from the original cycle (Pandey *et al.*, 1991).

Byrne *et al.* (1990) compared cycles 0, 2, 4, 6, and 8 of Tuxpeño Selección Sequía with cycles 0, 2, 4, and 6 of Tuxpeño-1 improved through international testing, in 12 environments with varying levels of moisture. A 1.6% yield gain per cycle was obtained for the drought selected population vs. 1.2% per cycle for the same population improved through international testing. While these data suggest that selecting for drought tolerance was more effective in providing drought tolerance over a range of moisture regimes, they also suggest that selection based on international testing increased drought tolerance over a range of moisture regimes. The authors cautioned, however, that rate of progress obtained in Tuxpeño-1 improved through international testing is not typical of many other populations improved through international testing. Rates of progress from international testing in 16 populations conducted by Pandey *et al.* (1986, 1987) and Eaton *et al.* (1990) ranged between 0.05 to 4.30% per cycle, compared to 1.24% per cycle, observed in Tuxpeño-1.

These results should also be viewed along with those of Edmeades *et al.* (1991) who reported that Rattray Arnold (1) 8149 was the highest-yielding entry in the 'early' drought trial evaluated in 11 international environments and Tak Fa 8536 was the highest-yielding entry in 'late' drought trial evaluated in 17 environments. The two varieties were developed based on international testing data and were evaluated under drought conditions along with several materials selected for tolerance to drought.

These results clearly suggest that recurrent selection, where progeny selection is based on international testing, has resulted in improved mean performance and stability of CIMMYT's tropical maize populations. Gardner *et al.* (1990) attributed the improvement to elimination of deleterious genes, shorter plant height, higher harvest index, and improvement in resistance to biological and environmental stresses.

Recurrent Selection Methods and Gains from Selection

The basic objectives of any recurrent selection program are to improve breeding populations by increasing the frequencies of favorable genes and gene combinations and to maintain adequate genetic variability for further improvement. Recurrent selection systems have been discussed extensively in the literature and summaries have been presented by Sprague and Eberhart (1977), Gardner (1978), Hallauer (1985), Hallauer and Miranda (1988), Paterniani (1990), and Pandey and Gardner (1992). Recurrent selection systems can be divided into two types: 1) Intrapopulation Recurrent Selection Systems, and 2) Interpopulation Reciprocal Recurrent Selection Systems.

For intrapopulation selection, the population should possess the most desirable alleles at as many loci as possible. Such systems are more efficient when the ultimate goal of the breeder is to develop an improved variety. For interpopulation selection, heterotic patterns are of great significance in choosing germplasm to include in each of the two reciprocal populations. Such systems are more effective when the ultimate goal is a hybrid (Pandey and Gardner, 1992).

Comparisons between intrapopulation and interpopulation selection methods indicate that selection in early cycles is for additive genetic effects with partial to complete dominance in both systems. They seem to be equally effective in increasing the interpopulation cross mean (Moll and Stuber, 1971; Odhiambo and Compton, 1989). At the same time, intrapopulation selection is more effective in improving population means, and S_1 family selection is definitely more effective in reducing inbreeding depression and improving means of selfed progenies (Odhiambo and Compton, 1989). S_1 family selection is also very effective for improving insect and disease resistances and environmental stress tolerances. Therefore, since reciprocal selection programs are more difficult and costly to run, it seems wise to use S_1 family selection in each of the two populations in the early cycles and switch to reciprocal FS selection after about five cycles when gains due to overdominance and dominance types of epistasis are likely to become relatively more important. For traits that are highly heritable, a few cycles of intrapopulation selection will be highly effective (Pandey and Gardner, 1992).

When population improvement is integrated with a hybrid program, Reciprocal Recurrent Selection (RRS) and Reciprocal Full-Sib Selection (RFS) provide new S_1 lines each cycle. These can be advanced to S_2 lines during the testing phase, and those related to the best interpopulation crosses can be further inbred and/or topcrossed and evaluated in hybrids. RFS produces heterotic pairs of lines which may form a useful hybrid. Jones *et al.* (1971) provide evidence to support the choice of RFS over RRS. An additional advantage is that new reciprocal pairs of S_1 lines for further development and use in hybrids are a natural spin-off each cycle of selection. However, no one has compared the systems on the same population (Pandey and Gardner, 1992).

For most of the recurrent selection systems, equations to predict progress from selection have been developed. Sprague and Eberhart, (1977), Gardner (1978), and Hallauer and Miranda (1988) summarize prediction equations. For intrapopulation selection, the general prediction equation for expected gain per year is:

$G_s =$ $SH/y = [(k\,\sigma_p)\,c\,\sigma_A^2] / [y\,\sigma_p^2]$

$S =$ selection differential (superiority of the mean of selected units over the σ population mean).

$=$ $k\,\sigma_p$ in normally distributed populations.

k = number of phenotypic standard deviations that selected units are expected to exceed population mean in normally distributed populations.

$\sigma_p^2 =$ phenotypic variance among selection units.

$=$ MS_f / re, where MS_f = the family mean square, r= No. of replications, e = No. of environments.

$\sigma_A^2 =$ additive genetic variance in the population.

c = proportion of additive genetic variance contained in the genetic component of variance among selected unit means.

H = $c\sigma_A^2/\sigma_p^2$, heritability on a selection unit basis.

y = number of years per cycle.

Factors affecting gains from selection are the number of selection units evaluated, the proportion selected, the magnitude of additive genetic variance, and the precision of the experiment. Except for HS family evaluation and selection, substitution of the family component of variance for $c\sigma_A^2$ will give biased estimates of expected gain for traits where nonadditive genetic effects are important. Where the units selected differ from those evaluated, estimates of additive genetic covariance between the two types of families are substituted for additive genetic variance. For reciprocal recurrent selection systems, expected gains in the interpopulation cross are calculated using components of variance among intercross family means (see references listed above).

Recurrent selection should be an integral part of any applied maize breeding program whether the ultimate product is an improved variety or a hybrid. Improved populations are superior sources of new inbred lines for use in hybrids as well as of new varieties. All recurrent selection systems have been effective in maize improvement (Sprague and Eberhart, 1977; Gardner, 1978, 1986). The choice of which system and which populations to use depends upon the ultimate goal (variety or hybrid), traits to be improved, time constraints (short term vs. long term), available germplasm and knowledge about them (locally adapted varieties, improved populations, pools, and bank accessions), and financial resources available (Pandey and Gardner, 1992).

Some additional factors that can directly influence the efficiency of international testing will be examined here along with strategies for enhancing international testing's efficiency and effectiveness.

Stratification of Environments

It seems logical that dividing sites into homogeneous groups and testing germplasm within groups could improve the efficiency of cultivar development. For international testing or multilocation testing, environments can be grouped using biotic and abiotic variables and/or yield. A mega-environment can be subdivided so that the environmental differences among subregions within it are small. Stratification will not completely eliminate the need for international or multilocation testing, as differences from season to season or year to year in the same subregion can be significant. If a large number of environments is involved, cultivars that yield relatively well under stress or optimum environments can be identified. If the combined analysis of data suggests the performance to be the same for both environments, even better.

Eberhart and Russell (1966) used stratification of environments effectively to reduce GE. Brown *et al.* (1983) also suggested that classification of testing environments into more homogeneous groups would improve efficiency of breeding programs and cited several studies in support of this assumption (Finlay and Wilkinson, 1963; Horner and Frey, 1957; Liang *et al.*, 1966; Guitard, 1960). Gardner *et al.* (1990) emphasized the need for classification of environments based on the use of the resulting products and for collecting good quality data for maximizing progress from selection in CIMMYT's maize program.

Choice of Breeding Locations

Identification of a few sites that more accurately predict performance of cultivars over a wide range of environmental conditions is a worthwhile objective. A breeding site should be such that the yield of selected genotypes at the site would consistently correspond to the yields over the range of environmental conditions in the mega-environment where the genotypes will be grown.

Whether genotypes should be tested under favorable or unfavorable conditions is a question which may never be answered to the satisfaction of all concerned. The debate is over which environments are more effective in discovering real or more useful differences among genotypes - stress or nonstress? The literature suggests that both genotypic and environmental variances are generally higher under high yielding environments. Allen *et al.* (1978) reported that high and intermediate-yielding environments were more effective in predicting crop performance in low yielding environments for several crops. Unfortunately, their study did not include maize.

While Finlay and Wilkinson (1963) argued against eliminating data from low yielding environments in the analysis of stability, as this would bias the selection toward genotypes specifically adapted to high yielding environments, Rosielle and Hamblin (1981) suggested that selection under stress environment would generally reduce yields under nonstress environments. For developing genotypes for nonstress environments, genetic variation under stress must be greater than under nonstress environments. Vela-Cardenas and Frey (1972) suggested that optimum environments should maximize heritability and gains from selection. Allen *et al.* (1978) proposed that there must be high and positive correlation between performance of entries at the chosen site and the mean of entries across sites where the trials are conducted.

Hamblin *et al.* (1980) argued that sites chosen must be able to predict yield over a range of environments, be able to discriminate among genotypes, and have a mean yield consistently above average. Brown *et al.* (1983) concluded that genetic and GE variances and heritability in different types of environments should determine the types of sites to be used. They also felt that, in an optimum selection environment, the trait of interest would express, genetic variance would be maximum, environmental and GE variances would be minimum, target environments where selection products would be eventually used would be accurately represented, the site would be easily accessible and less expensive to use, and most of these characteristics would be present from year to year.

While there is no general agreement that gains from selection or heritability are higher if progenies are selected under high yielding environments, most of the currently available evidence in the literature, the current plot management practices of maize scientists, and performance of recently developed cultivars under stress and nonstress conditions suggest that use of high yielding environments is generally more efficient in developing high yielding cultivars for both high and low yielding environments. It should be remembered that even though early rice and wheat varieties were developed for high fertility conditions, they adapted well over a large range of environmental conditions. Some more recent CIMMYT studies conducted with wheat also support the concept of testing in high yielding environments (CIMMYT, 1992). This is not to argue that if selection is aimed at developing germplasm for some specific stress condition, that selection would not be more efficient if evaluation of progenies was done under that particular stress.

One issue that does not generally invite too much debate is that a large number of environments (within a mega-environment) should be sampled in a population improvement program. Comstock and Moll (1963) provided theoretical evidence that gains from selection or heritability estimated from data of a single macro-environment would be seriously deficient as criteria for environments in which selection would be effective. Several approaches for the identification of such sites have been suggested over the years (Allen *et al.*, 1978; Hamblin *et al.*, 1980; Fakorede, 1986; Misevic and Dumanovic, 1989) but procedures such as AMMI (Gauch and Furnas, 1991), based on combined analyses of variance, regression, and cluster or principal component analyses appear more promising.

Evaluation of Genotypes

It is generally agreed that breeders should test their genotypes at several sites in the target environment. Should the data be collected across more locations or over a greater number of years? This depends on the magnitude of GE for the trait and breeders' interest in utilizing it. Large GE makes precise estimation of genetic variances, choice of breeding methods, reliable prediction of gains from selection, etc., difficult.

Development of genotypes that would perform reliably at the same or different site(s) across seasons and years requires multilocation testing of progenies. Entries that do well during a given season at a site will not necessarily do well during different seasons and years at the same site. The situation becomes more complicated when the environments are viewed beyond a specific site. Multilocation testing appears to be an ideal choice for developing cultivars for a range of environments, since environmental conditions for maize growing areas cannot be predicted accurately. Scott (1967) and Jinks and Pooni (1988) have shown that stability is a heritable trait and that it can be improved through selection. Entries that perform well across a range of environments are expected to respond less to environmental fluctuations. It is assumed that a variety identified as good based on multilocation testing will also be good under variable farmers' conditions.

If there are insufficient environmental differences among the sites where a trial is conducted, the trial will effectively have more replications (i.e., replications and locations would have same effect on error) and estimates of genotypic variances will then be biased upward by GE. Eberhart (1970) reported little increase in gains from selection with use of more than two replications and 3-4 locations, when S_1 progenies were used. In contrast, gains were maximized with seven or more locations for HS and six locations for FS. Hallauer (1980) suggested that two replications with 3-4 environments would be an acceptable compromise for progeny evaluation in most recurrent selection programs.

Gardner *et al.* (1990) examined CIMMYT maize yield data, using weighted mean estimates (weights used were inverse of the variance of each estimate) to gauge genotype, GE, and error variances for 12 populations (Table 5). The results indicated that good data from two replications at six sites (the number of replications and environments currently used for progeny testing at CIMMYT) would result in satisfactory progress from selection. More replications could not be justified. With data from only three locations, expected gains would be greatly reduced.

Obilana and Fatunla (1976) found that four replications were as effective as two years in reducing the standard error, and four locations as effective as three years. They noted that it was cheaper to increase replications than locations and recommended two years of testing in three replications at eight locations for releasing varieties.

International Testing and Selection Methods

Applied plant breeders develop and identify genotypes with high and consistent performance in target environments. Choice of an appropriate selection method is critical to meet the goals of the breeding program efficiently. Cultivars with greater genetic uniformity have been reported to be more sensitive to environmental variations than genetically heterogeneous cultivars. Sprague and Federer (1951) obtained a larger GE in maize for single crosses than for double crosses. Comstock and Moll (1963) did not find enough genotypic and GE variances among HS families and suggested that the situation would be different if families exhibiting greater genetic variance were used. This implies that S_1 and S_2 families would show greater GE than HS or FS progenies, due to the lower population buffering in the former. Therefore, they may need to be evaluated in more environments than HS or FS families to measure their genotypic values accurately. However, additive genetic variance is more important in the expression of differences among S_1 and S_2 than among FS and HS families. This would suggest that fewer environments may be needed for S_1 and S_2 progenies.

Quantities of seed available for different types of progenies poses limitations on number of locations and replications to be used for evaluation. Approximately 400-500 seeds per progeny may be needed for adequate testing and to provide enough extra seed for population regeneration and other breeding uses. In the tropics, where ear size is usually smaller than in temperate areas, reciprocal crosses can be made between two plants to ensure enough FS seed. In the case of HS families, seed from several ears of a HS family can be bulked. The situation is more difficult in case of S_1 and S_2 progenies. An S_0 or an S_1 plant may not provide enough seed in the tropics to meet the testing and other requirements of a breeding program. If the trait of interest exhibits relatively higher heritability, it would show lower GE. In such cases, extensive testing would not be necessary and seed quantity may not be a limiting factor.

It should be kept in mind that S_1 and S_2 lines developed from a previously unimproved population would be more variable and a greater frequency of them would be poor. Distributing such families could give cooperators a false, unfavorable impression about the potential of the germplasm in question and about CIMMYT germplasm in general. It may prove more difficult to convince the cooperators to grow such trials next time around. It would thus be advisable to improve a maize population for four-to-five cycles using full or half sib selection or a combination of full sib -S_1 selection, before deriving S_1 or S_2 progenies from them for international testing in the tropics (Pandey and Gardner, 1992).

Implications for CIMMYT's Maize Program

The central objective of CIMMYT's Maize Program is to provide superior maize germplasm to its clients. CIMMYT has the responsibility to ensure that the germplasm it distributes has a high probability of being useful to its clients, if it wishes to continue counting on their involvement in the process of germplasm improvement. International testing provides a vehicle for developing, improving, and distributing superior germplasm.

Nonetheless, international testing involves costs for CIMMYT and NARS. The Center must produce germplasm in sufficient quantities, clean, treat, prepare trials, ship, monitor that they are properly grown, receive data, analyze, prepare reports, and distribute reports. NARS must clear the germplasm through their customs, quarantines, grow them using their own land, water, and human resources, and collect and provide data to CIMMYT. International testing materials compete for resources with NARS' own materials and research projects. This competition is particularly critical when most NARS are experiencing financial difficulties. After all the investment, our clients must find something highly useful in our trials. How can CIMMYT increase the probability of success of the germplasm it distributes to its clients?

First CIMMYT must ensure that the germplasm it distributes to its clients is truly superior. This can be done by developing populations for important mega-environments or special trait populations, improving them effectively, and pre-screening them before sending them to NARS for evaluation. CIMMYT has the information on the types of germplasm needed by its clients and, therefore, we know which of our materials serve their needs, which should be withdrawn from international testing, and which should be developed and added to international testing. A population need only be tested at the sites chosen in its mega-environment of adaptation at the progeny level. At the variety or hybrid level, some cross-mega-environment testing should be encouraged.

Our data can be used to determine genotypic and GE variances for all populations, along the lines of Gardner *et al.* (1990). Using this information, we can identify populations that offer greater potential for improvement for different mega-environments. Populations must have relatively high genotypic variance and lower GE in general. Our clients can be encouraged to select genotypes that show relatively higher GE for their sites from this germplasm, if they wish to do so. Populations that are desirable but do not possess adequate genetic variability can be broadened through introgression of appropriate germplasm.

New materials can be developed and these and the existing ones improved. International testing can be the vehicle for improvement of germplasm in general but multilocation testing, in conjunction with some special nurseries, will suffice in many cases. The important traits for each mega- environment, and therefore, for each population, can be identified and an appropriate breeding and selection method employed for their improvement. Multilocation testing, involving CIMMYT and selected NARS, could focus on specific traits, such as insect resistance, disease resistance, drought tolerance, and other traits.

Multilocation testing would improve genotype stability for yield and other traits of general interest. We can focus on germplasm, environments, selection methods, and traits for different populations and environments. In addition, we can use our data to make intelligent choices on all these points.

Second, CIMMYT can modify its testing procedure to test widely only pre-screened and proven materials with NARS. Our data can be used for grouping environments and matching populations with environments. One could envision a decentralized program where breeding and selection can focus over a less variable range of conditions (a mega-environment), within which international and/or multilocation testing can be employed to evaluate progenies. If possible, breeding sites should be located within the mega-environment and meet the criteria previously described. Progeny evaluation can be done at key breeding sites and superior varieties/hybrids can then be tested over a much wider range of environmental conditions to determine their suitability for release, etc. Target environments can be defined by their biotic and abiotic characteristics and yield. Reliable environmental classification is now possible using any of several techniques previously mentioned.

We must offer clients the best germplasm available at CIMMYT at any given moment, promptly and regularly. One possibility is to pre-screen most CIMMYT germplasm using Center resources in Mexico and regional locations. This would provide an adequate sampling of environments in the majority of cases. We could include a few key NARS sites that meet the mega-environment classification requirements for the materials being evaluated and other criteria. CIMMYT should consider providing financial assistance for such collaboration. We can choose these sites but must be flexible, in case others want to participate in these efforts. Our progeny trials and, initially, variety and hybrid trials could be handled this way. Superior materials from such trials should be made available to NARS for testing and use in an EVT-type distribution system. Such a two-tier system would maximize genetic progress for the trait(s) of interest and streamline the germplasm distribution process. The system differs from our EVT/ELVT system, in that EVT's are offered to all collaborators without pre-screening.

The materials most useful in these widely grown trials can be recycled in appropriate populations to increase genetic progress and reinforce NARS' sense that their data are used to help improve the populations they will eventually use in their breeding programs.

Quarantine regulations are becoming more stringent and seed exchange is increasingly difficult. The problem particularly affects progeny trials, where some quarantine officers want to examine every packet. Under this system, quarantine problems will be worked out with the few selected NARS who would provide breeding sites, reducing logistics. For wider evaluations, since trials will involve only selected germplasm and fewer packets, quarantines officers should pose less of a problem.

Finally, we wish to emphasize that CIMMYT's international testing program has served national maize programs around the world and CIMMYT well. Nearly 900 maize varieties and hybrids released by NARS contain CIMMYT germplasm, covering approximately 50% of the area grown to improved cultivars in developing countries. Although it is impossible to be precise, nearly 25% of maize hybrids released by the private sector contain CIMMYT germplasm, as well. Thus, nearly 8 million hectares, or 13% of the tropical maize area, is planted to cultivars containing CIMMYT germplasm. It is highly unlikely that there exists a maize breeding program in the developing world that does not use CIMMYT's maize materials. The germplasm we now offer to our clients is superior in performance and stability to that supplied a few years ago. All this attests to the success of the Maize Program's international testing operation. Its effectiveness can be further increased by choosing germplasm more carefully. This means improving the germplasm needed by a large number of clients for large areas, and using materials with high mean and genotypic variance and low GE variance for the traits of interest. It also means classifying environments, choosing breeding and testing sites, matching breeding objectives with germplasm, sites, and breeding methods, and strengthening our partnership with clients so that it is based on equality, trust, and respect.

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Table 1. Genotype x environment interaction components of variance for each cycle of selection in 11 CIMMYT populations undergoing full-sib family recurrent selection.

	Cycles						
Population	0	1	2	3	4	5	6
				$X\ 10^{-4}$			
21	6763	1954	364	2103	2973	38075	
22	56269	3247	774	1862	9319	4116	2882
24	800	2529	1698	2147	669	2148	1006
27	843	1958	1426	963	3387	995	849
28	2604	1396	3232	1828	2127	2819	
29	17417	8230	1629	3798	1650	10064	
32	4291	919	9472	1480	2600		
35	1228	839	803	3231	1266		
36	1196	2637	2059	1685	93	1193	
43	22593	1248	620	2140	2924		
49	1153	1494	1152				

Table 2. Performance of different cycles of selection of four medium maturity tropical maize populations grown in seven environments in 1983-84.

Populations	Cycles	Yield (t/ha)	Days to silk	Ear ht. (cm)	Ears/ plant
Blanco Cristalino-1	CO	5.11	64	113	0.91
	C2	5.64	62	103	0.98
	C5	5.29	63	108	0.97
Mezcla Amarilla	CO	4.97	63	108	0.96
	C2	4.64	62	93	0.96
	C5	5.40	60	101	0.98
ETO Blanco	CO	4.84	64	108	0.88
	C1	5.04	65	111	0.92
	C4	5.46	64	104	0.96
Ant. Rep. Dominic.	CO	4.66	59	94	0.95
	C1	4.53	59	87	0.92
	C4	5.13	59	92	0.98
LSD (<0.05) within population		0.28	0.7	5	0.04
Gains/cycle (%)[a]		2.11	-0.31	0.47	1.05

[a] All gains are significant at the 0.01 level of probability.

Table 3. Performance of Poza Rica and Across EVs derived from different cycles of selection of ten tropical maize populations. EVs were grown at four Mexican sites in 1983-84.

Type of variety	Yield t/ha	Yield b[a]	Days to silk	Plant height (cm)
Poza Rica EVs	4.92	1.05	76	189
Across EVs	4.09	0.95	76	193
LSD (P<0.05)	0.19	0.15	0.4	2.7
EVs CO	4.78	1.06	78	196
EVs C3/C4	5.23	0.94	76	186
LSD (P<0.05)	0.13	0.08	0.3	2.3

[a] Stability parameter of Eberhart and Russell (1966).

Table 4. Yield and stability of different cycles of selections, averaged over several tropical maize populations.

Late maturity materials[a]			Medium maturity materials[b]		
Cycle	Yield	b[c]	Cycle	Yield	b[c]
	t/ha			t/ha	
CO	5.88	1.04	CO	4.89	1.04
C2	5.88	1.01	C1/C2	4.96	0.92
C4/C5	6.23	0.96	C4/C5	5.32	1.04
LSD (P<0.05)	0.11	0.04		0.14	0.06

[a] Means of eight populations evaluated at six sites.
[b] Means of four populations evaluated at seven sites.
[c] Stability parameter of Eberhart and Russell (1966).

Table 5. Estimates of means, components of variance, and expected progress from full-sib family recurrent selection in 12 CIMMYT populations.

Population	Mean[a]	Components of variance[a] Error	G X E	Genotypic	Expected gain[b] 6 env.	3 env.
		X 10^{-4}			%	
21	5.09	8515	3712	1422	3.49	2.86
22	5.28	8111	2287	1375	3.39	2.83
24	4.97	6736	1760	1955	4.86	4.26
27	4.54	5997	1297	1771	5.13	4.52
28	4.75	7259	2138	1433	4.04	3.41
29	5.24	7449	3102	1108	2.92	2.38
32	4.08	6578	1704	1611	5.24	4.42
35	4.92	5525	1150	1286	3.89	3.37
36	5.19	6598	1486	1481	3.92	3.37
43	5.56	9555	2194	1705	3.75	3.17
48	6.09	5176	1282	1399	3.33	2.90
49	5.05	5783	1269	1440	4.04	3.51

[a] Weighted means where weights were the inverses of the variances of the parameters estimated each cycle of selection.
[b] Expected gains from selection calculated assuming the ratio of dominance variance to additive genetic variance to be 0.9377 (average of 99 maize genetic studies reported by Hallauer and Miranda, 1988) and a selection intensity of 20%.

Overview of International Testing, CIMMYT Maize Program

P. Byrne

Preliminary Activities

CIMMYT's Maize Program has its roots in a cooperative venture of the Mexican government and the Rockefeller Foundation begun in the 1940s to improve maize and wheat production in Mexico. The maize section of the program gradually expanded to include most maize growing areas of the developing world. Program scientists evaluated a wide array of germplasm sources and put together many broad-based maize populations as a prerequisite to population improvement, which was undertaken shortly afterward.

In the late 1960s and early 1970s several types of international trials, including International Maize Adaptation Nurseries and International Opaque-2 Maize Trials, were conducted as initial tests of adaptation of maize varieties over a wide range of environments. By 1973, CIMMYT had decided that 28 populations (including five opaque-2 populations) had been sufficiently improved for uniformity, yield, and other agronomic characteristics, and met important germplasm needs in target countries. These populations formed the basis for a systematic international testing program instituted in 1974.

International Progeny Testing Trials (IPTTs)

In 1974 full-sib progenies of each of the 28 advanced populations were organized into trials known as IPTTs. These trials, which are the basic element of CIMMYT's international testing system, have served the dual functions of 1) distributing information and materials to a network of maize researchers in developing countries and 2) generating data for use in a full-sib (FS) population improvement scheme.

The first two cycles of selection of these populations involved two growing seasons per cycle. In the first season, 250 FS families plus 6 checks were evaluated for yield and agronomic characteristics in a two-replication, 16 x 16 lattice trial (IPTT). Each IPTT was grown at one CIMMYT station in Mexico and five other locations volunteered by national program cooperators and chosen to represent in a broad sense the environment for which a population was targeted. Simultaneously, one replication each was evaluated in disease, insect, and high-density nurseries at a CIMMYT station. In the second season, families selected on the basis of their IPTT performance combined over locations and evaluations in the stress nurseries were recombined, and the next set of progeny produced.

Beginning in 1976 a modified FS recurrent selection procedure, in which one cycle of selection is completed in four cropping seasons or two years, was employed (Fig. 1). This system allowed sufficient time for IPTT results from the southern hemisphere to be returned and used for population improvement, and provided the opportunity for intra-family selection. Along with this change, the populations undergoing improvement in the IPTT system were divided into two groups, so that about half were available for distribution as IPTTs each year. The system functioned as follows. In Season 1 progeny were regenerated by making reciprocal FS crosses and selecting the 250 best pairs of ears at harvest. In the following season the IPTT was grown at up to six locations, as described above. In Season 3 the 250 FS families were planted in a nursery, and plants within families were selected for a major trait of importance to that population, such as shorter plant height, earlier maturity, or resistance to stalk borers or diseases. Normally, three-to-eight plants in each FS family were self-pollinated and two-to-five S_1 ears per family were selected at harvest. Meanwhile, based on results of the IPTTs across locations, the best fraction of the FS families was selected. The selection intensity was generally 35-40% during the first five cycles and 15-20% thereafter. S_1 families from selected FS families were planted in Season 4 and recombined using a bulk of pollen from the selected families. Selection for the major trait was again practiced during this season. To regenerate FS progeny for the next cycle, half-sib ears harvested in Season 4 were planted ear-to-row and reciprocal plant-to-plant crosses made between plants originating from different FS families.

Corresponding to each population in the IPTT system are one or more broad-based gene pools of the same germplasm class, which are also undergoing improvement (Tables 1 and 2). From time to time small amounts of germplasm from corresponding pools have been introgressed into the advanced populations. The proportion of introgressed germplasm varied, but was usually 15% or less during a given cycle.

Whereas the breeding work for most of the populations was carried out at CIMMYT experiment stations in Mexico, some populations were handled by CIMMYT regional programs. Populations 22, 28, and 31 were selected for downy mildew resistance in Thailand and the Philippines, and Population 43 was selected for resistance to maize streak virus by CIMMYT staff at IITA in Nigeria. As of 1989, all IPTT populations are again being managed from Mexico.

The number of populations under improvement in the IPTT system has changed over the years, from as many as 28 in 1979 to 17 in 1991-92. Populations have been discontinued, added, merged with other populations, replaced completely by new germplasm sources, and temporarily withdrawn and later resumed. Apart from three short-lived populations (Populations 91, 92, and 93) which were included in the system in 1987-88, no new populations have been added since Population 23 in 1985.

Recent Modifications to the IPTT System

Since 1987, the following modifications have been introduced into the standard IPTT system described above:

1. Recognizing the frequently used heterotic pattern existing between Populations 21 (Tuxpeño-1) and 32 (ETO Blanco), a modified reciprocal recurrent selection (MRRS) scheme involving these populations was initiated in 1985. The half-sibs were sent out for evaluation for the first time in 1987. In this procedure, in which three years are required to complete a cycle of selection, yield trial entries are testcrosses derived by crossing S_1 and/or S_2 families of one population with a synthetic variety of the other population. The testers were EVs in C_1 and synthetic varieties in C_2.

2. By the late 1980s, the Maize Program had received numerous comments from national program cooperators about the expense of evaluating trials as large as the standard IPTTs (512 5-m rows). Also, CIMMYT breeders, were of the opinion that the number of families could be reduced from 250 to a more manageable size and at the same time maintaining enough genetic variability for long-term population improvement. Thus, in 1989 the size of IPTTs was changed from a standard 16 x 16 lattice to a variable size square lattice (from 11 x 11 to 16 x 16) depending on the number of pairs selected at harvest. Because feedback from cooperators and CIMMYT regional staff argued for

a standard size trial, in 1990 and 1991 all IPTTs were 12 x 12 lattices. This size was considered by some to be too small for continued progress from selection in long-term populations, and in 1992 trial size was increased to a 14 x 14 lattice (196 entries or 392 5-m rows). At the internal review of International Testing, there was general agreement that this size offered a reasonable compromise between practical considerations of trial management expenses and theoretical considerations about population size and maintenance of genetic variability.

3. Another generation of self-pollination was 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. It also provides an opportunity to evaluate more homogeneous S_2 progeny for disease and insect reaction, and to eliminate lines which do not respond well to inbreeding.

4. 1987 was the last year of QPM (Quality Protein Maize) IPTTs. Thereafter, QPM work concentrated on the development of hybrid-oriented germplasm rather than on population improvement.

Experimental Variety Trials (EVTs)

Yield and agronomic data from each IPTT site are used to identify the best FS families, usually 10, for formation of experimental varieties (EVs), which are the entries in EVTs. These are developed by making plant-to-plant crosses among the selected families in all possible combinations, forming a balanced composite sample of seed from ears selected at harvest, and advancing to the F_2 stage by bulk pollinating plants resulting from the composite sample. In the first few years, F_1 seed from crosses was tested. Later F_2 seed was used in EVs, as yield depression was observed from F_1 to F_2.

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 "Tlaltizapan 8844," for example, was developed from the 10 best families of IPTT 44 tested at Tlaltizapan, Mexico in 1988. In addition, a site-specific EV can be formed upon request from cooperators who have found certain families to be superior, based on field observations of characteristics of interest to them. In this case a number is inserted in parentheses after the name of the test location, as in Takfa (1) 8736. For each IPTT one experimental variety, termed an "Across EV," is formed on the basis of combined information from all sites reporting data. An example is Across 8622, which was developed on the basis of 1986 IPTT 22 results from El Salvador, India, Mexico, and Thailand.

EVTs are organized according to ecological adaptation (tropical, subtropical, or highland), maturity, grain color, and endosperm type (opaque-2 or normal) (Tables 1 and 2). They typically include from 10 to 20 new EVs, 2 stable, high yielding EVs from previous years (termed reference entries), and 2 local checks supplied by the national program cooperator. The trials are arranged in a randomized complete block design with four replications. Each plot consists of four 5-m rows, but only the two central rows are used for recording data. Sufficient seed is provided to permit overplanting and thinning to the desired stand, which is recommended to be 53,000 plants/ha. Distribution of EVTs began in 1975.

Both our regional staff and NARS cooperators have asked for the inclusion of a wider variety of materials, especially stress-resistant germplasm sources, in EVTs. Therefore, the 1991 and 1992 EVTs included a number of new materials that performed well in the 1989 Preliminary Evaluation Trials (PETs; described in greater detail below) and / or were considered to have traits of interest to a significant number of cooperators. These materials were from the hybrid, pathology, physiology, entomology, and late and early tropical and subtropical germplasm development units at HQ and from CIMMYT regional breeding programs. In preliminary analysis of the 1991 EVTs, some of these entries have performed quite well (Table 3).

In line with a gradual de-emphasis of research on quality protein maize, QPM EVTs were last offered in 1990.

Elite Variety Trials (ELVTs)

ELVTs were established in order to provide smaller trials containing a subset of pretested varieties to national programs with limitations in trained personnel and other resources. Thus, beginning in 1976, varieties which gave the most promising results in EVTs were designated elite varieties and evaluated for a second year in ELVTs. Although it was foreseen that the distribution of these elite trials would be greater than that of the EVTs, in practice the number of sets distributed per trial for both EVTs and ELVTs was similar.

ELVTs had the same design as EVTs, but were broader in the type of germplasm included. For example, tropical late white varieties from EVT 12 and tropical late yellow varieties from EVT 13 were combined in ELVT 18A; ELVT 18B combines yellow and white tropical intermediate; subtropical ELVT 20 combines early, intermediate, and late maturities, and white and yellow grain colors in the same trial (Table 1). While such combinations might have been appropriate in the early years of international testing in order to combine a wide range of materials in a single trial, national programs have become increasingly interested in a more limited range of germplasm types. Many of our cooperators, for example, are interested in only one color of maize.

To provide a second year of testing for promising varieties while limiting a trial to a given class of germplasm, it was decided in 1991 to include elite varieties for a second year in the same EVT in which they were originally tested (Table 3). This arrangement also allowed for a more direct comparison of EVs developed in different years.

Preliminary Evaluation Trials (PETs)

At intervals of three or four years the Maize Program has organized PETs as a vehicle for preliminary in-house evaluation of new germplasm materials. These materials are assigned to trials according to ecological adaptation and maturity, and are grown by CIMMYT regional and HQ staff and a very limited number of national program cooperators. Cycles of selection, varieties, and synthetics have all been included as entries. PETs are useful in informing breeders how their new materials compare to other CIMMYT materials across a range of international sites. PET results have been used to identify promising entries for inclusion in EVTs, and might also be used to decide when a new population should be promoted to the IPTT system.

Special Trials

In addition to the above mentioned trials which are an integral part of the population improvement program, several special trials are conducted by the various subunits in the maize program. A few examples are: Line evaluation trials (LET), hybrid trials, stress-tolerant germplasm trials, trials arising out of special projects handled by Post-Docs and Associate Scientists. These trials are conducted for a specific purpose, and thereby are usually not recurrent in nature. Evaluation is done in more than one environment and are usually grown by CIMMYT regional and HQ staff. International testing unit provides assistance in the conduct of these trials through field book preparation, trial shipment, data entry and analysis (whenever possible and on request by the staff).

Agro-Ecological Information

For a valid interpretation of trial data, some knowledge of the ecological and climatic conditions in which a trial is evaluated is necessary. Prior to 1989 only a limited amount of such information was provided by cooperators. CIMMYT requested data on plot size, fertilization, and planting and harvest dates; solicited general comments on trial conditions; and provided sheets for recording rainfall and temperature data. Beginning with the 1989 trials, a sheet requesting more extensive agro-ecological information was sent with each trial (copy attached at the end of chapter). This information is reported along with trial results and is stored in an organized fashion to facilitate its future use.

Trial Distribution

In November or December of each year about 400 maize researchers in more than 80 countries are sent a letter announcing CIMMYT's international maize trials for the coming year. Cooperators return a trial request form indicating the number of sets of each trial they want to evaluate along with the proposed planting sites and dates. CIMMYT HQ staff review the appropriateness of each request and, together with regional staff, make final decisions on trial distribution. Most cooperators in the international testing network are public sector researchers in developing countries, and these collaborators receive priority in trial distribution when trial numbers are limited, as is the case with IPTTs. Generally EVT's and ELVT's are distributed without any restrictions to all cooperators whether public or private, as long as enough sets of the trials are available. Occasionally, researchers in more developed countries, such as Greece, Portugal, or South Africa, request and grow CIMMYT maize trials.

Since its inception in 1974, the international testing program has distributed some 1489 IPTTs, 6705 EVTs, and 3155 ELVTs, (Tables 4-6, Fig. 2). A total of 1432 EVs have been developed and evaluated in international trials during this period.

The decline in the number of trials distributed in recent years is due to a number of factors. One of them is a decrease in the number of standard international trials offered by CIMMYT headquarters. As mentioned previously, the number of IPTT populations has been reduced, QPM trials have been gradually phased out, and ELVTs have been shelved, at least temporarily. To some extent, this decrease has been offset by a growing number of CIMMYT regional trials (Chapter 5) and special trials organized from headquarters (data not shown). Trial distribution to West and Central Africa has declined since

1989 because of an agreement with the Maize Program of the International Institute of Tropical Agriculture (IITA), which gives primary responsibility for support of national programs in the region to that institution. The large number of EVTs distributed in 1988 (Fig. 2) appears to be a combined effect of an unusually large number of trials offered (possibly materials on hold from previous years) and an unusually large demand from cooperators (e.g., Peru, which normally receives some 6 trials, was sent 36 in 1988). Finally, requests for trials from some national programs has declined, at least partly due to their budgetary constraints.

Performance: EVs versus Local Checks

CIMMYT has designed its international maize trials to be conducted by national research programs, thus enabling them to explore the potential for utilizing CIMMYT germplasm under local conditions. A good index of this potential for a given environment is the performance of CIMMYT materials relative to that of locally adapted cultivars. Figure 3 shows the percentage of variety trials (EVTs plus ELVTs) in which the best CIMMYT EV yielded equal to or better than the best local check, based on experiments with similar plant stands for all varieties. Percentages for tropical trials (mean of 72%) are consistently higher than those for subtropical trials (mean of 57%) (Figs. 3A and 3B), probably reflecting the existence of more advanced national programs and the availability of more improved germplasm in many subtropical areas. The improvement over time of CIMMYT QPM germplasm relative to local checks is seen in Figure 3C; mean percentage for the first nine years is 48, compared to 63 for the last six years of testing. Trends over time are more difficult to discern in the tropical and subtropical classes, although there may be a slight downward tendency in both cases, indicating the availability of better local materials.

International Testing Reports - Some Recent Changes

Results from the international testing trials are presented to our cooperators twice a year, a preliminary report which includes data received by a particular cut-off date (usually June) and a final report 4-6 months later including complete results. The report in its present form is a product of several minor modifications and additions done over the years. As mentioned earlier, starting with 1989, agro-ecological information is furnished along with the trial results wherever available. In the mid-1980's, the mean performance of entries in EVTs and ELVTs across environments were further stratified according to region (eg. South America, Asia, etc.) and expressed along with the overall means. This aided in identifying region-specific genotypes. In some years the grouping of environments was done using cluster analysis to identify homogeneous set of agro-ecological environments. Starting with 1987 reports, Russell-Eberhart's stability parameters were included for the entries from EVTs and ELVTs. In the same year, stratified ranking diagrams were included showing the number of locations in which a particular entry ranked in the top, middle and bottom one-third of all the entries tested in that trial. With the advancements in computer technology and power of desk-top publishing, the reports of the future will include more easy to read graphs and eye-pleasing fonts.

Feed-back from National Program Leaders and CIMMYT's Internal Review

In September 1991, several national maize program leaders participated in a six-week advanced Maize Breeding course conducted at CIMMYT. Their knowledge and experience as cooperators was tapped through a brain-storming session in which several issues related to international maize testing program were discussed. The feed-back obtained from these sessions are summarized in Appendix 1. Later, in early December 1991, an internal review of international testing was conducted with several of our outreach staff participating. Recommendations and observations from this exercise are summarized in Appendix 2.

Varieties Released

Once a cooperator has evaluated a trial and examined the results of data analysis, the next step is to request from CIMMYT seed samples of the most promising entries. A cooperator may proceed with seed multiplication and more extensive testing of these materials, and one or more may eventually be released as a variety, without additional breeding effort. Alternatively, a researcher may carry out selection for local adaptation or other traits in these materials prior to their release. A third route toward the utilization of CIMMYT germplasm is to cross it to other materials and proceed in a number of different ways to obtain a new variety or hybrid. The fourth route is to use these varieties as parents of nonconventional hybrids.

In 1991 CIMMYT's Economics Program undertook a major study of the impacts of CIMMYT maize and wheat research. One part of that study involved surveying NARS on the number of maize varieties released in their countries and the contribution of CIMMYT germplasm to those varieties. Results of that survey, plus additional information received subsequently, show that varieties containing at least some contribution from CIMMYT are grown on 13.2 million hectares in the developing world (Table 7). Additional analysis on patterns of variety release and other aspects of CIMMYT's impact is contained in *1991-92 World Maize Facts and Trends: Maize Research Investment and Impacts in Developing Countries.*

Table 1. Relationship between gene pools, populations, and variety trials in CIMMYT's normal maize improvement program.

Adaptation	Grain color	Type	Pools	Populations	EVT	ELVT
Tropical-Full Season	White	Flint	23	25	12	18A
		Dent	24	21, 22, 29, 43		
	Yellow	Flint	25	27	13	
		Dent	26	24, 28, 36		
Tropical-Short and Intermediate Season	Yellow	Flint	17	31	14A	18B
			21	26		
		Dent	18, 22			
	White	Flint	15	30	14B	
			19	23, 32		
		Dent	16	49		
			20			
Subtropical-Short, Intermediate, and Full Season	Yellow	Flint	29	46	16A	20
			33	33		
		Dent	30	48		
			34	45		
	White	Flint	31	34	16B	
			27			
		Dent	32	42, 44, 47		
			28			

Table 2. Relationship between gene pools, populations, and 1989 variety trials in CIMMYT's quality protein maize improvement program.

Adaptation	Grain color	Type	Pools	Populations	EVT	ELVT
Tropical-Short season	White	Flint	15 QPM			
	Yellow	Flint	17 QPM	61QPM	15A	
		Dent	18 QPM			
Tropical-Full season	White	Flint	23 QPM	62 QPM	15B	
		Dent	24 QPM	63 QPM, 64 QPM		
	Yellow	Flint	25 QPM	65 QPM	15C	19
		Dent	26 QPM	66 QPM		
Subtropical-Short season	White	Flint	27 QPM			
	Yellow	Flint	29 QPM			
Subtropical-Intermediate season	White	Flint	31 QPM	67 QPM	15D	
		Dent	32 QPM	68 QPM		
	Yellow	Flint	33 QPM	69 QPM		
		Dent	34 QPM	70 QPM		

Table 3. Summary of results of 1991 EVT 16A combined over 14 locations. Entries 7-9 are new materials from the Hybrid, Entomology, and Physiology units, respectively. Entries 10 and 11 are elite varieties selected on the basis of their performance in 1990 EVT 16A.

Variety		Region			Overall Means			Eberhart-Russel Stability Parameters for Yield/	
Number	Name	II kg/ha	III kg/ha	VI kg/ha	Yield kg/ha	Days silk	Plant height	b	MS(D)
9	TL-SPS 88591	7715	8015	6351	7199	67	212	1.13	**
2	SIDS 8845	/7412	8354	5662	6972	67	204	1.14	NS
11	Tlaltizapan 8833	7411	8102	5368	6734	64	197	1.04	NS
10	Tlaltizapan 8845	7112	8306	5264	6727	65	197	1.12	NS
1	DUC TRONG 8845	6991	8278	5317	6725	67	202	1.20	*
12	Capinopolis 8645 RE	6668	7695	5344	6461	65	200	0.94	**
8	ACROSS 86590	7123	7361	5192	6317	67	209	0.94	**
7	S8833	7589	7360	4980	6280	66	203	1.02	**
4	La Platina 8848	6693	7666	4293	5962	61	192	0.97	**
3	Tlaltizapan 8848	5443	7614	4005	4641	59	180	0.85	NS
5	Pichilingue 8793	6209	6817	4171	5501	60	179	0.98	**
6	Pelotas 8793	5726	7147	3954	5468	59	179	0.82	NS
13	La Platina 8546 RE	6401	6500	4077	5356	61	190	0.78	**
Means		6807	7632	4921	6257	64	196		
Number of locations		2	6	6	14				
Effect of varieties		NS	**	**	**				
Variety X location interaction		**	**	**	**				
5% LSD		2548	971	938	633				
CV (%)		18	13	15	14				

NS = Not significant at the 0.05 probability level
** = Significant at the 0.01 probability level

Regions: II = Central America, North America, and Caribbean
III = North Africa and Near East
VI = Asia

Table 4. Distribution of IPTTs, 1974-1992.

	South America	Caribbean, Central & N. America	Mideast/ N.Africa	Sub-Saharan Africa	Asia	Others	Total
1974	17	73	8	10	44	1	153
1975	16	66	9	20	27	0	138
1976	10	49	4	6	16	0	85
1977	13	33	2	11	12	0	71
1978	22	30	4	9	9	0	74
1979	21	39	1	8	7	0	76
1980	11	30	1	10	14	0	64
1981	13	21	1	16	16	0	67
1982	16	17	4	11	18	0	66
1983	26	34	1	17	16	0	94
1984	21	23	5	18	18	2	87
1985	25	33	4	17	20	0	99
1986	19	20	4	9	19	0	71
1987	13	37	1	11	19	0	81
1988	8	11	3	8	11	0	41
1989	12	16	5	20	18	0	71
1990	7	18	3	8	8	0	44
1991	9	15	6	9	16	0	55
1992	9	15	3	5	20	0	52
TOTAL	288	580	69	223	328	3	1489

Table 5. Distribution of EVTs, 1974-1992.

	South America	Caribbean, Central & N. America	Mideast/ N.Africa	Sub-Saharan Africa	Asia	Others	Total
1975	42	66	10	30	29	2	176
1976	44	84	10	44	36	1	219
1977	41	69	18	41	25	1	195
1978	62	81	33	75	44	2	297
1979	39	64	29	67	46	5	250
1980	72	109	10	162	70	5	428
1981		43					
1982	69	151	16	160	104	13	513
1983	73	133	16	155	129	10	516
1984	84	124	14	141	127	12	502
1985	78	109	24	128	151	10	500
1986	67	41	17	133	243	0	501
1987	73	71	11	142	139	3	439
1988	124	109	25	168	343	0	769
1989	91	28	43	110	195	0	467
1990	50	49	36	89	129	2	355
1991	34	60	12	67	76	0	249
1992	66	59	20	55	127	2	329
TOTAL	1109	1450	344	1767	2013	68	6705

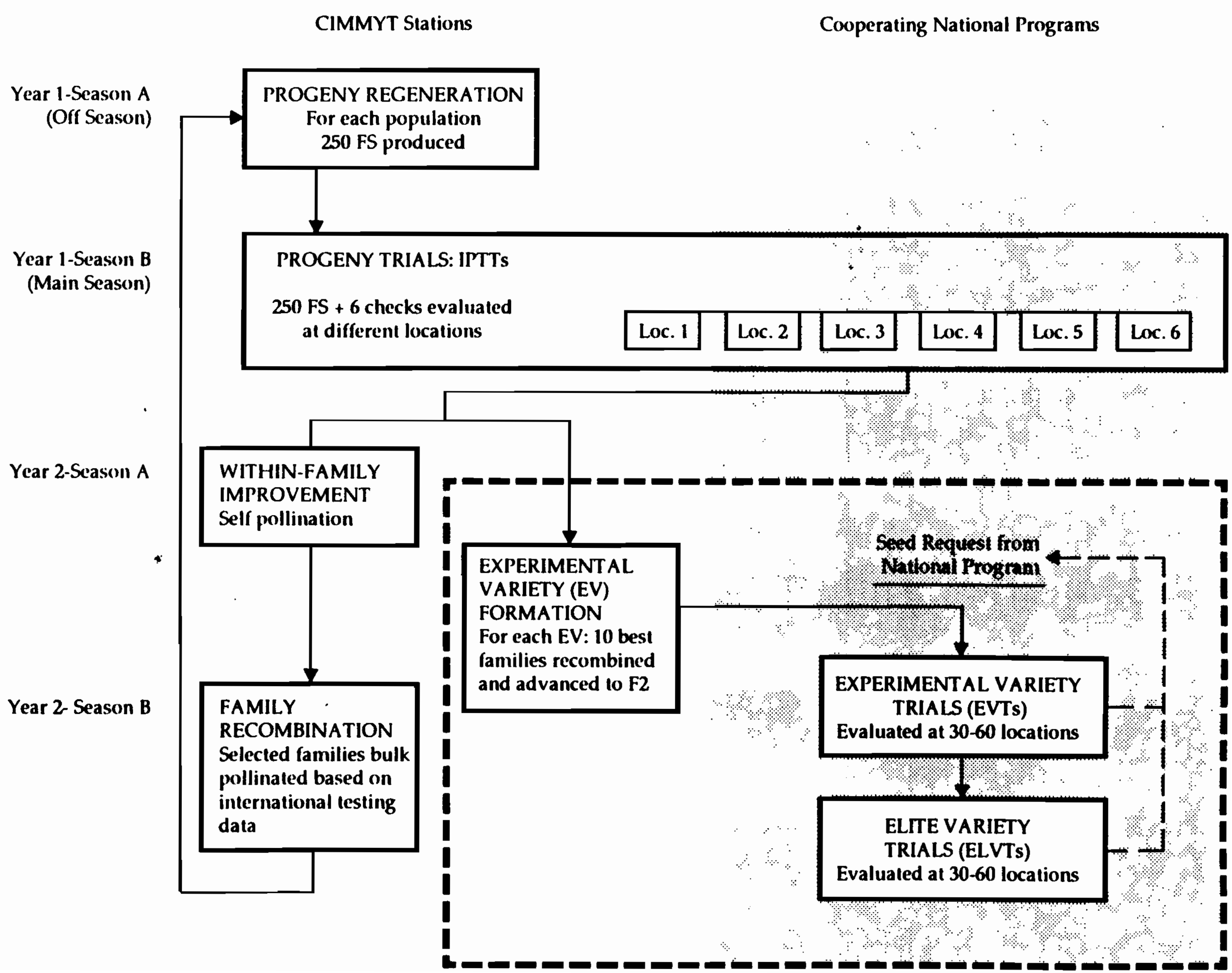
Table 6. Distribution of ELVTs, 1976-1991.

	South America	Caribbean, Central & N. America	Mideast/ N.Africa	Sub-Saharan Africa	Asia	Others	Total
1976	34	70	8	47	44	2	205
1977	42	61	17	43	23	0	186
1978	40	86	21	68	32	0	247
1979	33	63	22	68	42	4	232
1980	48	62	11	116	49	5	291
1981	70	80	13	134	58	12	367
1982							
1983	21	48	5	83	57	3	217
1984	22	48	8	73	39	1	191
1985	35	50	20	71	51	5	232
1986							
1987	49	71	28	129	108	2	387
1988	45	21	22	68	56	0	212
1989	40	20	21	69	8	10	231
1990	6	12	9	44	45	0	116
1991	13	4	1	11	12	0	41
TOTAL	498	696	206	1024	697	34	3155

Table 7. Developing country area, (million ha) under varieties that contain CIMMYT contributions.

Region	Some CIMMYT	Mostly CIMMYT	Total CIMMYT
Sub- Saharan Africa	0.7	1.3	2.0
West Asia & N. Africa	0.5	0.0	0.5
Asia	3.7	1.4	5.1
Latin America	3.6	2.0	5.6
All developing countries	8.5	4.7	13.2

Figure 1. Steps in population improvement and experimental variety development, evaluation, and use.



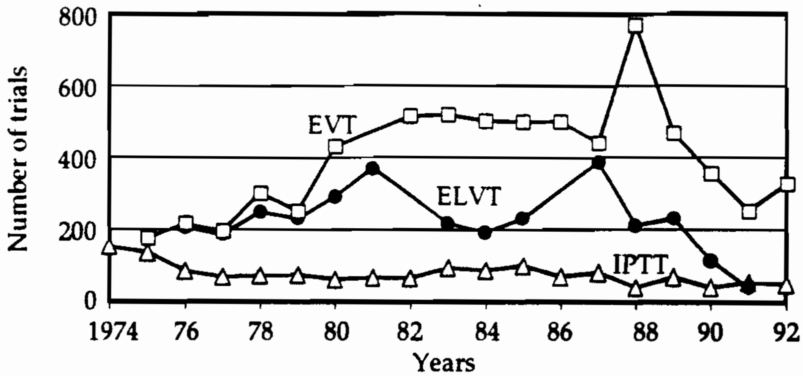


Figure 2. Distribution of CIMMYT maize trials, 1974-92.

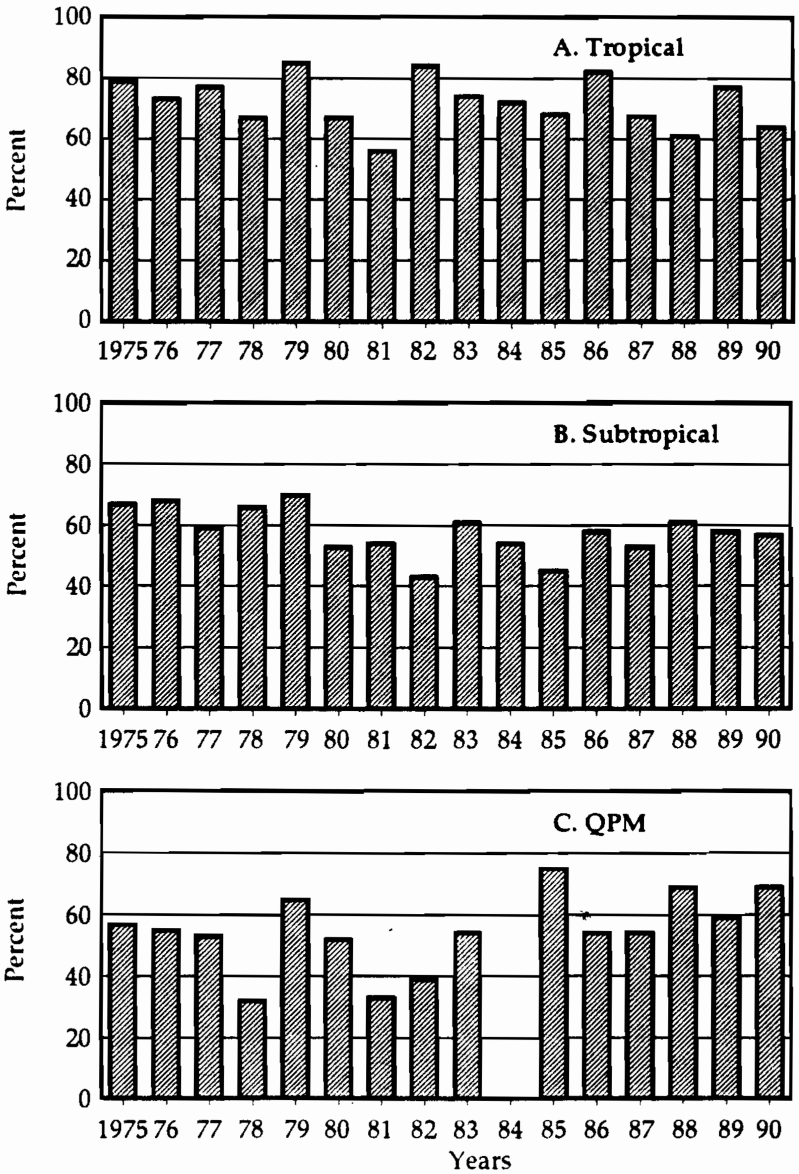


Figure 3. Percentage of variety trials in which CIMMYT EV's yielded more than or equal to the best local check, by type of trial.

FOR COOPERATOR

C I M M Y T
INTERNATIONAL MAIZE TESTING UNIT
GENERAL NOTES TO BE RECORDED

SIDE A

COPY TO RETURN

FOR CIMMYT USE ONLY
TRIAL NAME: ____________
YEAR: ________ PLAN: ________

COUNTRY: ____________ LOCATION: ____________
COOPERATORS(S): ____________
INSTITUTION: ____________ ABBREVIATION: ____________
ADDRESS: ____________

ADDRESS USED FOR RETURN OF ANALYSIS (IF DIFFERENT): ____________

LATITUDE: ____________
LONGITUDE: ____________
ELEVATION: ____________ m above sea level

DATE PLANTED ____ ____ ____
DATE HARVESTED ____ ____ ____
Month Day Year

CHECK VARIETIES:

Entry No.	Check name

PLOT SIZE:

A No. of rows harvested ____________
B Row length at harvest ____________ m
C Distance between rows ____________ m
D Distance between hills ____________ m
E No. of plants/hill ____________
F Plot size = Ax(B+D)xC ____________ m^2

UNITS USED TO RECORD DATA:
Please check [X] appropriate box and provide requested information

Variable	Name of disease/insect	Counting	1-5* scale	Other (specify)
Lodging				
Ear rot				
Disease (1)				
Disease (2)				
Insect (1)				
Insect (2)				
Bad husk cover				

*** 1 = Best 5 = Worst**

OTHER COMMENTS ON DATA RECORDED: (Metric units are assumed for field and grain weight and for plant and ear height. Please indicate if otherwise.)

____

CIMMYT INTERNATIONAL MAIZE TESTING UNIT

GENERAL NOTES TO BE RECORDED, SIDE B

WEATHER AND MANAGEMENT INFORMATION FROM PLANTING TO HARVEST
Please check [X] appropriate box and provide requested information

MOISTURE	mm	WEATHER	
Total rainfall	______	Normal	______
Water applied by irrigation	______	Abnormal	______

If daily temperature and rainfall data are available, please send us a copy.

SOIL	SOIL TEXTURE		% ORGANIC MATTER		SOIL pH	
	Sandy	______	Very low (<1%)	______	<4	______
	Sandy loam	______	Low (1-2%)	______	4-5.5	______
	Clay loam	______	Medium (2-5%)	______	5.5-7	______
	Clay	______	High (>5%)	______	> 7	______
	Other:	______	Exact value if known:	______	Exact value if known:	______

MANAG.	FERTILIZER APPLIED:	Kg/ha		Yes	No
	Nitrogen	______	Chemical insect control	___	___
	Phosphorus (as P_2O_5)	______	Chemical weed control	___	___
	Potassium (as K_2O)	______	Organic fertilizer	___	___
	Other: ______	______	Liming	___	___

GENERAL PERFORMANCE		CROP SEASON		SOWING TIME		DISEASE PROBLEM		INSECT PROBLEM		WEED PROBLEM	
Good	___	Major	___	Early	___	1*	___	1*	___	1*	___
Fair	___	Minor	___	Normal	___	2	___	2	___	2	___
Poor	___			Late	___	3	___	3	___	3	___
						4	___	4	___	4	___

NUTRIENT PROBLEM		SOIL TOXICITY		DROUGHT		FROST	
1*	___	1*	___	1*	___	1*	___
2	___	2	___	2	___	2	___
3	___	3	___	3	___	3	___
4	___	4	___	4	___	4	___
Specify: ______		Specify: ______		What stage? ______		What stage? ______	

* 1 = Not present or negligible 2 = Slight 3 = Moderate 4 = Heavy

CIMMYT USE ONLY

OTHER COMMENTS ON TRIAL PERFORMANCE OR GROWING CONDITIONS: (e.g., stresses, explanation of missing plots, opinions of trial entries, etc.)

____
____
____
____

4

CHAPTER

Germplasm Development and Regional Testing: Africa

H.Pham and K. Short

The primary emphasis in germplasm development of the program at Harare is on midaltitude materials. This type of germplasm is planted on most of the maize land in eastern and southern Africa. Since the program's initiation in 1985, several streak resistant populations and inbreds have been developed and are being utilized by NARS in the region. Since 1988, CIMMYT has also posted a breeder to Zimbabwe to work on tropical lowland early germplasm, particularly for resistance to maize streak virus. Improvement for this trait in tropical materials has been excellent. Both breeders at Harare focus on midaltitude materials, with limited attention to early tropical germplasm sources for eastern and southern Africa. A CIMMYT breeder located at Boake, Côte d'Ivoire, is responsible for work on stress resistance in lowland tropical late germplasm, particularly for western and central Africa, in collaboration with IITA.

Lowland Tropical Maize Research

According to CIMMYT's mega-environment data, there are two million hectares of maize grown in the lowland tropical ecologies of eastern and southern Africa. Early and intermediate maturing maize types predominate and white is the preferred grain color. Major limiting factors for maize production are maize streak virus (MSV), tropical leaf rust and blight, *Diplodia* and *Fusarium* stalk rots, and *Chilo partellus* stalk borers. Drought is the most severe abiotic constraint for maize production in many countries in the region. Strong interest in hybrids exists in most national breeding programs.

The objective of the lowland breeding program at Harare is to generate source germplasm and intermediate products with acceptable yield levels and the required genes for controlling the negative effects of the major biotic and abiotic stresses encountered in the region. Research efforts center around the following:

- Attaining high levels of resistance to maize streak virus for important germplasm groups in the region. Breeding procedures used are the genetic conversion of elite germplasm and the introgression of MSV resistant materials into adapted maize. We are improving resistance to MSV in four populations of two heterotic groupings.

- Developing germplasm resistant to other major diseases and insects. Yield stability is emphasized in the evaluation of progenies in multilocation testing.

- Identifying early generation lines and delineating heterotic groupings through systematic combining ability tests.

Midaltitude Maize Research

Midaltitude maize germplasm is the predominate type in eastern and southern Africa, with seven million hectares planted annually. This ecology can be defined as tropical zones in Africa between 23°S and 23°N at elevations between 800 and 1,800 masl. The midaltitude zone comprises a large part of eastern and southern Africa with additional areas in Nigeria, Cameroon, Madagascar and La Reunion. Maize in this zone is white and predominantly semident. The environment is characterized by hot days and cool nights during the growing season with periods during vegetative-to-pollination stage where extensive cloud cover and intermittent rain can greatly change growth parameters. Delay in planting date will result in reduced plant height and greatly reduced yields. Length of growing season is normally greater than 5 months. Yields in this environment under excellent management can be extremely high. *H. turcicum* and *P. sorghi* are the two most important foliar disease problems, especially in humid areas. MSV is endemic in this zone; severity fluctuates according to rainfall patterns and time of planting. *Diplodia* and *Fusarium* ear rots can be very severe, especially in humid areas. Drought causes considerable season-to-season fluctuation in yields in certain parts of this area. *Busseola fusca* and *Chilo partellus* can also cause yield reductions, especially in the low input marginal production zones.

Early-to-intermediate maturity germplasm occupies approximately 3 million hectares of production in the midaltitude zone. This mega-environment has more seasonal drought stress as well as the problems indicated previously. Sources of this germplasm type have received less attention in the past. Results from trials, on-farm surveys and other less formal data collection indicate that if more appropriate, drought tolerant, early-to-intermediate germplasm were available, the area planted to this type of maize would likely expand. CIMMYT is thus strengthening research considerably on this class of maize.

We have developed several populations with good levels of resistance to MSV and adaptation to the region for evaluation and are improving them through S1 *per se* and S1 testcross evaluations. We are applying relatively intense pressure for earliness, drought tolerance, grain type, disease reaction, and yield during the selection of families for recombination.

The intermediate germplasm development program has developed a number of useful alternatives at the population, inbred and hybrid level. Seven streak resistant populations are in recurrent selection programs as indicated below:

Population	Research Target	Methodology
INT-A	A heterotic group	S1 x tester
INT-B	B heterotic group	S1 x tester
ZM605	B heterotic group	S1 x tester
ZM609	N use efficiency	S1 *per se*
DR-A	A group - drought	S1 *per se*
DR-B	B group - drought	S1 *per se*
ZM601	A group - drought	S1 *per se*

These populations are very useful *per se* or as sources of new superior lines.

Late maturity midaltitude maize is planted on 5 million hectares in eastern and southern Africa. This environment can have very high yield potential, as characterized by the Kitale area of Kenya, southern highlands of Tanzania, parts of Malawi, Zambia and Zimbabwe. This area is either planted predominantly to hybrids or rapidly taking up hybrid cultivars. CIMMYT research related to this environment has a correspondingly strong emphasis on the hybrids. Four late maturing, streak resistant populations are in recurrent selection with a specific heterotic target as indicated:

Population	Research Target	Methodology
LAT-A	A heterotic group	S1 x tester
LAT-B	B heterotic group	S1 x tester
ZM607	A heterotic group	S1 *per se*
[MSRxPool9a]	Upper midaltitude	S1 *per se*

The S1 *per se* or *S1 x tester* recurrent selection schemes are providing many early generation line spin-offs to the inbred and hybrid development program. A number of late maturing inbreds are ready to be announced. ZM607 has been particularly useful as a source of new inbreds.

Special Emphasis Research Targets

Insect resistance

In collaboration with ICRISAT at Matopos, Zimbabwe, we are receiving sufficient *Chilo partellus* larvae to artificially infest lowland and midaltitude materials. Results indicate some of the MBR lines from CIMMYT Mexico have good levels of resistance to this borer. The MIRT population is under selection for combining *C. partellus* and MSV resistance at the lowland site in Mzarabani. We also have a pilot project on mass rearing *Busseola fusca* in collaboration with K. Leuschner of ICRISAT Matopos. Progress so far is very encouraging. Once the technique has been refined, we hope to begin screening midaltitude germplasm for resistance to this important pest.

Drought tolerance

Three populations—DR-A, DR-B, and ZM601—are being improved for tolerance to drought. ZM601 is being shuttled between Zimbabwe and Mexico to identify genes of value in drought prone environments. DR-A and DR-B are being improved in Zimbabwe at the Makoholi research station using S1 per se testing. It is hoped that the Makoholi station can be upgraded to facilitate this screening effort.

Nitrogen use efficiency

ZM609 has undergone recurrent selection for N use efficiency for two cycles. Inbred lines derived from the C1 selections for efficiency and inefficiency are showing remarkable differences in per se performance at low nitrogen levels. The N efficient lines are also showing encouraging results in hybrid combinations at both high and low nitrogen.

Hybrids

The increasing interest in hybrid maize in eastern and southern Africa requires that CIMMYT provide resource germplasm that, at the very least, possesses resistance to MSV. A program to evaluate inbred lines as single-cross and three-way-cross hybrids assists in identifying lines with good specific combining ability and provides guidance in their utilization. A set of these lines is ready for announcement to national programs.

Regional Trials and Germplasm Distribution

Regional trials

Preliminary Evaluation Trials (PETs) provide a mechanism for the evaluation and distribution of improved germplasm from the CIMMYT Harare station. These trials, which comprise 12-15 entries and 3-4 replications, are sent to national program cooperators and private seed researchers for evaluation. Cooperators thus have the chance to look at new germplasm in fairly small trials and CIMMYT researchers obtain feedback on the materials' performance under different climatic constraints of the region. To date we have been distributing two such trials, a lowland tropical PET and a midaltitude PET, to about 12 locations in alternate years. The CIMMYT Harare program, though, has developed to the point where germplasm distribution is of growing importance and we expect to replace these PETs with five types trials:

1. Lowland tropical PET
2. Early-to-intermediate maturity midaltitude PET
3. Late maturity midaltitude PET
4. Hybrid midaltitude PET
5. Inbred midaltitude PET

Due to their higher yield potential and the interest of national breeders, we feel it is important to distribute hybrid trials for the midaltitude ecologies but not the lowland tropics. Although at present only late maturing hybrids are offered for testing, intermediate maturing hybrids could enter the trials in the near future. The inbred PET trials will closely parallel the hybrid PET. The objective is to give cooperators a chance to see not only the hybrids but their respective parents in the area of interest.

Although we have distributed the PETs on a yearly basis, some types could be distributed less often, depending on the demand and our ability to generate competitive materials for testing. The elite varieties identified from the results of these PETs are tested further in international PETs distributed from headquarters and may ultimately be included in EVTs.

Eastern Africa Cooperative Regional Maize Variety Trials

The Eastern Africa Cooperative Regional Maize Variety Trials (EACRMVTs) were initiated to strengthen research cooperation among national scientists of the region. These trials were distributed in 1990 for the three main ecological zones of the region: high altitude (> 1800 masl), midaltitude (800-1800 masl), and low altitude (< 800 masl). Entries are hybrid and open pollinated varieties contributed mainly by the participating national programs of the region and CIMMYT. These trials could be conducted once every two or three years.

Cooperative research with CIMMYT headquarters

CIMMYT Harare maintains strong links with headquarters. Germplasm sources developed in Mexico or other CIMMYT programs are continuously being evaluated for their utility in eastern and southern Africa. Useful sources are further developed to improve their adaptation and subsequently evaluated in PETs. Promising materials are returned to CIMMYT Mexico for international testing at selected CIMMYT or NARS locations in a PET.

Trials are expensive to conduct. Special efforts should be made to coordinate the germplasm distribution efforts of CIMMYT Mexico and Harare, especially when working with some of the weaker NARS. The PETs organized by CIMMYT Harare cost much less to conduct than trials organized by CIMMYT Mexico and distributed in the region. In addition, materials from Harare are of much more interest to national breeders. CIMMYT Harare personnel have the advantage of personally visiting NARS in the region frequently and have thus built up considerable expertise as to types of materials required by specific countries.

Cooperation with IITA

Under the present agreement with IITA, CIMMYT entries for regional trials in western and central Africa can only be distributed in conjunction with IITA from Ibadan. Materials from CIMMYT Harare are sent first to the CIMMYT breeder in Côte d'Ivoire for preliminary evaluation under western Africa conditions and to increase seed. Promising entries are only then incorporated with other entries from IITA for distribution in that region.

5

CHAPTER

Germplasm Development and Regional Testing: Asia

C. De León and G. Granados R.

Background

Of the approximately 100 million tons of maize produced in Asia, over 75% is grown in China, and most of that lies in the country's northern temperate zone, where yields are high. Since CIMMYT is concerned with maize in the tropics and subtropics, we work with Chinese maize scientists primarily in the four southeastern provinces, where yields are lower and our improved germplasm can most readily be employed. Other major producers in the region (with more than 500,000 ha of maize area each) are India, Indonesia, Nepal, Pakistan, the Philippines, and Thailand. Vietnam and Bhutan, with less maize area, are also important, the former because of interesting developments in the cultivation of transplanted winter maize and maize after floating rice and the latter because maize is the country's most important crop. Asian countries (notably China, India, and Indonesia) encompass a wider array of maize production environments, cropping patterns, and management practices than are found in entire regions elsewhere in the world.

Average maize yields in the region are relatively low, only 1.6 t/ha, excluding the temperate zone of China. This figure reflects the secondary status of maize across most of the region; it is usually planted in upland areas where rice performs poorly or on marginal lands, primarily during the summer or rainy season and without irrigation.

In some areas (parts of Bhutan, India, Nepal, and Vietnam), maize is grown in the winter with or without irrigation. The total area planted to winter maize is relatively small (perhaps 1.5 million ha), but yields are good because of the cooler temperatures, longer grain filling period, and lack of moisture stress. The favorable conditions and low risk have prompted some farmers in the state of Bihar, India, to adopt hybrid maize and fertilizer for winter maize production, while for summer maize relying on local varieties and an inadequate supply of manure.

As a consequence of the low ratio of farmland to agricultural population, labor intensive technologies are appropriate in many cases, and highly productive systems are employed that would be totally impractical in other parts of the world. During the winter of 1988 farmers in Vietnam, for example, transplanted over 130,000 ha of winter maize into paddy fields to fit the crop into a rice-rice-maize sequence. The common use of multiple cropping (sequential, relay, and intercropping) has given rise in many parts of the region to a demand for early maturing varieties, even though the growing season is long enough for full season materials.

Adoption of improved varieties by farmers ranges widely in the region, from nearly 100% in Thailand to 40% in southern China to about 20% in India. In the more favorable areas, commercial farmers are adopting hybrid maize. Production of hybrid seed by private companies is expanding particularly fast in the Philippines, Thailand and India. In most Asian countries, the public sector is developing hybrids as well. Nearly all of the maize area in northern China, for example, is planted to single-cross hybrids. In the southern part of the country, open pollinated varieties (improved and local) still predominate, but hybrid breeding is heavily emphasized. CIMMYT germplasm has proved especially useful in southern China, both for population improvement and hybrid development. India's national program also offers hybrids but has experienced difficulty in getting them to farmers. Recent changes in legislation have encouraged the national seed corporation, plus a large number of private companies, to develop more aggressive seed production programs. It is likely that hybrid development will continue in various countries of the region and that a growing number of farmers in favorable areas will adopt these products. For marginal lands there is a pressing need for varieties that tolerate both abiotic stresses (such as drought, soil aluminum toxicity, and low fertility) and biotic stresses, mainly borers and various diseases.

Major Biotic and Abiotic Constraints

Drought, waterlogging, and low soil fertility are the most important constraints of maize production in the region, and their effects are exacerbated by various diseases and insect pests. Drought is a particular problem in much of Burma, southern China, India, Indonesia, Pakistan, the Philippines, Thailand, and Vietnam.

As elsewhere, N is the most limiting nutrient, followed by P; the response to K varies greatly according to location. In general, K requirements are minimal. Zinc deficiency has been observed in many parts of India and on one of the principle soil series in Thailand, where routine application of P fertilizer has worsened the problem. Micronutrient deficiencies are probably more widespread than is reported, especially where multiple cropping is practiced and all crop residues are removed from the land for fodder.

In addition, Southeast Asia has about 400,000 ha of acid soils, primarily in southern China, India, the islands of Kalimantan and Sumatra in Indonesia, Malaysia, Mindanao in the Philippines, and Vietnam. High aluminum saturation is an important factor in several of these areas. Although little maize is currently grown on these soils, it could be produced fairly efficiently if aluminum tolerant varieties were available.

Downy mildew is the most important disease, and occurs in many countries of the region. It devastated maize crops in Indonesia, the Philippines, Taiwan, and Thailand during the early 1970s and is still a severe problem in much of Indonesia, Laos, the Philippines, and Taiwan. During recent years losses have been much reduced through the use of resistant germplasm. Most of the hybrids available in the region are not resistant to downy mildew, and commercial seed of these materials is treated with metalaxyl (Ridomil or Apron) fungicide. But now that the protection afforded by this chemical is breaking down in some areas of the Philippines and Thailand, private seed companies are selecting for resistance to the disease. Newly introduced germplasm is highly susceptible to the disease and breeding programs are required to improve their materials for resistance to downy mildew before they can be used.

Stalk rots and turcicum leaf blight (*Exserohilum turcicum*) reduce yields in areas of Bhutan, China, northern India, the highlands of Nepal, and Pakistan. The former is most important in China, India, Pakistan, the Philippines, and Thailand, especially when maize is allowed to dry in the field before harvest. The latter is important in the cool, humid environments provided by mountainous areas and winter plantings in Bhutan, southern China, India, Nepal, Pakistan, and northern Vietnam.

The insects known as stem borers (*Ostrinia furnacalis, Chilo partellus,* and *Sesamia calamistis*) are a problem in some parts of the Philippines, India, Indonesia, Nepal, and Vietnam, where they limit the farmers' choice of sowing date or cause severe damage during some years.

The Asian Regional Maize Program

CIMMYT established the Asian regional maize program (ARMP) in 1974. Initially located in Delhi, India, the program was moved in 1981 to Bangkok, Thailand, and research began to develop germplasm resistant to downy mildew. As a result of this and similar work on other diseases in collaboration with national programs of the region, germplasm popular in specific zones was made more useful through the addition of resistance to major endemic pathogens. An important function of the regional program is to assist national programs in utilizing germplasm developed at CIMMYT headquarters and other sites. We also develop germplasm in the region through cooperative arrangements with national programs, focusing on traits that cannot be handled as effectively in Mexico.

Downy mildew resistance

Over the past several years, we have successfully improved CIMMYT populations for resistance to downy mildew. Some of this resistant (DMR) germplasm has been returned to Center headquarters for distribution through the Maize Program's international testing network. Recently, we initiated the development of four new populations (of differing maturities and grain colors), which could possibly serve as the next generation of DMR germplasm, depending on the performance of these materials in comparison with the ones now available. The new populations were developed by crossing the best performing experimental varieties available at CIMMYT with sources of DMR from the Philippines. They are now being selected for DMR at Farm Suwan in Thailand and the University of Southern Mindanao Agricultural Research Center (USMARC) in the Philippines, where the most virulent species causing the disease is found.

Breeding for resistance to the downy mildew disease

Downy mildew resistance has been increased in the advanced populations 22, 28 and 31, and the populations returned to CIMMYT headquarters for distribution through the international testing system.

Using Population 28 as the male parent, crosses were made to several white and yellow populations. In 1989, F1 seeds of all crosses were assembled in Varietal Cross (VC) trials 1 and 2, and distributed as follows:

Trial	Entries	Countries	Locations	Data returned
VC-1 (white)	49	3	6	4
VC-2 (yellow	49	5	7	4

Various cycles of selection of Pops. 22, 28 and 31 were assembled in a trial with the following distribution:

Trial	Entries	Countries	Locations	Data returned
Cycles of selection	12	2	4	3

Four broad-based populations developed by ARMP being improved for DMR:

Population 100 - Early White-DMR
Population 145 - Early Yellow-DMR
Population 300 - Late White-DMR
Population 345 - Late Yellow-DMR

Various cycles of selection of Pop 100, 145, 300 and 345 were assembled in a trial and distributed as follows:

Trial	Entries	Countries	Locations	Data returned
Cycles of selection	20	2	2	4

In 1989, two experimental varieties (EVs) were developed in each of the four DMR populations. The EVs were developed by crossing selected S2 lines in a diallel scheme. Parental S2 lines and their F1 crosses have been assembled in diallel trials. Requests for the various diallels are as follows:

Trial	Entries	Countries	Locations
Diallel SW-DMR 89100-1	28	5	11
Diallel SW-DMR 89100-2	21	5	10
Diallel SW-DMR 89145-1	55	7	15
Diallel SW-DMR 89145-2	66	4	10
Diallel SW-DMR 89300-1	15	4	9
Diallel SW-DMR 89300-2	21	4	7
Diallel SW-DMR 89345-1	28	7	12
Diallel SW-DMR 89345-2	36	4	8

We have been increasing downy mildew resistance in two extra early (EE) broad based gene pools, EE White-DMR and EE Yellow-DMR. In 1990, the above six populations (100, 145, 300, 345, EEW and EEY) plus several other entries received from CIMMYT headquarters were assembled in various Asian Stress Trials (AST), as follows:

Trial	Entries	Countries	Locations	Data returned
AST-1 (Drought)	6	7	17	7
AST-2 (Earliness)	15	8	18	9
AST-3 (Disease)	16	9	14	8

Breeding for aluminum tolerance

We are working with national programs in the selection of acid tolerant varieties from Population SA3 and others developed by CIMMYT regional staff in Cali, Colombia. Population SA3 has proved to be one of the most tolerant germplasm sources for acid soils with high aluminum saturation. As a result of our international multilocation evaluation of Population SA3, several acid soil/aluminum tolerant varieties have been generated and evaluated in aluminum tolerance trials (ATTs) throughout the region:

Trial	Entries	Countries	Locations	Data returned
ATT-1	10	5	25	18
Cycles of selection of Population SA3	10	3	7	7

Breeding for stem borer resistance

Several entries received from CIMMYT/Mexico are being evaluated for their resistance/tolerance to stem borers present in Asia. Trials to evaluate their resistance/tolerance have been distributed as follows:

Trial	Entries	Countries	Locations	Data returned
AST-4 (Borers)	8	5	11	3
AST-4/92 (MBR)	9	2	5	-
AST-4/92 (MIRT)	6	2	5	-
AST-4/92L	18	2	5	-

In a recently initiated project for developing germplasm resistant to stem borers, materials from the Multiple Borer Resistance (MBR) Population are being exposed to the Asian borer species *Chilo partellus* and *Ostrinia furnacalis.* The participants in this collaborative effort are the national programs of India and the Philippines. Materials selected in Asia will be sent back to Mexico for recombination with borer resistant populations, although some selections could also be employed directly in the region.

Breeding for resistance to turcicum leaf blight

This important disease of maize in subtropical environments has become especially damaging in Asia during recent years with the expansion of area planted to winter maize, mainly in Bhutan, southern China, India, Nepal, Pakistan, and Vietnam. In the past CIMMYT's subtropical germplasm has proved to be very susceptible to *H. turcicum,* and, as a result, it has been less widely accepted than the Center's tropical materials. To supplement efforts at headquarters in Mexico to improve resistance to this disease in various populations, we are laying the groundwork for a cooperative breeding program in Asia. In cooperation with researchers in southern China, India, Nepal, and Pakistan, we are currently mapping the races present in susceptible winter plantings by means of isogenic lines having three major genes for resistance. Once more is known about the races present in Asia, we can initiate a program for developing resistant germplasm. Selections are being made under heavy disease pressure at a site in southern India under a collaborative project with the All India Coordinated Maize Improvement Project (AICMIP). Several turcicum blight resistant and susceptible entries have been distributed and evaluated in nonreplicated observation nurseries as follows:

Trial	Entries	Countries	Locations	Data returned
Turcicum obs. nursery 1	63	4	5	4
Turcicum obs. nursery 2	60	3	4	3

Other regional trials
Selected highland entries from CIMMYT headquarters were assembled in a Transition Zone Trial and distributed as follows:

Trial	Entries	Countries	Locations	Data returned
TZT (Highlands)	6	5	9	3

Future Trends and Recommendations

Resource constraints will limit quantitative changes in our trial array. Although we will probably add no new populations, however, we may introduce additional materials into present populations to improve their makeup for traits such as yield or downy mildew resistance.

We recommend that trials which contain a combination of entries from CIMMYT headquarters and regional breeding programs be coordinated and distributed from Mexico. Headquarters should organize different sets of trials to evaluate germplasm available in regional programs with tolerance/resistance to various biotic and abiotic stresses. So far, these have been handled by scientists in different units and not as an organized, systematic effort. Regional programs should submit entries for the various types of trials to be distributed, and selected entries should later enter the regular EVT system. In our perception, PETs fulfill a certain purpose but are limited in their capacity to help national programs select useful germplasm, because they are based primarily on yield.

Regarding the handling by CIMMYT of germplasm from national programs, we do not feel the Center should directly evaluate national program entries, but it may play a role in demonstrating germplasm developed by our cooperators. In the Asian Regional Maize Workshops, for example, we plant demonstration trials at one or several locations in the country where the workshop is held. Each trial comprises selected entries from national programs and outstanding CIMMYT entries that have been evaluated in Asia. Workshop participants have a field book and can enter data on promising materials, which are available upon request either through the ARMP or the corresponding country program. This allows a free flow of germplasm between national programs in the region.

The FAO/RAPA program for the Asia-Pacific region has attempted to organize regional trials that include entries developed by national programs, but the response of those programs has been less meaningful than originally expected. Because most materials from national programs in the region are of CIMMYT origin and the information on performance of national program varieties can be traced back to when those entries were tested internationally, it has been suggested that FAO/RAPA discontinue the trials .

Maize germplasm from IITA has been distributed in the region for several years, but most entries are white grained, susceptible to downy mildew, and extremely late for requirements in the region.

6

CHAPTER

Germplasm Development and Regional Testing: South America

H. Ceballos and S. Pandey

The activities of our program center around two types of environments: 1) the highlands of Colombia, Ecuador, Peru, and Bolivia, where different types of highland maize such as floury, morocho, chullpi (sweetcorn), cangill (popcorn), and blue (or black) maize are grown, and 2) the tropical lowlands of all these countries with the addition of Venezuela, Brazil and Paraguay. To a lesser extent we collaborate with a program in northern Argentina. Chile and Uruguay do not grow much tropical corn or conduct much maize research.

Four different types of regional trials are coordinated by our program. NARS provide seed to be included in ERSAT, ENSAT and ERVEZAS (described below). We prepare the trials and distribute them to cooperators. They send us data from each location. After carrying out individual location and across location analyses, we make the results available to NARS.

Progeny testing is an integral part of breeding projects to evaluate progenies of a given population in several different environments. The main objective of these evaluations is to select materials for stability and good performance (high yield) across environments. These trials involve progeny testing of acid soil tolerant populations (ASTP) and are different from the IPTTs distributed from headquarters.

Variety/hybrid evaluations are organized in the region to facilitate the exchange of materials and information among the participating NARS. The main objective of these trials is to allow each NARS to see the products of the other programs. Stability of performance is also studied. Two types of variety/hybrid trials are conducted: 1) highland maize variety trials (ERVEZAS) are separated by grain type into floury, morocho and special types (blue maize, popcorn, sweet corn), and 2) lowland trials for normal soils (ERSAT) and acid soils (ENSAT).

Technology validation trials have recently been conducted in Ecuador, Peru and Bolivia for ear rot inoculation techniques. The main objective is to test a given set of special research techniques under different environmental and genetic conditions.

Theses and other special projects are also frequently coordinated by our program. Recently, four BS (Universidad de Palmira and Universidad del Valle, Colombia), seven MS (Universidad de Pelotas and Piracicaba, Brazil, Universidad de Chapingo, México, and Universidad de Palmira), and three PhD (Iowa State University, Kansas State University, and Universidad de Chapingo) theses trials were conducted in the region to address local problems using local genotypes and environments.

The last two types of trials are distinct from what we usually consider international testing and thus will not be included in the following discussions.

Progeny Testing Trials

The progeny trials handled by us consist almost exclusively of the progenies from our acid soil tolerant populations (Table 1). These trials have between 169 and 256 entries arranged in a lattice design, with no standard check. The progenies of SA3-SA8 are always grown under five acid soil environments at

Carimagua, one acid soil site at Quilichao, and one normal soil site at Palmira (all locations are CIAT experiment stations in Colombia). Due to high soil variability in the acid soil environments (ASE), three replications are grown under each environment (18 reps under acid soils), but only two reps in the normal soil of Palmira. Because of limitations in seed, plots in ASE are 2 m with 5 hills and 2 plants per hill. No thinning is practiced. An effort is made to grow at least one set of progenies of each ASTP in one other country that may be interested in a given population. We usually contact the concerned country to offer the trial. In some cases, sets of progenies have also been grown outside the region in collaboration with CIMMYT's Asian regional maize program (ARMP) (Table 2). Progenies have usually been full sib families. This year, however, we will evaluate S1 progenies in all ASTPs except SA5. Evaluations are made during August-December each year. A selection index program is used to choose the best families, which are then planted and recombined during February-June.

The most important logistical issues related to the trials are seed availability, getting back data on time for the recombination phase of our breeding project, and data reliability. There is little time to deliver the new progeny trials to other countries (particularly those in Asia), to be planted and harvested in time to include the data in the selection index. Even in countries from our region (e.g. Venezuela), planting is usually done in May-June but our progeny trials are planted late in the season, by the end of July.

In addition, ASE are marginal environments, with levels of different elements in the soil usually close to either lethal toxicity or deficiency. Soil variability is usually large and CVs range from 35 to 60% (Tables 3 and 4). Identification of more suitable locations, careful adjustments, and statistical manipulation, such as the moving mean analysis (Diers et al., 1991) are the approaches taken to improve the precision of these progeny trials. The moving mean analysis proved to be efficient in the particularly variable soils of Quilichao (Table 4). Finally, strict quarantine regulations in such key countries as Brazil delay seed delivery to our collaborators and reduce their full involvement in the project.

Downy mildews are common in acid soil environments (e.g., Venezuela and Brazil), making it advisable to combine acid soil tolerance and downy mildew resistance in the same germplasm. This is being done with a close collaboration between our programs at Cali and Bangkok. We are currently evaluating, under the acid soil environment of Quilichao, S2 families derived from the four downy mildew resistant populations handled by the ARMP. We are also increasing S1 families from selected plants of our ASTPs that showed resistance to downy mildew when evaluated in Thailand. Resistance or tolerance to other major stresses needs to be pursued more vigorously in the ASTPs.

Variety/Hybrid Trials

ERVEZAS are generally planned during Highland Workshops held every year or two. Each country names the materials it would include and requests the number of trials it is interested in growing. The number of entries generally ranges from 7 to 15. ERVEZAS are usually grown at 5-8 locations (Table 5). So far, no highland hybrid has been successfully developed, so only OPVs are included in these trials. CIMMYT organizes ERVEZAS but we do not contribute germplasm to them. Since the growing cycle of most Andean highland maizes is about 8-9 months, the pace of improvement of the different populations is relatively slow. Therefore, ERVEZAS are conducted ever 2-3 years.

Lowland maize trials (ERSAT and ENSAT) are planned during our Biennial South American *Maiceros* Meeting or in occasional maize coordinators meetings. As in the case of ERVEZAS, each country (and also CIMMYT) offers the entries it wants to include and the number of trials it is interested in growing (Table 6). At the moment, OPVs and hybrids are put in the same trial. In the near future we may have distinct trials for the two types of maize. The number of entries included in ERSAT and ENSAT ranges from 15 to 20, evaluated in about 20 different environments. ENSATs are also grown outside the region in Africa and Southeast Asia. Some ENSAT trials are set up by our program without prior consultation with NARS and include only varieties from our program (Table 3).

It should be recognized that the usefulness of the exchange of highland maize among different NARS is almost nil, since the high GxE interaction of these materials renders them useless outside their area of adaptation. Another limitation to the success of introduced highland materials is the grain quality requirements of the people living in the different areas. There has been, however, some encouraging results, such as the impact of *Ancho de Pairumani* (derived from Mexican germplasm) in Bolivia, or the extensive use of *Blanco de Urubamba* (Cuzco) and *Cacahuacintle* (México) by the maize programs of every Andean country. The new entomology and phytopathology lab set up in Peru (financed by CIMMYT) will serve all Andean countries. Once it becomes operative, it will generate insect tolerant materials that will require international testing within the Andean region. With regard to lowland tropical maize, germplasm exchange among different regions has been more fruitful and straightforward.

CIMMYT's Role in Exchange and Evaluation

CIMMYT's presence in the region is vital for the exchange of germplasm and information among South American NARS. There is no other institution that matches our impact, continuity, and closeness with the maize programs of those NARS. Two IICA Institutions, PROCIANDINO (Venezuela, Colombia, Ecuador, Peru and Bolivia) and PROCISUR (Argentina, Chile, Uruguay, Brazil and Bolivia) could assume the responsibilities to coordinate and finance these regional trials. However, the very grouping of these cooperative projects already precludes the exchange of materials and information between Brazil and Colombia, for example. In addition, there is no certainty that these projects would have the required continuity.

The Latin American Maize project (LAMP) has also contributed to some extent to the exchange of germplasm within the region. The materials included have been mainly landraces from different germplasm banks and, therefore, have little direct impact on breeding programs of the participating countries.

The Future

Our project on tolerance to acid soil has already identified the first set of superior experimental materials, which will now be subjected to a more extensive testing in many different ASEs. As the project reaches maturity, international testings will become increasingly important. It is, therefore, necessary for us to identify adequate sites with the proper level and type of edaphic stress. It is not easy, however, to find appropriate environments. Table 3 shows, for example, mean yields above 5 t/ha at certain locations which may not be providing the desirable level of stress. We need to improve our knowledge of the different types of edaphic stresses in acid soil environments to better direct our efforts. Geographical information systems analysis may prove a useful tool to this end. The best materials identified from acid soil testing could be included in standard international trials distributed by headquarters in Mexico.

Quantitative spatial analysis (e.g. geostatistical and covariate analyses) is currently used to increase the precision of our trials in acid soil environments and is increasing our understanding of the actual relationship between the different sources of stress (Al toxicity, P deficiency, low pH, Mn toxicity, Zn deficiency, etc.) and yield (Knapp et at., 1992).

References

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Knapp, E.B., S. Pandey, and H. Ceballos. 1992. The use of spatial analysis in nutrient stress maize breeding. In: First International Symposium on Environmental Stress: Maize in perspective. March 8-13, Belo Horizonte, Brazil.

Table 1. Populations improved for tolerance to acid soils by CIMMYT at Cali, Colombia.

Pop.	Kernel color and texture	Users
SA3	Yellow Fling/Dent	Latin America and Asia
SA4	Yellow Dent	Latin America
SA5	Yellow Flint	Latin America and Asia
SA6	White Dent	Africa and Latin America
SA7	White Flint	Asia and Latin America
SA8	White Flint	Latin America

SA4 and SA5 are heterotic among themselves, as are SA6 and SA7.

Table 2. Environments where progenies of the last cycle of selection of acid soil tolerant populations were grown.

	Carimagua										
Pop.	Lote 1	Lote 2	Lote 3	Lote 4	Lote 5	Quilichao	Palmira	Brazil	Peru	Venezuela	Thailand
SA3	X	X	X	X	X	X	X	X	-	-	X
SA4	X	X	X	X	X	X	X	-	-	-	X
SA5	X	X	X	X	X	X	X*	-	X	-	-
SA6	X	X	X	X	X	X	X	-	-	-	-
SA7	X	X	X	X	X	X	X	-	-X	-	

Progenies of population SA8 were not available yet.

Table 3. Yield (t/ha) of the CIMMYT acid tolerant maize varieties and two local checks evaluated in 12 international environments during 1990-91.

	Napo Ecuador	Ferke I. Coast	Sinemati. I. Coast	Napo. Ecuador	Chiapas Mexico	Villavi. Colmb.	Villavi. Colmb.	Carimag. Colmb.	Carimag. Colmb.	Angiang Vietnam	Binhauc Vietnam	La Ceiba Venez.	Mean
pH	4.8	5.5	6.5	4.8	4.4	4.6	4.6	5.2	5.5	5.0	6.5	5.3	
Al saturation (%)	-	-	-	-	67	40	70	75	45	-	-	-	
P (ppm)	-	-	-	-	-	10	10	6	6	-	-	11	
Variety													
Cali87SA3	0.81	6.31	4.63	0.42	-	1.30	2.26	0.56	0.17	5.00	6.17	-	-
Cali 88SA3-T	0.70	6.14	4.99	0.46	3.42	1.72	4.32	0.40	0.37	5.38	5.82	3.52	3.08
Cali 88SA3/Cms36	0.65	5.42	5.47	0.63	2.65	2.39	3.25	0.71	0.24	4.16	5.44	3.28	2.85
Sitiung 88SA3	1.15	5.03	5.52	0.73	3.69	2.19	3.28	0.40	0.29	4.42	5.41	2.94	2.91
Cms361.12	3.78	4.67	0.60	4.36	2.03	2.92	0.15	0.13	2.82	3.83	2.05	2.36	
Cali8828-T	0.77	5.11	5.60	0.47	3.32	2.99	2.99	0.24	0.18	3.55	4.96	3.11	2.77
Cali8843-T	1.32	5.12	5.41	0.84	2.49	2.33	2.81	0.26	0.23	3.91	5.37	2.53	2.72
Cali88SA3-S	1.00	4.84	6.05	0.65	3.87	1.89	3.32	0.56	0.14	4.37	5.69	3.53	2.98
Cali8828-S	0.64	4.99	5.03	0.71	2.29	1.96	3.08	0.26	0.36	2.68	4.19	2.83	2.41
Cali8843-S	1.03	5.32	5.32	1.15	2.60	1.37	1.89	0.21	0.17	3.06	5.03	1.77	2.42
CHECK # 1	*0.56*	*5.79*	*6.15*	*0.58*	*2.32*	*2.63*	*4.95*	*0.42*	*0.19*	*4.44*	*5.57*	*2.68*	-
CHECK # 2	*0.88*	*6.07*	*5.95*	*0.70*	*1.85*	*1.59*	*3.66*	*0.54*	*0.36*	*4.49*	*5.71*	*2.82*	-
Mean	0.87	0.66	5.33	5.40	3.02	0.39	0.24	2.03	3.23	4.02	5.27	2.82	2.77
CV (%)	44	73	14	11	29	57	73	28	25	9	9	23	20
LSD 5%	0.55	0.69	1.07	0.84	1.28	0.32	0.25	0.82	1.18	0.52	0.71	0.95	0.22

Table 4. Efficiency of *lattice design* and *moving mean analysis* in six environments for populations SA5 and SA6.

	Lattice		Mov. Mean			Lattice		Mov. Mean		
Lote[a]	CV	Effic.	CV	Effic.	Yield (t/ha)	CV	Effic.	CV	Effic.	Yield (t/ha)
Carimagua B	50	108	50	111	1.01	49	115	49	126	1.11
Carimagua C	48	118	45	142	0.82	47	119	45	138	0.77
Carimagua D	45	109	44	118	1.29	70	100	70	103	0.75
Carimagua E	40	133	40	140	1.52	40	129	42	122	1.35
Quilichao	40	138	34	201	3.54	39	113	34	158	3.32
Palmira	9	100	-	-	8.03	12	100	-	-	8.30

[a] Carimagua B= 45% Sat. Al. and 12 ppm P, Carimagua C = 45% Sat. Al. and 6 ppm P, Carimagua D = 75% Sat. Al. and 20 ppm P, Carimagua E= 55% Sat. Al. and 10 ppm P, Quichao = 55% Sat. Al. and 8 ppm P, and Palmira = Normal soil.

Table 5. Number of entries included and sets requested in the latest ERVEZAs (highland maize variety trials).

		Number of trials requested				
Trial	No. of Entries	Colombia	Ecuador	Peru	Bolivia	Total
Floury	13	1	2	5	2	10
Morocho	11	1	2	4	2	9
Special types	7	2	2	3	2	9

Table 6. Number of entries and environments included in the latest ENSAT (Acid soil) and ERSAT (Normal soil) lowland tropical maize trials.

	Participating program										
Trial	Venezuela	Colombia	Ecuador	Peru	Bolivia	Brazil	Paraguay	Argentina	Thailand	CIMMYT	Total
Entries provided											
ENSAT	-	-	-	1	-	6	-	-	-	7	14
ERSAT	2	3	4	2	1	2	1	-	-	3	18
Trials requested											
ENSAT	2	2	1	3	1	4	1	-	2	2	18
ERSAT	2	3	2	2	2	5	2	1	-	1	20

7

CHAPTER

Developing and Testing Stress-Resistant Maize

J.A. Deutsch, G.O. Edmeades, D.C. Jewell, H.R. Lafitte, and J.A. Mihm

Stress resistance breeding can cover a wide range of work. The Maize Program has defined stress resistance for its breeding purposes to include only the following traits: insect resistance, drought tolerance, nitrogen-use efficiency, and acid soil/aluminum toxicity tolerance. Clearly there are many other factors that reduce maize yield, including stalk rots, ear rots, maize streak virus, downy mildew, and *Striga* spp., to name a few. However, they occur commonly either worldwide or in a particular region, and are relatively easier to manage in both nurseries and trials. The four stresses mentioned previously, though widely occurring, require higher levels of technology for effective breeding and are less easy to manage in trials. Difficulties shared in working on them include 1) new or limited methodology, 2) limited source germplasm available, and 3) the need for special nursery/trial management or conditions.

Breeding for stress resistance is not a new undertaking. In research on drought and insect resistance, the perspective has changed from methodology development to source and population development, whereas work on nitrogen-use efficiency continues to emphasize the former. Acid soil/ Al^{+3} tolerance breeding was initiated as exploratory research but has rapidly developed into germplasm enhancement. All of the stress breeding populations continue to require special handling for maximum selection gain. It is also important to note that the program is attempting to streamline breeding for drought tolerance and insect resistance characteristics through the application of new technologies in molecular biology and that special trials are required for this research.

Testing and germplasm development of stress resistance materials at selected locations, through a network of highly motivated collaborators, appears to have increased both the percentage return and utility of the data from the trials.

The relatively high priority placed on these traits by the Program reflects in part work at CIMMYT to define and delineate major maize production zones in the developing world. In the course of these efforts, it was found that over 10% of the maize is grown on acidic soils (pH below 5.0), with half suffering from Al^{+3} toxicity; 53% of the maize area is seriously affected by serious insect pests; 31% is subject to drought (Table 1), some as often as every year with yield losses of over 50%. Nearly 95% of the maize is produced with or requires nitrogen fertilization.

Drought Tolerance Breeding

In 1976, CIMMYT began work in selection for drought tolerance. We concentrated on identifying traits that were associated with drought tolerance, were heritable, and improved yield under drought while maintaining yield under well-watered conditions. In an evaluation of the first three cycles of selection, anthesis-silking interval (ASI) emerged as one of the most important traits associated with drought tolerance. Other traits—small tassel size, erect leaves, leaf rolling, and reduced canopy temperature—were also identified as potentially useful characteristics.

Subsequent research involving one of the most promising materials, population Tuxpeño Sequía, and three elite populations added in 1985, confirmed the effectiveness of ASI and ears-per-plant under drought stress—together with yield under well watered conditions—as yardsticks for selecting families that perform well when faced with either circumstance. Thus, selecting for drought tolerance (particularly with ASI as the main criterion) does not necessarily reduce yield potential.

The next step was to find germplasm with other mechanisms for drought tolerance and incorporate these into elite maize. To this end, the Program began evaluating germplasm bank materials catalogued as originating from drought prone areas and any other maize genotypes identified (i.e., from the literature, personal communications, or bank data) as drought tolerant. These are being recombined with the best "elite" drought resistant germplasm available to form two new populations, DTP1 and DTP2. In concert with breeders at headquarters, the CIMMYT regional program at Zimbabwe is developing a population (ZM601) more tailored to eastern and southern Africa.

As our understanding of selection mechanisms for drought tolerance improved, it then seemed logical to begin publicizing and distributing the resulting germplasm to NARSs in a systematic manner, rather than simply on request, as had been the practice. The EVTs and IPTTs of the normal distribution system were tried, but seemed to offer only a partial solution. Drought tolerant materials in those trials produced high yields, but their added qualities under stress were not revealed. Given that the materials were developed under specific environments and intended for use there, it seemed logical that cooperators should be encouraged to test them under the same circumstances, particularly in the case of progeny testing. Although many of the same cooperators receive IPPTs, EVTs, and ELVTs, ideal test locations and trial practices (particularly irrigation) may differ for drought tolerant materials. Therefore, separate drought international progeny trials (DIPTs) and drought experimental variety trials (DEVTs) were established for distribution within a network of cooperators selected according to their need for such materials and/or their capability to handle the trials.

Selection scheme

A full-sib recurrent selection scheme was used for improving Tuxpeño Sequía in Mexico. However, to provide a sufficient quantity of seed for additional testing outside of Mexico would have required a significant change in the pollination system, without any benefit in potential selection efficiency. The physiology group had previously found that S1 evaluation gave a good differential of ASI and drought tolerance, yet could be managed by most NARSs. More highly inbred material can be stressed too easily, as a result of inbreeding depression, while full-vigor material requires more stress to obtain a similar level of response. Also, since the traits had shown a large additive effect and S1 formation would help to improve the inbreeding tolerance of the germplasm, it seemed that a S1 recurrent selection program would be a good choice for improving the populations. As an intermediate step, a large number of families are pre-screened under drought at an experiment station in northern Mexico and, at the same time, sib-increased for inclusion in the trial, which helps to improve apparent heritability.

The first DIPT and DEVTs were distributed in 1990. Cooperators are divided into a drought development network (DDN), which grows the DIPT, and a drought testing network (DTN), which grows the DEVTs. Characteristics of DDN cooperators include 1) national responsibility for breeding for drought tolerance, 2) the ability to achieve uniform stress that reduces the yield of trial entries at least 50%, 3) a testing site with uniform soils, 4) the capacity to record basic daily weather information, and 5) the capability to record shelled grain and 100 kernel weight. Characteristics of the DTN cooperators are 1) responsibility for identifying drought resistant varieties, 2) a high probability that stress at their locations is severe enough to cause at least a 50% yield reduction in trial entries, 3) a testing site with uniform soils, and 4) the capability to record shelled grain weight. DDN cooperators also participate in the DTN, but the reverse is not true. A listing of the past cooperators for both networks are shown in Table 2.

Insect Resistance Breeding

The search for insect resistance has focused on lepidopterous insects, both stalk borers and armyworms. Mass rearing and infestation techniques were well defined in the USA for European Corn Borer and served to a lesser extent for work with tropical lepidopterous species. Artificial infestations were first made at CIMMYT in the mid-1970s and have continued since then. Improved rearing and infestation methodologies (many developed by our staff), dramatically increased selection efficiency for insect resistance. Still, progress was slow-to-nonexistent in the early cycles, basically because insect resistance was not the primary selection criterion in the populations used. Likewise, though elite for other characters, the populations apparently had at best only low gene frequencies for resistance factors.

This changed in 1984, when we began to form new populations using source germplasm known to possess proven high levels of resistance to insects. One result is multiple borer resistance (MBR) Population 590, which provides high levels of stable resistance to multiple species of lepidopterous insects. As CIMMYT can only test for three species, the material was sent to other cooperators who could artificially infest with additional lepidopteran pests, self the best plants, and return small samples of seed to Mexico for recombination.

The first insect resistant progeny trials (IRPT) were sent out in 1986 and 1988 to evaluate insect resistance and select the best plants from the host resistant families. Fairly successful on this count, it became apparent that the materials nonetheless fell short in levels of disease resistance. C3 was not formed. Instead, resistant S1s received from cooperators were crossed with the multiple disease resistant population. Selection for insect resistance has continued in Mexico in the crossed germplasm and the subset of resistant MBR materials. Those showing the highest levels of insect and disease resistance are being recombined to form a population, with multiple resistance to both disease and insect pests for temperate/subtropical environments.

In 1986 the development of a population to provide high levels of stable resistance to multiple species of lepidopterous insects in germplasm adapted to lowland tropical environments was initiated. The objectives were similar to those described above, however, special attention was paid to selection for disease resistance in combination with insect resistance. The first IRPT for this new population (390) was distributed for international testing in 1990/91.

Insect resistance cooperators are also grouped into two networks: one for insect resistance development (IRDN), which grows the IRPT, and another for insect resistance testing (IRTN), which grows the IREVTs. IRDN cooperators have 1) national responsibility in breeding for insect resistance, 2) ability to artificially infest the trial and take the resistance ratings, 3) a testing site with uniform soils, 4) the capability to record shelled grain weight. Characteristics of the IRTN cooperators have 1) a responsibility for identifying insect resistant varieties, 2) the ability to infest or a high probability that natural infestation will be epiphytotic, 3) a testing site with uniform soils, and 4) the capability to record shelled grain weight. IRDN cooperators can also be IRTN cooperators, but the reverse is not true. Table 3 lists past IRDN cooperators and the insect(s) for which they have tested.

Acid Soil and Aluminum Toxicity Tolerance

Acid soils and problems with heavy metal toxicity are found in many parts of the world. Previously, much of this area was considered too marginal to be important. But as world population pressure has increased the need for grain, more of this area has come into production. Many of the soils are not intrinsically poor, but suffer from levels of toxicity that reduce yield.

CIMMYT started work on acid soil tolerance in the late 70s in one population (SA-3) in Columbia using half-sib recurrent selection. This level of effort was maintained by CIMMYT until 1985, although several national programs embarked on large integrated programs of breeding for resistance and soil amelioration to lessen the effect. The germplasm base used in most of the programs is related to the Cateto race—not necessarily a narrow base, but not one of wide utility in other areas which needed help. Beginning in 1985, CIMMYT's regional program at Cali, Colombia, first screened a wide array of populations to identify new sources of resistance, particularly white grain germplasm. Several materials were identified and 4 new populations were developed in a two-step process.

The materials were first screened on a population level, then the best were replanted under acid soil conditions and selfed. The S1 selections from this material were then evaluated per se for tolerance to acid soils and with testers to assess heterotic potential and general combining ability. Two heterotic populations each of white (SA-4 and SA-5) and yellow (SA-6 and SA-7) grain color were made. A reciprocal recurrent selection program has been used to improve these populations.

One of the major problems in this research is that acid soils with Aluminum toxicity tend to lack uniformity, making it difficult to identify superior genotypes. As the program began, one of the first priorities was to look at ways to improve the uniformity in testing. In evaluating the soils of the test sites, it was seen that there was a great difference in the Al^{+3} saturation of the soils, even though the pH was not radically different. Standardization of this saturation at a high but uniform level was attempted through application of varying amounts of lime. This has helped to improve the efficiency of selection by lowering the variation. The selection work continues in the population, with the four newer materials now in C3.

As work progresses, the demand for these materials has increased. Unfortunately, few countries have the expertise to develop quality, uniform testing sites for acid soil tolerance. Inclusion of too many sites with little or no stress will reduce the efficiency of selection for acid and Al^{+3} tolerance. Therefore, careful selection of locations is a very high priority.

Initial research has been accomplished on identifying maize that is tolerant to alkaline soils (high pH) and on a single, alkaline-soil-tolerant population that was formed (Population 490). Work continues at a low level to develop this population and compare acid- and alkaline-soil-tolerant materials. This research is expected to shed light on the adaptation of maize to different soil types.

Nitrogen Use Efficiency

Research on nitrogen-use efficiency (NUE) is still in the development stages. Although improvement in yield under low N has resulted from the selection pressure applied, the methodology is still unproven and appropriate traits for selection are not readily obvious. As this will be germplasm with a high potential demand, a solidly defined selection methodology for use by collaborators is extremely important so that appropriate selection pressure can be brought to bear. The development of a network will probably not be easily controlled, as it appears clear that the demand for both developing and testing the germplasm could be high.

The Importance of Other Traits

In some cases a tradeoff between yield potential and yield stability has been observed. CIMMYT has tried to minimize the effect of this tradeoff by including results from trials at full potential in the selection system, either as a formal part of an index or as a reference used for independent culling. We recognize that for many of these stresses, neither we nor the farmer knows exactly what level of stress to expect in any year. High stability of yield at a low level will not be of benefit in the long term as farmers attempt to improve their productivity through improved cultural practices. A balance between maintaining a reasonable yield potential and developing maximum resistance is a must in these stress resistant materials.

A related issue is how to set the relative importance of other traits, particularly disease resistance, which would be a must under normal improvement programs. Drought, for instance, is frequently a constraint in areas where downy mildew may be a problem. Unfortunately, the two traits are not easily associated in the same nursery. Deciding on new trait combinations and when to begin working on them is not a trivial task. Many of the traits are highly polygenic, not easily evaluated, and may need environmental conditions in direct contrast to one another for most efficient selection. Networks can help with this problem, since not all locations will have identical conditions and in fact may provide the contrasting conditions in each year needed to maintain pressure for all possible trait combinations.

The current research aimed at increasing the efficiency of breeding for stress resistant germplasm through the application of new tools from molecular biology is expected to assist us in the task of combining traits for the formation of new, widely applicable germplasm. This is particularly true of restriction fragment length polymorphism (RFLP) assisted breeding.

Table 1. Extent of selected stresses in the principal maize producing countries of the Developing World.

		Maize area (000s ha)		
Region/country	Total	Affected by moist. stress	Having acid soils	With serious insect prob.
Latin America				
Argentina	3,250	500	0	250
Brazil	12,000	5,800	3,350	12,000
Colombia	586	90	120	388
Guatemala	775	150	50	—
Mexico	7,090	1,770	—	4,260
Paraguay	478	—	150	478
North Africa and Middle East				
Egypt	748	—	—	748
Morocco	435	408	—	378
Turkey	538	220	—	22
West and Central Africa				
Benin	470	110	—	260
Cameroon	546	27	—	546
Cote d'Ivoire	565	120	—	—
Ghana	380	165	—	60
Nigeria	1,830	180	200	1,300
Eastern and southern Africa				
Angola	600	—	—	600
Ethiopia	970	50	—	900
Kenya	1,425	395	—	1,245
Malawi	1,300	30	—	275
Mozambique	1,000	650	—	—
Tanzania	1,630	255	—	1,040
Zaire	1,382	2	—	—
Zimbabwe	1,354	1,134	—	—
Asia				
India	5,860	1,877	1,640	2,886
Nepal	572	572	—	412
Pakistan	870	360	—	—
China (south)	2,191	717	—	—
Indonesia	2,800	1,000	—	—
The Philippines	847	—	—	847
Thailand	2,229	408	—	—
Total	**55,281**	**17,030**	**5,570**	**29,455**

Table 2. List of collaborators and location of Drought Network Trials, 1990.

Collaborator	Location	Early Var.	Late Var.	Progeny
Dr. N. Baracco	Tucuman, Argentina	x	x	
Ings. Segundo Reyes and D. Alarcón	Lodana, Ecuador	x	x	
Ing. José Morán	Hualtaco Piura, Perú	x	x	
Dr. Catherine Mungoma	Golden Valley, Zambia	x	x	
Dr. N.N. Singh	New Delhi, India	x	x	x
Dr. M.D. Arha	Godhra, Guajarat, India	x	x	
Dr. C. Kitbamroong	Tak-Fa, Thailand	x	x	xx
Ing. Noel Moradiaya	Choluteca, Honduras		x	
Dr. M.B. Vidakovic	Golden Valley, Zambia			x
Dr. L. Brizuela	La Lujosa, Honduras			x
Trials conducted by CIMMYT staff	**Location**	**Early Var.**	**Late Var.**	**Progeny**
	Zimbabwe, Harare	x	x	x
	Obregón, Mexico	xx	xx	
	Sinematiali, Ivory Coast	x	x	x
	Poza Rica, Mexico	x	x	
	Tlaltizapán, Mexico		xxxx	
	Obregón, Mexico			x
	Tlaltizapán, Mexico		x	

x = Number of Trials

Table 3. List of collaborators and locations of Insect Network Trials, 1985-92

Colaborators/Location	Test Insects	P590 (MBR)[a] C1	P590 (MBR)[a] C2	P590 (MBR)[a] EV	P390 (MIRT)[b] C1	P390 (MIRT)[b] EV
Univ. Mississippi Starkville, MS	FAW, *Spodoptera frugiperda*	86	88	89		
	SWCB, *Diatraea grandiosella*	86	88	89		
USDA Tifton, GA	FAW, S. frugiperda	86	88	89		
Cornell Univ. Ithaca, NY	ECB, *Ostrinia nubilalis*	86	88	89		
Univ. Delaware Newark, DE	ECB, *O. nubilalis*	86				
Univ. Missouri Columbia, MO	ECB, *O. nubilalis*	86	88	89		
	SWCB, *D. grandiosella*		88	89		
USDA Ames, IA	ECB, *O. nubilalis*			89		
Univ. Wisconsin Madison, WI	ECB, *O. nubilalis*		88	89		
Univ. Ottawa Ottawa, Canada	ECB, *O. nubilalis*			90		
ICIPE Mbita Point, Kenya	SSB, *Chilo partellus*	86			90	
AICMIP, IARI N. Delhi, Hyderabad, India	SSB, *C. partellus*		88	91	92	
	PSB, *Sesamia*	88	88	92		
NARC Islamabad, Pakistan	SSB, *C. partellus*	88				
IITA Ibadan, Nigeria	AfSCB, *Eldana saccharina*	86				
	PSB, *S. calamistis*	86				
PANNAR, Inc. Greyton, S.Af.	AfMSB, *Busseola fusca*	86				
CPNS, EMBRAPA Sete Lagoas, Brasil	FAW, *S. frugiperda*	91		91		
	LCSB, *Elasmopelpus lignosellus*	91		91		
INRA Guadaloupe	FAW, *S. frugiperda*			91		
	CEW, *Helicoverpa zea*			91		
UPLB Los Banos, Philippines	ACB, *O. furnicalis*				92	92
TARI, AVRDC Taiwan	ACB, *O. furnicalis*			92		92
CIMMYT	MLH, *Cicadulinu mbila*/Maize streak				90	
- Harare, Zimbabwe	SSB, *C. partellus*	90				92
- Tlaltizapan, Mexico	SWCB, *D. grandiosella*	86	88	89	90	91,92
- Poza Rica, Mexico	SCB, *D. saccharalis*	86	88	89	90	91,92
	FAW, *S. fugiperda*	86	88	89	90	91,92

[a] MBR = Multiple borer resistance
[b] MIRT = Multiple insect resistance, tropical

8

CHAPTER

Biometrics Issues

P. Byrne and J. Crossa

Introduction

In the world of maize research, CIMMYT's international testing system is unique because of the variety of germplasm offered, the broad range of environments sampled, and the wide spectrum of management conditions encountered. CIMMYT's system also differs from some multilocation testing strategies in that each location of a trial is designed to provide useful information in its own right relative to that location, as well as to contribute to an across-site analysis. These characteristics bring with them a set of biometrical considerations which, if not unique, at least merit different emphases than those of testing systems designed for more limited target environments or based on different strategies. The next few paragraphs present a general approach toward the design and analysis of CIMMYT's multilocation trials. Subsequent sections contain more detailed discussion of specific issues.

A general feature of multilocation yield trials is the occurrence of a considerable and complex genotype x environment interaction (GE). This phenomenon is part of the behavior of the genotypes and confounds their observed mean performance with their true values. GE complicates the selection of superior genotypes and therefore affects the amount of progress achieved through selection. The usefulness of yield data depends greatly on the precision with which it can be used to predict yield in different locations and in future years. The main problem for improving precision of yield estimates is that data collected in multilocation trials is intrinsically complex, having two fundamental aspects: structural pattern and nonstructural noise. The function of the experimental design and statistical analysis of multilocation trials is to eliminate as much as possible the unexplained variability (noise) contained in the data and thus obtain more precise genotypic yield estimates.

Three basic types of "error control" strategies exist for increasing the precision of genotypic yield estimates:

1. Partition error variation
2. Partition genotypic variation
3. Partition genotype-environment variation

Error variance can best be controlled by removing interblock variation from experimental error through incomplete block designs, such as the square lattice, generalized lattice, or row-and-column designs.

The second strategy includes spatial analyses (such as nearest neighbor analysis) to adjust for trends in soil fertility, soil moisture, or other factors. This adjustment is usually more efficient than conventional blocking and produces more precise genotypic yield estimates than conventional analyses.

The third strategy removes noise variation from GE and is related to the use of a more appropriate statistical model for fitting the data. Worth additional investigation to this purpose are recently developed multiplicative models for assessing GE and obtaining better predictions of yield performance.

Because these three error control strategies are applied to different and orthogonal sources of variation, they can be used independently or simultaneously. Although the usefulness and relative importance of the three strategies for international maize trials needs further study, it can be postulated that for appropriately planned trials more accurate yield estimates would be obtained by integrating the three approaches.

Experimental Design

The experimental designs used for standard international trials are described in Chapter 1. Listed below are several suggestions for trial design to achieve greater efficiency, both in the statistical sense and in economizing resources for growing trials.

Randomized complete block vs. incomplete block designs.
EVTs and ELVTs have always been designed as randomized complete blocks (RCB). Experience with international trials in the Wheat Program and special trials in the Maize Program has shown that for EVT-size trials the use of incomplete block designs improves efficiency significantly in many cases. Software for generalized lattice designs, in which any number of entries can be accommodated, has been developed by the Scottish Agricultural Statistics Service (SASS), and has been used in the Maize Program for several years. SASS recommends as a general guideline that variety trials for 15 or fewer entries be designed as RCBs and those with 16 or more entries as lattices. If we followed this guideline, about half of our variety trials would be designed as lattices. Using incomplete block designs would require that cooperators be somewhat more conscious of field layout to ensure that all plots within a block were planted physically adjacent to each other. Otherwise, the potential increase in precision from lattice designs would be achieved at no additional cost, as the software to handle these designs will be included in the new CIMMYT/MSU/SASS software system (See description in a later section of this chapter). Cooperators who wish to analyze the data from these trials themselves will still be able to carry out an RCB analysis.

Two-row vs. four-row plots
In our variety trials should we move from four-row plots, in which only the two central rows are harvested, to two-row plots, in which both rows are harvested? The advantage would be a reduction by half in the amount of seed and land required and a smaller reduction in shipping and labor costs. The major disadvantage would be possible loss in precision due to unequal competition effects among plots. Gross differences in competition effects among entries would be reduced if only materials of similar maturity were included in a given trial. Within maturity groups, how significant are competition effects among varieties? A study to investigate the importance of those effects was undertaken in 1990 using two EVTs, each grown at two CIMMYT stations in Mexico. The trials were planted in four-row plots and data recorded for each row separately. Then rows 1 and 4 of each plot were added or averaged together to obtain data for the unbordered treatment, and rows 2 and 3 were added or averaged to obtain bordered treatment values. Results showed few differences between bordered and unbordered treatments (Table 1). However, because trial management at CIMMYT stations is often better than at other locations where our trials are grown, these results may underestimate the importance of border

effects at other sites. Also, because competition effects vary among materials and are to some extent unpredictable, greater differences between bordered and unbordered treatments may occur in other trials.

Number of replications

Another way of reducing trial size would be to reduce the number of replications from four to three or two. Private sector multilocation testing systems often balance a low number of replications per site against a large number of sites, with the objective of drawing conclusions across an entire target area. The objectives of CIMMYT trials differ in that each trial must stand alone to provide useful information for a given location. In order to estimate the effect of a reduction in the number of replications on trial precision at a single site, data from eight locations each for eight variety trials from 1989 and 1990 were analyzed. One and two replications were deleted at random from each trial to obtain data sets with two and three replications, in addition to the standard four-rep data sets. Standard error of the difference between two yield means was obtained for each set, and percent efficiency calculated as the ratio of standard error for the larger number of reps to standard error for the smaller number of reps, multiplied by 100. Results showed that three-rep trials were 88% as efficient, on average, as four-rep trials, and that the use of two replications was 74% as efficient (Table 2). To test the hypothesis that lower yielding sites might lose more efficiency when number of replications was reduced, mean yield (which ranged from 1.4 to 9.1 t/ha) was correlated with percent efficiency for each location. The non-significant values obtained (0.09 and -0.09 for 4 vs. 3 reps and 4 vs. 2 reps, respectively) indicate no consistent trend between yield level and effect of reduction of replications.

Density

While the standard population density of 53,000 plants/ha seems appropriate for intermediate to late maturity trials, it is well below the density required for optimum yield expression in extra-early and early materials. In addition, there is evidence of significant genotype x density interaction in these materials. However, early varieties are not always planted at high density by farmers, especially in areas where drought stress is common. Should CIMMYT change to higher recommended densities for early and extra-early trials?

Data Management and Analysis

Since 1979 a Fortran software system developed at CIMMYT and operating on a "mainframe" computer has been used to analyze CIMMYT international maize trial data. The functioning of the system is described below.

When field book data sheets arrive at CIMMYT, they are visually checked by the Maize Program's data manager and by the breeder responsible for the class of germplasm involved. Any problems with the data—i.e., missing plots, doubts about the identity of a data column, etc—are noted and appropriate actions taken, typically things such as eliminating a variable from the analysis or requesting clarification from a cooperator about certain information. Next, the data manager fills out a "steering sheet" that identifies the year, trial, and location of the data set, defines the format for key entry, identifies data columns with a list of variable codes, specifies any data conversions, and indicates variables for which analysis of variance should be carried out. The sheet also contains information on trial design, number of replications, plot size, cooperator name, and local checks. The field book sheets plus the steering sheet are sent to for key entry.

Usually within a few days the data is entered in a computer file, which is then processed by the data manager. From a menu in the Fortran system he chooses the option for data filtering, which flags any data point that lies outside certain guidelines. Ear height, for example, should be between 25% and 75% of plant height; number of rotted ears must be less than or equal to the total number of ears. This data-checking option also displays a list of minimum, maximum, and mean values for each variable. Based on the results of the filtering program, the data manager may need to refer back to the original data sheets to check a dubious value. He then must decide whether to accept or modify values in the data set.

The next step is analysis of variance, which is carried out using the information included in the steering sheet. For IPTTs the ANOVA option produces both ANOVA tables and a listing of means. For EVTs, two separate steps are needed to obtain the ANOVAs and means. The output of these processes is checked and if the results appear reasonable, copies are made and sent to the cooperator, to the relevant regional office, and to the appropriate CIMMYT headquarters breeder.

Multilocation analysis is done across all locations, as well as stratifying the locations into geographic regions (e.g., Asia, Central America, South America, West Africa, etc.). Additionally, cluster analysis is done to identify groups of similar environments using a program written in SAS. Currently we are reporting Eberhart-Russell stability parameters, but in the future results from AMMI analysis, as well as Shukla's stability variance statistic, will be included for which we have software available.

Some of the limitations that we have currently with the Maize system is that it can handle only square lattice and RCB designs, which takes care of all our needs as far as International Maize trials are concerned. But for special trials, which involve other experimental designs including alpha lattice, split-plot, etc., the analysis is done using SAS and other programs like Alphagen. Wherever applicable we are also using PC-based statistical packages. The current maize system does not permit searching or querying the huge amount of historical data that is being stored. This limitation will be rectified when we move on to the proposed CIMMYT-MSU software system, which will give us more power and flexibility for utilizing historical data through a unified database.

Reporting International Trial Results

Results of analysis of international trials are reported in three stages:

1. As soon as an individual location trial analysis is completed it is sent to the cooperator. This is normally done within three weeks of receiving the data sheets.

2. In early summer of the year following trial distribution, a formal preliminary report is published. It contains entry means and agro-ecological information for individual locations and a preliminary combined location analysis.

3. The following winter a final report is produced which contains individual location results received since the preliminary report was prepared and a new combined location analysis.

How efficiently does this reporting system meet the needs of our cooperators? To the extent that timeliness is an important component of the value of the information, we continuously strive to improve it. Delays encountered in mail service to and from CIMMYT can result in a lapse of up to three months between the cooperator sending data sheets and receiving an individual site analysis. By that time it may be too late to request and receive seed of promising materials for planting in the following growing season. Some cooperators with computer facilities avoid the wait by analyzing their data themselves. The delay in obtaining any type of multilocation results is even longer. This is due partly to the slow rate at which data is returned to CIMMYT and partly to the time required to prepare and print the publication.

The content of the reports also receives considerable attention. For individual site analysis, changes in the way some variables are reported has been proposed. Reporting yield in kg/ha, for example, conveys a false impression of the precision with which that variable is estimated; stating yield in t/ha to two decimal places may be a better option, e.g., 6.32 t/ha rather than 6317 kg/ha. In the section containing agro-ecological information it is not always obvious which stress problems were the most important. A suggested alternative is to ask researchers to state directly which were the two or three factors that most limited yield in their trials.

Regarding the content of the preliminary and final reports, in which results from many individual sites are followed by an across-site summary, a major question is how and to what extent researchers use information from sites other than their own. Cooperators have indicated that in decreasing order of importance they examine results from their own locations, from other sites in their own countries, from sites in neighboring countries, and to a lesser degree, from sites in other regions believed to be similar to their own. Several cooperators have mentioned the usefulness of the agro-ecological information in the testing reports in helping them identify similar sites.

Another consideration in an efficient reporting strategy is its cost. Estimates of the cost of a published International Testing preliminary or final report are in the range of US $10-15 per copy, which includes Maize Program, editing, and design staff time, along with printing and shipping costs. Some options for reducing the cost and improving the timeliness of reporting include preparation of a quicker, less formal document, at least for the preliminary report; production of smaller reports divided according to germplasm class (e.g., lowland tropical, subtropical, and highland), each with a more limited target audience than the present combined report; and distribution of reports on diskette to those able to take advantage of that technology.

CIMMYT/MSU/SASS Information System

In November 1991 the CIMMYT Maize Program and Michigan State University signed a two-year memorandum of understanding for the joint development of software to support crop breeding research and associated activities. Subsequently, SASS agreed to provide its experimental design and analysis software for integration into the system. The PC-based software, developed using the FoxPro database package, will become the core software resource for international testing operations and for individual scientists at headquarters and in regional programs. It is also envisioned that the system will be shared with national program cooperators.

Among the functions to be offered by the system are seed inventory, experimental design, trial and nursery management, field book and label printing, data analysis/reporting/storage/query, project documentation, seed shipment documentation, and cooperator mailing list maintenance. Many of the problems with the present system will be resolved. A wide selection of trial designs and analyses will be available via SASS software products. Unbalanced data sets and missing values will be accommodated. Because data will be stored in a series of inter-related databases, a vast array of searches and queries will be made possible. For example, one might ask for a list of all trials in which a particular genotype appeared; then ask for all locations of those trials in South America at an elevation greater than 1000 meters; then narrow the list further by specifying only locations for which *E. turcicum* data are available; finally one could request a list of yield and *E. turcicum* means for the genotype of interest and local checks, for all locations that met the previous criteria.

The system will provide basic across-site analysis, and possibly Eberhart-Russell stability analysis, but not a wide array of options for GE or stability analysis. Because of the large number of approaches to these issues (Crossa, 1990) and the complexity of software required for some of them, it is not considered appropriate to provide these functions within the system. However, data will be easily imported and exported to facilitate its use in other software packages.

National programs which acquire the CIMMYT/MSU/SASS software will be able to analyze their own data quickly and easily before sending it to CIMMYT, and will thus avoid some of the delays of the present system. For ultimate customization of reporting, cooperators could be sent all the data for a given year on diskette; with the aid of the new software they could search, query, and combine data for analysis according to their own criteria.

Use of Historical Data

An unexploited CIMMYT resource is the huge amount of maize trial data collected since 1974, approximately 1000 sets from progeny trials and 5000 sets from variety trials. As mentioned in a previous section, much of this data plus associated trial information is not in a readily accessible format. However, preliminary work to verify and organize the data files has begun, with the goal of converting them for uploading into the CIMMYT/MSU/SASS system database.

An investigation of the historical data has been carried out under a CIMMYT/University of Nebraska project titled "Evaluation, Management, and Utilization of Maize Germplasm and Breeding Systems". The project was funded by a USAID/USDA/CSRS grant and ran from 1986 to 1990. A number of useful conclusions and observations regarding selection responses, genotype-environment interaction, yield stability, broad vs. narrow adaptation, grouping of environments, genetic variability, and other themes were made (Gardner et al., 1990; See Appendix 4.)

Much more investigation of these data could be undertaken, however, given that the data will soon become more accessible and that new analysis techniques regularly appear. One objective of exploring the historical data should be to group testing sites in a consistent and meaningful way. The EVT across-site summaries in the international testing reports present means for sites grouped by region (South America, Central America/Mexico, etc.), because this is an easy and sometimes useful grouping. It is realized, however, that locations in different regions may have more in common in terms of germplasm performance than sites within the same region. The challenge is to identify groupings of sites that show long-term similarities in discriminating among maize genotypes. Cluster analysis and other similar techniques based on single-year yield data have identified different groups of sites in different years, sometimes putting together locations with large differences in altitude, latitude, or other physical parameters. Classification of sites based only on agroclimatic factors such as altitude, rainfall, and maximum and minimum temperatures (Pollak and Pham, 1989) is somewhat helpful, but its usefulness would be enhanced by inclusion of yield trial data among the classification variables. What is needed is a systematic multi-year approach to site classification that differentiates useful trends from noise, takes advantage of both environmental parameters and germplasm performance data, and does not conflict with subjective knowledge about similarities among sites.

A related objective is to group CIMMYT maize germplasm and to identify groups of environments that interact positively for yield with particular germplasm groups. One way of doing this was demonstrated by Crossa et al. (1990), who analyzed two CIMMYT EVTs using the additive main effects and multiplicative interaction (AMMI) model (Gauch, 1988). Additional investigation with this technique may help clarify appropriate target environments for specific CIMMYT materials and thus choose testing locations more systematically. More careful selection of testing sites for progeny trials, according to Crossa and Gardner (1989), should reduce the GE variance relative to the genetic variance, with substantial increases in the rate of population improvement.

Yield stability is of key importance to the eventual users of CIMMYT germplasm, developing country farmers. Determining a reliable, easily implemented, and easily understood method to identify stable and productive genotypes, however, has been an elusive goal (Gardner et al., 1990). Although considerable work has been done on the stability of CIMMYT's maize germplasm (Crossa et al. 1988a, 1988b, 1989), additional studies that compare and validate various stability methods could take good advantage of our historical data.

The Geographic Information Services unit, recently established at CIMMYT, offers possibilities for combining maize trial data with weather, soils, and other geographic information in a variety of informative ways. Crop modelling researchers would also constitute potential users of organized, accessible historical trial data.

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Table 1. Student's t-tests and correlations between yield of bordered and unbordered treatments in four 1990 variety trials.

Trial	Location	t-test **	Correlation coefficients* Simple	Rank	N
EVT 14B	Poza Rica	0	0.88	0.88	14
EVT 14B	Tlaltizapan	2	0.91	0.81	14
EVT 16A	Tlaltizapan	1	0.96	0.92	13
EVT 16A	El Batan	1	0.95	0.94	13

* All are significant at $P<0.01$.
** Number of entries for which Student's t-test showed significant differences between bordered and unbordered treatments.

Table 2. Efficiency of 2, 3, and 4 replications for yield estimation in 8 CIMMYT maize variety trials using 8 locations per trial.

Trial	Mean percent efficiency* 3 vs. 4 reps	2 vs. 4 reps
89 EVT 12	89	73
89 EVT 13	89	73
89 EVT 16A	81	67
89 EVT 16B	87	76
90 EVT 15B	86	66
90 EVT 17	91	83
90 ELVT 18A	87	78
90 ELVT 20	91	73
MEAN	88	74

* $\text{Efficiency} = \dfrac{\text{Std. error (larger no. of reps)}}{\text{Std. error (smaller no. of reps)}} * 100$

9

CHAPTER

Logistical Aspects of International Testing

P. Byrne

Seed Treatment

Seed packaged in trials is treated with a slurry mixture of the insecticide Furadan and the fungicide Thiram. Semevin has been proposed as a replacement for the highly toxic Furadan. While field performance of Semevin has been quite good, the Maize Program's experience with that product has not been entirely successful because Semevin does not stick well to maize seeds. For treating miscellaneous seed samples (i.e., seed not included in a trial), a mixture of diatomaceous earth (insecticide) and Thiram powder is used. While diatomaceous earth is effective against maize weevils, there are doubts about its effectiveness against the larger grain borer (*Prostephanus truncatus*), an insect of quarantine significance. Malathion powder is also considered ineffective against this pest. We are constantly on the lookout for more effective insecticide treatments.

Seed Shipment

The Maize Program's International Testing Unit annually makes about 400 seed shipments, which include trials as well as miscellaneous seed samples requested by cooperators. The international shipment of seeds is a complicated process requiring 1) knowledge of phytosanitary regulations and import restrictions, which differ from country to country; 2) effective seed treatment and packaging; 3) selection of the most appropriate shipping method; 4) production of multiple documents to accompany each shipment; 5) systematic record-keeping; and 6) in the case of private companies, billing the consignee for shipping costs.

Procedures to carry out these various steps are only semi-automated at present, but functions to prepare shipping documentation and store shipment information will be included in the CIMMYT/MSU/SASS information system (See section on Biometrics). One of the benefits of this system will be the ability to search and query a database containing information on shipments. Specific subsets of this information is often requested by CIMMYT administration or donor agencies, and providing the requested reports is very time-consuming under the present system.

Problems with seed shipments regularly arise, occasionally caused by errors at CIMMYT, sometimes due to errors by shipping agents or airlines, and often related to bureaucratic problems with customs agents or other officials in the country of destination. CIMMYT tries to notify consignees immediately after shipping about the details (airway bill number, airline, flight, date of shipment) of a shipment, so that a cooperator can trace it. In many cases cooperators do not have a telex, EMAIL, or FAX, so notification is by mail, which may take a month or more. An "Acknowledgment of Receipt" form is included in each shipment, but is only returned by about half of those who receive shipments.

An official Mexican phytosanitary certificate, stating the general health of the seeds, is included with all seed shipments. However, many countries require additional declarations regarding absence of specific diseases or insects, and CIMMYT is not permitted to add these to the Mexican certificate. To resolve this problem, CIMMYT's Seed Health Unit has produced a "Seed Health Certificate" (annexed to this chapter) which verifies the absence of organisms of quarantine significance. There have been two reports by receiving countries of phytosanitary problems with CIMMYT maize seeds, one involving a pathogen and the other an insect. Both reports are suspect, but they point out the necessity for CIMMYT to pay utmost attention to phytosanitary concerns.

At present CIMMYT maize seed shipments do not include a "material transfer agreement" or policy statement regarding restrictions on the use of the germplasm. However, such a policy has been discussed within the broader framework of intellectual property rights and the CGIAR. (See discussion in draft *1991-92 World Maize Facts and Trends: Maize Research Investment and Impacts in Developing Countries.*)

International Trials Calendar of Events

Although a new set of international trials is offered every year, the complete chain of events connected with a set of trials extends over three calendar years. A typical schedule of events is as follows:

	1990 Trials	1991 Trials	1992 Trials
Oct 89	Plan trials		
Nov 89	Announcement letter		
Jan-May 90	Trial preparation		
Mar-Aug 90	Trial shipment		
Sept 90	Data begins to arrive; individual site analyses		
Oct 90		Plan trials	
Nov 90		Announcement letter	
Jan-May 91		Trial preparation	
Mar-Aug 91		Trial shipment	
June 91	Begin preliminary report		
Sept 91		Data begins to arrive; individual site analyses	
Oct 91	Begin final report		Plan trials
Nov 91			Announcement letter

Data Return

Historically CIMMYT has received data from about three-quarters of the IPTTs shipped, and from somewhat more than half of the EVTs and ELVTs distributed (Figure 1). The higher rate of return for IPTTs is explained by the fact that sites and cooperators are more carefully selected for those trials. Although these recovery rates seem low, they are not out of line with the experience of the CIMMYT Wheat Program and several other international centers, which report similar return percentages.

A combination of factors appears to explain why data recovery rates are not higher. Cooperators have mentioned late arrival of trials as one reason why they could not be planted. In some cases, delayed shipment from CIMMYT has been responsible, especially for IPTTs and for areas which are planted from March to May. A more common cause for late arrival of seeds, however, are delays encountered en route from CIMMYT to their final destination: in airports, customs offices, phytosanitary departments, and Ministry of Agriculture headquarters. As mentioned previously, CIMMYT is not always able to notify cooperators promptly about seed shipment details so that they can trace shipments from their end.

Sometimes trials arrive on time, but a cooperator is not able to plant them because of land or budgetary constraints. On other occasions trials may be sown but later lost to drought, floods, or severe disease, insect, or animal damage; or a cooperator may not have enough funds available to hire harvest labor. Political instability in several countries in recent years has led to suspension of research activities, abandonment of trials, and curtailment of mail service. There have been some cases of data sheets lost in the mail. Finally, there are reportedly some cooperators who grow trials and collect data but do not return the data to CIMMYT, or return it after a long delay.

What can CIMMYT do to increase the rate of data recovery for its international trials? Among the suggestions are the following:

- Ensure that all trials are shipped from CIMMYT with sufficient lead time for early arrival at the planting site. To the extent possible, this is already being done. EVTs are normally ready to ship by February, which is early enough to meet virtually all planting schedules. IPTTs are more problematic in that, under the current system, they are not harvested until spring and cannot be shipped until April or May. A population improvement system which allows harvest of progenies in autumn would eliminate this time constraint. Other factors beyond CIMMYT's control, such as late receipt of trial requests or delayed arrival of import permits, also prevent timely shipment.

- Greater involvement of CIMMYT regional staff in advising cooperators on selection and execution of trials, visiting trials in the field, and evaluating results. In CIMMYT's earlier years, this was a major part of the workload of regional staff. More recently, however, regional programs have worked on their own research agendas and trial networks, and have spent less time facilitating the international trial system.

- If data do not arrive within a reasonable amount of time after the anticipated harvest date, send a reminder letter to the cooperator.

- Penalize cooperators who do not return trial data by not sending them trials in the future. This assumes that we know the reasons why data are not returned. If a cooperator does not receive trials because of a shipping error or if the trials are lost to flooding or drought, it would not be fair to refuse that cooperator trials in the future. What CIMMYT might do is to encourage accountability by urging cooperators to provide a brief message on progress or difficulties in handling their trials (i.e., whether or not they were planted or harvested).

- Reward cooperators who return their data promptly. This is already done after a fashion, in that our more reliable cooperators are given preference in trial assignment when quantities are limited. As an additional gesture of appreciation, the names of reporting cooperators are now listed on the first page of the International Testing reports. It may be useful to implement other measures to this end.

Decentralization

Since 1974 the Maize Program has maintained an International Testing Unit headed by an international staff member. Historically, most new germplasm produced by Maize staff entered into the system of international trials, which were organized, distributed, analyzed and reported by that unit. Since the mid-1980s, however, CIMMYT's germplasm development efforts have become more decentralized both at headquarters and in regional programs. Special trials on hybrid research, drought stress, insects, and other topics have been managed from headquarters independently of International Testing. Regional offices have offered trials of germplasm selected for resistance/tolerance to regionally important stresses. The result is that the International Testing Unit manages trials which represent a progressively smaller share of the Maize Program's available germplasm. Still, the number of trials handled by International Testing is much greater than the number handled by other units combined.

To completely decentralize international testing operations, given the present state of automation and available personnel, would be an overwhelming burden on CIMMYT scientists. Decentralization also runs the risk of poor coordination in dealings with national programs and inefficiencies caused by several individuals carrying out the same operations. Some intermediate degree of decentralization of trial management, however, will be facilitated by the CIMMYT/MSU/SASS information system, which will permit uniform design, analysis, and data storage for a variety of types of trials. Even with the improved software, however, some kind of centralized data management/information/seed shipment unit will be required.

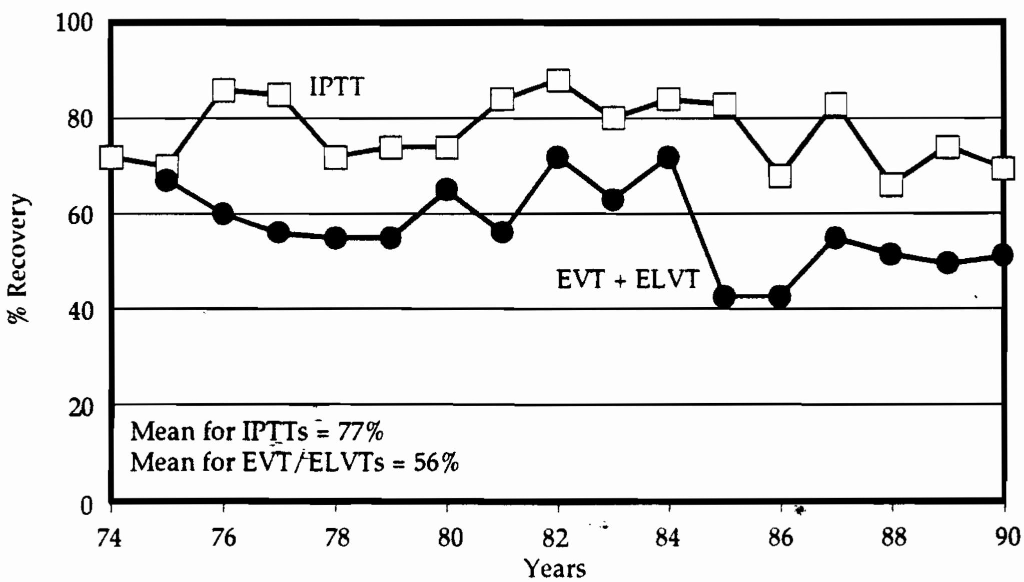

Figure 1. Percent of trials distributed for which data was returned, 1974-90.

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APPENDIX

Discussion of CIMMYT's International Maize Testing Program by national maize program leaders, October 14-15, 1991

Participants were welcomed to the one and one-half day program by Maize Program Director R. L. Paliwal, who emphasized the importance to CIMMYT of the opinions of national programs on international testing issues. Associate Director R. Wedderburn, serving as moderator throughout the event, then explained how the discussion process would be organized. Next, P. Byrne, coordinator of International Maize Testing, presented background information on the testing program: objectives, history, organization, results, and some issues for consideration.

The participants were then divided into four subgroups, each with five to seven members and one CIMMYT resource person. Each subgroup appointed one of its members to be spokesperson. The composition of the subgroups was as follows:

1.	José Luis Quemé*	Guatemala
	Luis Gerónimo Gomez	Argentina
	Santiago Crespo	Ecuador
	Roger Urbina	Nicaragua
	Audberto José Millán	Venezuela
	Kevin Pixley	CIMMYT
2.	Mónica Menz*	Bolivia
	Alejandro Navas	Colombia
	Adán Aguiluz	El Salvador
	Alfonso Peña Ramos	México
	Carlos Tirado Soto	Perú
	Sam Vasal	CIMMYT
3.	Vijay Kumar Saxena*	India
	Baffour Badu-Apraku	Ghana
	Mugo Ngure	Kenya
	Nonito Franje	Philippines
	Nick Lyimo	Tanzania
	Chokechai Aekatasanawan	Thailand
	Leonid Kozubenko	USSR
	Willy Villena	CIMMYT
4.	Charas Kitbamroong*	Thailand
	Peter Sallah	Ghana
	M. Y. Sharma	India
	Ahmad Bankeh Saz	Iran
	Ngo Huu Tinh	Vietnam
	Lewis Machida	Zimbabwe
	Ganesan Srinivasan	CIMMYT

* Spokesperson

During the next hour and a half the task of each subgroup was to decide on a list of important discussion topics related to international testing. In this phase the emphasis was placed on identifying general themes for discussion rather than on detailed consideration of those themes. To provide an organizational framework participants were asked to consider the following points in deciding on the topics to be discussed:

1. The need for and utility of international testing
2. The breeding systems used and types of germplasm offered
3. The design, size, organization, and management of trials
4. Trial analysis and reporting
5. Any other topic.

The whole group then reconvened and the spokesperson of each subgroup presented its list of topics. Under the leadership of the moderator, duplicate or related topics were combined and a consolidated list of topics which received priority from all subgroups was formulated.

The session again broke into four subgroups, each discussing the topics it considered most important and offering suggestions where appropriate. Approximately four hours were available for this phase. The following morning, the whole group reconvened and the spokespersons presented the consensus opinions of their subgroups. This was followed by a general discussion including all participants, and final comments by CIMMYT staff.

A summary of the discussion for each topic follows.

1. Is the information sent to cooperators about available trials and germplasm timely and complete? If not, how could this be improved?

   Participants felt that the announcement letter on available trials should be sent to cooperators earlier and that more complete information on trial entries should be included. One subgroup suggested that trials be made available for two years, so that if a cooperator was not able to plant a given trial one year he could request it the next year. Apart from trial announcements, participants recommended an annually updated list of germplasm materials being developed by CIMMYT, both at headquarters and in regional programs. Because most of the new materials being developed have not yet entered the international testing system, some cooperators felt out of touch with the Maize Program's recent germplasm development activities.

2. Should trials be organized to meet regional needs for specific traits?

   All subgroups suggested that CIMMYT should organize trials targeted to specific needs in various regions, especially for evaluation of materials resistant/tolerant to region-specific stresses (e.g., maize streak virus in Africa, downy mildew in Asia, acid soils in South America). The utility of global trials for more generally adapted materials and to evaluate resistance/tolerance to broadly distributed stresses was also recognized.

3. Should a broader range of trials be offered with regard to genetic structure (e.g., lines, hybrids, topcrosses) or germplasm characteristics (e.g., drought tolerance, borer resistance)?

   Regarding genetic structure, the participants communicated their interest in materials more directly related to hybrid development. They suggested that CIMMYT offer materials such as inbred lines, partially inbred lines, and hybrids for evaluation. It was felt that continued emphasis should be given to heterotic patterns and stress resistance in the development of inbred lines.

   As for trials with special purpose germplasm, one subgroup endorsed the concept of networks of cooperators and CIMMYT scientists concerned with a particular stress problem, similar to the ongoing maize drought network. Trials could be offered through the network cooperators on a flexible basis, not necessarily every year. Another subgroup felt that special purpose germplasm should be broadly available to national programs in the form of trials, but that screening for selection purposes should be undertaken by CIMMYT and carefully chosen collaborating programs.

4. How long should a material remain in the IPTT population improvement system?

   A population should remain in the IPTT system as long as there is continued demand for that population and the progress from selection is acceptable. One subgroup commented that greater progress might be made through the IPTT system if each population was more specifically targeted to a group of similar environments.

5. What criteria should be used to introduce new germplasm into the international testing system?

   New germplasm entering the international testing system should be in an advanced stage of improvement and should possess a combination of characteristics for which there is sufficient demand. The Preliminary Evaluation Trial (PET) system for initial testing of new materials was considered useful.

6. Should additional experimental varieties (EV's) be formed on the basis of IPTT data combined over similar environments?

   While some participants felt that additional EV's should be formed on the basis of data from two or three similar environments, others considered that one EV for each location and one "across-location" EV was sufficient. One subgroup expressed the opinion that, because the rate of yield gain in the IPTT system is only about 2% per cycle, EV's need not be formed after every cycle of selection.

7. How should CIMMYT allocate the distribution of a limited number of trials to locations and cooperators?

   The environmental characteristics of a location should be consistent with the objectives of a given trial. CIMMYT should also take into account the previous performance of cooperators in managing CIMMYT trials. One subgroup suggested modifying the methods used in the IPTT system so that seed supply would not be a limiting factor.

8. What trial designs and sizes should be used in the international trials?

Concern was expressed about the size of CIMMYT trials, and it was recommended that CIMMYT explore options for reducing trial size without losing precision of the results. One subgroup considered a 12x12 lattice an appropriate size for IPTT's, and another subgroup felt that the range of 12x12 to 15x15 was acceptable. For IPTT's, additional seed per packet was recommended to permit overplanting and obtaining a uniform plant stand.

9. Should CIMMYT make available non-replicated observation trials?

This point was discussed by only one subgroup, which felt that non-replicated trials would give a cooperator the opportunity to observe many more materials than is possible in the current 4-replication EVT's. They recommended including both CIMMYT and local checks in the trials and grouping materials by plant height.

10. Should CIMMYT provide resources to national programs to cover trial management expenses?

Participants were in agreement that the trials they requested and grew were for their own benefit, and therefore that no compensation should be expected. However, one subgroup suggested that CIMMYT should consider providing resources to national programs for growing trials which are largely of interest to CIMMYT.

11. How can the rate of return of trial data (50-60% in recent years) be increased?

Among the recommendations were to:
—Strengthen the spirit of cooperation through visits by CIMMYT regional staff to observe the trials
—Limit the number of trials sent to cooperators with a poor record of data return
—Send reminder notes to cooperators if data is not received within a reasonable amount of time
—Emphasize to cooperators the importance of data from every site, not only to CIMMYT but also to other cooperators
—Ship the trials earlier so they will arrive in time for planting during the normal growing season.

12. How can reporting of trial results be improved with respect to timeliness and quality of reports?

An attempt should be made to prepare and send the reports earlier. One subgroup felt that the quality of data might improve by adjusting yield for plant stand.

13. What should CIMMYT's role be in the regional or international evaluation of national programs' or other institutions' germplasm?

It was felt that CIMMYT should play a coordinating role in the sharing and evaluation of national program germplasm within a region. The example of the CIMMYT-coordinated PCCMCA trials in Central America was given. The feeling was also expressed that CIMMYT should collaborate with other institutions to avoid duplications in trials being offered (e.g., CIMMYT and IITA trials).

Following the presentation and discussion of ideas by participants, CIMMYT staff members responded. P. Byrne expressed his appreciation for the many ideas and comments generated during the exercise. He explained that some suggestions could be implemented relatively quickly (e.g., provision of more complete information on CIMMYT maize germplasm; more timely mailing of the trial announcement letter), and that others would be discussed further during the upcoming internal and external reviews of international testing (to be held in December 1991 and March 1992, respectively). He mentioned that new software is being developed jointly by CIMMYT and Michigan State University which will allow cooperators to do more of their own trial analysis, according to their specific needs and interests, in the future.

R. Paliwal thanked the participants for their enthusiastic and constructive attitudes during this feedback exercise, and assured them that all suggestions would be given careful consideration in the coming months. On the issue of trial coordination, he stated that CIMMYT would work as closely as possible with other agencies to avoid duplication, but that national programs themselves must play a major role in deciding which germplasm is most advantageous for their purposes. Finally, he stated that a summary of this exercise would be sent to all CIMMYT staff and to national maize program leaders/coordinators who participate in the international testing network.

CIMMYT Maize Program: Internal Review of International Testing December 4-5, 1991

Major Conclusions and Recommendations

These meetings constitute the second in a three-stage evaluation of Maize International Testing that includes 1) the gathering of feedback from national program representatives, 2) an internal review to deal with the issues raised and identify additional themes, and 3) an external review by an expert panel to treat the themes identified in the first two stages. The following are the main conclusions and recommendations that resulted from the internal review. For further detail, consult Internal Review of International Testing: Summary Notes, Suggestions, and Recommendations (Appendix 3).

1. Germplasm improvement is a fundamental aim of Maize International Testing, but carefully targeted distribution of germplasm will remain an important function through EVTs and ELVTs. The free exchange of germplasm will continue to underlie CIMMYT research, including that concerning hybrid oriented materials (see point 7). The program should maintain the present system of EV formation but target sites for IPTTs. Regional staff will contribute to site selection.

2. In addition to the full sib system, other breeding schemes (such as half sib S1 and S2) will be employed to improve the populations and also the timeliness of nursery shipment, increase the amount of seed available for testing, and generate hybrid oriented resource germplasm.

3. A population should be left in the system as long as it is in demand and sufficient progress is being made in improving it. Variability in a population may be replenished by introgressing new germplasm, once this germplasm has undergone appropriate testing.

4. The standard size for IPTTs will be 196 entries in a 14 x 14 simple lattice with two replications per location and a 15-20% selection intensity. (Designs for stress trials may differ from this.) The alpha lattice design will be considered and, if approved, incorporated into the CIMMYT/MSU data management system now in development.

5. The Source and Stress Resistance subprogram will develop and improve materials for insect resistance, drought tolerance, and nitrogen use efficiency and test the germplasm in special networks. Superior materials from network trials may then be incorporated into EVTs. Regional programs will focus on resistance/tolerance to downy mildew, Al toxicity, corn stunt, and maize streak virus. The program will regularly evaluate the tolerance/resistance of germplasm improved in regional programs for specific traits and elite materials sent to headquarters for general improvement and international testing. The increased emphasis on stress breeding should not diminish the attention given to yield potential.

6. Regional programs will continue to manage regional trials, as their resources permit.

7. An intensified focus on hybrid oriented resource germplasm is indicated. The strategies for accomplishing this need to be considered carefully. Interpopulation improvement should be continued.

8. Regional staff should obtain agroclimatic data from cooperators, where such information exists, for grouping test sites and refining our definition of maize mega-environments. Historical trial data will eventually be converted to an accessible electronic format (the CIMMYT/MSU data management software under development will have this capacity).

9. The International Testing Unit should devote more time and resources to analyzing the volume of data that has accumulated in the last 20 years.

10. The International Testing system should give attention to targeting trials to specific mega-environments and regions, keeping their needs in focus, and not only global trials.

11. Preliminary reports will henceforth be prepared separately for each trial type in a simple document and distributed rapidly to cooperators, along with preliminary across-site analyses. The final report will continue as a bound publication. Software for improved analysis (e.g., AMMI, spatial analysis, and techniques for estimating genotype stability) will be evaluated. The program will move increasingly toward providing cooperators with data in electronic formats and allowing them to perform analyses.

12. Suggestions for increasing the rate of data return include shipping seed in a timely manner, having cooperators' names printed in annual reports, sending reminder notes to cooperators who are late in returning results, and having regional staff visit cooperators.

13. The products of the joint CIMMYT-MSU project to develop a PC-based, VAX-linked data management system will greatly facilitate the handling of trials and data analysis at CIMMYT, and will be delivered in a format that national programs can use.

CIMMYT Maize Program:
Internal Review of International Testing December 4-5, 1991

Summary Notes, Suggestions, and Recommendations

Introduction: Ripusudan L. Paliwal, Director, CIMMYT Maize Program

Dr. Paliwal welcomed participants and described the three stages in this review process: 1) feedback from NARSs representatives, particularly during special discussions held October 1991 with participants in the advanced crop improvement course at headquarters; 2) an internal review which, among other things, would allow us to identify themes for treatment during the third step; and 3) an external review conducted by an expert panel and covering issues raised in the internal review. He also added three questions for discussion: 1) Is the present organization of international testing the most relevant and efficient? 2) As regional programs augment research activities, what is their role in international testing? 3) What is the implication of intellectual property rights for international testing and the Maize Program in general?

Session I: Population improvement as it relates to international testing

Moderator: Carlos de Leon

Presentations by discussion leaders:

A.Broadly adapted germplasm of global importance (Surinder Vasal, Jim Lothrop) - Voiced concerns about the low number of populations, the lack of information about materials dropped from the testing program, and the need to replace discontinued populations with new materials. Distribution and improvement are compatible. Regional offices are not equipped to conduct extensive testing programs of their own. Given the significant GxE of highland materials, the move is toward improving populations by testing in targeted regions (e.g., collaboration on drought with INIFAP in central Mexico), rather than through international testing.

B. Stress tolerant/special purpose germplasm (Jim Deutsch, Rene Lafitte) - Focus on resistance/tolerance to drought and insect pests; aluminum toxicity, downy mildew, and streak are dealt with in regional programs. Nitrogen use efficiency also gaining prominence, and may become a priority in the near future. Stress tolerant germplasm requires specialized test sites and techniques, implying careful preselection of cooperators by CIMMYT. Due to the polygenic nature of traits, S1 selection used instead of full-sib or top cross. A drought tolerance testing network has been established, one cycle of trials sent out, and the results analyzed and returned to cooperators in a xeroxed bulletin.

C. Germplasm of regional importance (Gonzalo Granados) - International testing the basis of the Maize Program's success. We still lack certain germplasm types needed by national programs (e.g., early materials with resistance/tolerance to downy mildew and flooding for Asia, floury morocho for South America). Must go further in developing hybrid oriented germplasm. Should standardize the size of IPTTs.

Discussion

Need to improve communication between headquarters and regional programs concerning site selection. Geographic/mega-environment information should figure in selection. Once the best locations are chosen, regional programs can help evaluate the choices. A complete description of our populations should be sent to cooperators. "Improvement" should guide our efforts, but carefully targeted distribution will continue to be a function of testing.

Reciprocal recurrent selection and a full sib recurrent selection scheme are currently being used in the improvement of certain CIMMYT populations. Other breeding schemes, such as the half sib, will be added to improve some populations. Also suggested was the use of design II and partial diallel matings to generate progeny and information that contribute to the development of hybrid oriented germplasm.

Most objected to changing from a two- to a three-year population improvement cycle as a way to improve the timeliness of seed preparation and shipment.

If a population remains in demand by cooperators and sufficient progress is being made, it should be left in the system indefinitely. Where the variability in a given population has been exhausted, introgression of new germplasm should be done only after that material has been properly tested. Researchers in the various units of the resident program should be involved in chosing the germplasm to become part of a population.

Regarding the optimal size for IPTTs, opinion favored a minimum of 196 entries in a 14 x 14 simple lattice with two replications per location, due to the multiple characters considered in the evaluation of progenies in Iptts. A specific number of entries and replications should be set so that cooperators can plan (excepting special purpose trials). A 15-20% selection intensity should be used in population improvement, when 190 progenies are evaluated.

In testing stress tolerant germplasm, flexibility should exist to decide upon specific designs that fit the requirements of the germplasm evaluated. For developing sources of resistance, evaluation and selection should be carried out in areas where the specific stress is present. Regarding a possible yield "penalty" associated with breeding for stress tolerance, participants seemed to feel that both yield and stress tolerance are attainable within a given material.

Regarding populations improved in regional programs for specific characters and subsequently sent to headquarters for global distribution, levels of tolerance/resistance should be monitored regularly by ensuring that at least some sets of the relevant IPTT or EVT are evaluated under stress.

Regional variety trials are popular with cooperators but place an excessive demand on limited resources of regional programs. The CIMMYT/MSU data-management software currently in development could help. The idea of managing regional trials from headquarters was rejected.

Session II: Varietal testing and germplasm distribution

Moderator: Hugo Cordova

Presentations by discussion leaders:

A. Broadly adapted germplasm of global importance (Surinder Vasal, Pat Byrne) - In the past 15 years, 10,000 sets of EVTs and ELVTs sent to nearly 100 countries, some 1,200 to 1,500 EVs formed and evaluated, and approximately 200 CIMMYT-based varieties released in developing countries. The main purposes of international testing are to 1) distribute germplasm to national programs, 2) maximize the possibilities for both CIMMYT and the cooperator of identifying useful germplasm (as opposed to seed companies' testing systems, which are designed only to help the company identify useful germplasm), and 3) obtain trial data from a range of sites for targeting environments and populations. Regarding design of variety trials, a recent study showed that reducing from four to three replications resulted in a 12% loss in efficiency; going to only two reps diminished precision by 25%. The alpha lattice design can enhance efficiency and should be used for trials of more than 15 varieties. With regard to plot size, research at CIMMYT stations showed little evidence of an effect of border rows, but because of unpredictable competition effects and conditions in cooperators' fields, continued use of the four-row design, rather than reducing to two rows, was recommended.

B. Stress tolerant/special purpose germplasm (Jim Deutsch, Rene Lafitte) - The Source and Stress Resistance subprogram will develop and improve this material, with emphasis on insect resistance, drought tolerance, and nitrogen use efficiency. Work is also conducted in regional programs to incorporate these traits into materials being improved for resistance/tolerance to downy mildew, Al toxicity, corn stunt, and maize streak virus. Efforts underway to form stress networks. Cooperators and sites must be chosen to ensure natural occurrence of stress or infestation/inoculation capabilities (also, capacity and willingness for special management/data recording; e.g., ASI in drought trials). Standard EVTs, usually conducted under optimum conditions, do not facilitate stress selection. Need to ensure through preliminary testing that material sent out as resistant is truly so. There is no inherent yield penalty associated with stress-tolerant germplasm; the present materials are simply at an early stage of development.

C. Germplasm of regional importance (Carlos de Leon) - Maize for Asia should possess downy mildew resistance, plus earliness and resistance/tolerance to borers, Al toxicity, drought, and aflatoxins. In Eastern and Southern Africa, streak, turcicum, and downy mildew are primary constraints. For West Africa, full season, white grain maize with drought tolerance and resistance to streak virus. In South America, important constraints are Al toxicity followed by turcicum in the highlands and downy mildew in the lowlands. Corn stunt is the major constraint on the coastal lowlands of Central America, and ear and stalk rot on the Atlantic coast. Need to work on resistance/tolerance to combined stresses.

Discussion

Should continue present system of EV formation, but target sites for IPTT evaluation. We could reduce the number of sites for EVTs by preselection of cooperators and pretesting EVs at no more than 25 locations, singling out elite varieties to form global ELVTs for wider distribution. Under this scenario, EVTs would be more for national programs interested in a specific population; ELVTs for those interested in a certain type of maize but not necessarily a specific population.

There was no clear consensus on the options for reducing trial size. The use of the alpha lattice design should be explored and, if approved, built into the CIMMYT/MSU software.

The issue of plant density should be addressed by CMR. Higher densities may be feasible in early maturing material, but farmers usually plant at relatively lower densities.

In the handling of stress resistant/tolerant germplasm, specific trials would be designed for each trait to be tested initially within special networks. Elite materials would be subsequently added to international trials. PETs could constitute an intermediate step in this process or serve to compare new, broadly adapted materials with established germplasm (as has been the case). Elite checks should be included in the network trials to make the necessary comparisons for selection of the best resistant entries and maintain yield potential. Cooperators must be well-informed of developments and activities, if stress targeted germplasm is tested within special networks. The most resistant and high yielding new varieties developed by the stress unit will be promoted to EVT testing only after careful evaluations under the proper environment, in order to protect our main distribution system.

Session III: Line and hybrid evaluation

Moderator: Jim Lothrop

Presentations by discussion leaders:

A. Broadly adapted germplasm of global importance (Surinder Vasal) - The Maize Program has carried out several experiments on heterotic patterns within CIMMYT germplasm and the results have been published. Special efforts have been made to develop germplasm that possesses inbreeding tolerance and to sort material into heterotic groups. Interpopulation improvement using the well-known heterotic pattern Pop. 21 (Tuxpeño) and Pop. 32 (ETO) has been undertaken, and CIMMYT has developed A and B heterotic groups in white grain for tropical and subtropical germplasm. Conventional double cross, three way cross, and single cross hybrids, as well as nonconventional topcross hybrids, have been developed and tested. We could include the best of these in international trials.

B. Stress tolerant/special purpose germplasm (Jim Deutsch, John Mihm) - Inbreeding has been used in the stress breeding program. There are many good S2 and S3 lines, and some lines have been inbred further for RFLP work. Research across a wide range of materials is needed on possible dominance effects for certain traits. Lines are being developed as part of population improvement; program not yet to the point where it will concentrate on developing hybrids. Some early generation insect resistant lines from the MBR population have been used in commercial hybrids in South Africa.

C. Germplasm of regional importance (Hugo Córdova) - Initially only three Central American countries produced hybrids; now all have released hybrids based on lines from CIMMYT headquarters and locally developed materials. The regional work is coordinated by the Guatemala national program and includes the evaluation of inbreds, testcross formation, hybrid evaluation, and data analysis and reporting. The CA regional hybrid program is an excellent model but will be hard to duplicate elsewhere.

Discussion
All CIMMYT lines should be tested for combining ability as a spin-off from the regular line development program. Outstanding experimental hybrids thus identified could form part of EVTs. Occasionally, experimental hybrids could be sent in a separate trial and not included in EVTs with OPVs. Free flow of germplasm a prerequisite for regional hybrid networks. Interpopulation improvement a useful strategy.

No consensus on whether regional programs should test hybrids first or headquarters ship directly without regional testing (more favored second option).

Intellectual property rights not yet an issue for Maize Program (by disseminating information on germplasm, we avoid patenting by others). Exception: use by Program of patented material from outside sources. "Privatization" growing; we should provide hybrid oriented source germplasm.

Session IV: Operational aspects of international testing

Moderator: Willy Villena

Presentations by discussion leaders:
(Pat Byrne) - The basic steps in handling trials (two-year cycle): 1) trial announcement, 2) trial request, 3) preparation/shipping seed and forms, 4) data processing and preliminary report, and 5) final report.

About $5,000/trial cycle saved if boxes were used in place of tin cans for shipping seed. Cooperators tend not to complete the column in field book for comments on the experiment. Shipment booklets should include information for standard data recording and (possibly) agroclimatic and soil data. How can old field books (stored since 1974) be used? Rate of data return: 50% over the years and decreasing. Possible remedies: visits by regional staff to experimental plots, not sending trials to cooperators who do not return data, sending reminder notes to late returners, emphasizing the mutual responsibility of cooperators toward other network members, and shipping trials earlier.

Discussion
The present system is "tight:" i.e., the four-generation, two-year IPTT cycle using full sib family selection gives little leeway for improving the timeliness of IPTT shipment. Problems with workers, customs, and seed preparation getting "bumped" by other priorities. Suggestions for making the present schedule more efficient included: 1) making sure that sufficient hired help is available during seed preparation and shipment; 2) sending out trial announcements earlier, along with more complete information on the types of trials and entries; and 3) investigating the use of other breeding systems that would reduce the number of generations per cycle and provide a larger number of seeds per family.

Field book sheets were judged appropriate. Instruction booklets for experiment management/data recording should be simplified and emphasize the need for adequate land preparation.

IPTTs aimed more at improving populations; EVTs primarily for germplasm distribution. Gain by selection in population improvement better attained from experiments with good plant stand. Full sib family structure in IPTTs means insufficient seed for more than six trials. Switching to a half sib family structure would provide for three seeds per hill for as many locations as required.

Regional staff can help follow up on missing or incomplete data; should be sent notice of which cooperators to contact.

Asking cooperators to provide daily temperature and rainfall data is out of the question. Where agroclimatic data are recorded at the experiment station, canton, or county, we should obtain. Key data: elevation, latitude, longitude, temperature, and rainfall during the growing cycle. Historical agroclimatic data from experiment stations could be collected by regional staff while visiting experimental plots.

To increase data return rate, it was suggested that CIMMYT 1) ship seed in a timely manner, 2) print the cooperators' names in annual reports, 3) request date of planting and send reminder notes where necessary, and 4) have regional staff visit cooperators to motivate them and check experiments.

Session V: Trial analysis and reporting

Moderator: Jonathan Woolley

Presentations by discussion leaders:
(Pat Byrne, José Crossa) - The statistical analysis of trials serves to 1) identify patterns of genotype response across environments and 2) study GxE. Analyses can be across locations and years, or of individual sites. Alternatives to improve quality of estimation: 1) control of local variation through spatial analysis (e.g., nearest neighbor adjustment) plus incomplete block designs and 2) across-year analyses, such as pattern analysis, AMMI, and SHMM, that allow better prediction by separating patterns from "noise."

Reports late in reaching cooperators (approximately two-month turn around time). Production/shipping of reports costs around US$14/copy. The final report might be improved by increasing the use of graphics, giving data in t/ha, and replacing additive means with standardized values. Should eventually move to electronic reporting.

Discussion
With regard to data analysis, interest expressed in testing new methods to increase trial precision and improve interpretation, such as incomplete block designs (including alpha-lattices), AMMI, spatial analysis and improved techniques for estimating stability of genotypes. Software is available, but evaluation needed (perhaps by a postdoc). Incomplete block designs should be tested on new trials; other techniques could be evaluated using existing data. CIMMYT has technology transfer responsibilities; should thus spread new statistical techniques to collaborators.

The preliminary report should be prepared separately for each trial type in a simple document and distributed rapidly to the collaborators who received that trial, along with a preliminary across-site analysis for the sites available. The final report should still be produced in a bound publication. No obvious solution for speeding up the final report, which has to wait for late data. Collaborators should be encouraged to analyze their own data using PC packages such as MSTAT, the CIMMYT/MSU data management system (when ready), and even analysis by hand calculator. We should train people to handle and interpret data.

The Maize Program should use historical trial data to define mega-environments and group sites or genotypes. Accessing data from old tapes slow. Putting sets of trials or years on diskettes or the whole international trials database on CD-ROMs were suggested. Not clear whether trials of low yield result from bad management or appropriate management but taking into account local stresses. The latter desirable to get a wide range of yield conditions in international testing. For modelling, precise rainfall data is required.

Conclusion: Impressions of past and present Program directors

Former Maize Program Directors Drs. Ernest W. Sprague and Ronald P. Cantrell gave their impressions on Maize International Testing at CIMMYT and the internal review itself, after which Dr. Paliwal provided brief closing remarks.

Dr. Sprague underlined the importance of international testing to the Maize Program. Regarding stress breeding, he said that the Program should not lose sight of yield and pointed out that a balance between both yield and stress breeding priorities is attainable. He said the Maize Program needs to maintain its focus on national programs, and expressed concern about the evidence of declining interest on the part of cooperators. He expressed approval of the move toward developing hybrid oriented germplasm and identified the free exchange of germplasm as a major precondition for collaborative efforts in hybrid research.

Dr. Cantrell said the Maize Program enjoys great esteem among both public and private research institutes and is evolving appropriately in four areas: 1) toward less structure but able to establish the structures (e.g., regional programs) required to deliver its germplasm, 2) toward more specifically targeted germplasm products, 3) from varieties to hybrids, and 4) toward a better understanding of the needs of CIMMYT's clients.

He recommended giving attention to the exchange of information and germplasm and echoed Dr. Sprague's concern about a loss of contact with national programs. CIMMYT can assist national programs by helping them decide when to take up hybrid development and by providing hybrid oriented source material. Program priorities in basic research should be based primarily on the needs of national programs.

He said that the success of the Maize Program will ultimately not depend on money and recommended "educating" donors to bring their views on research priorities into closer congruency with those of the Program. Regarding intellectual property rights, he suggested that the Program maintain its stance as a "service provider" and not restrict the free distribution and use of its germplasm. He said that international testing should embrace no-cost options immediately but beware of adjustments with high hidden costs.

Dr. Paliwal promised that all suggestions would be kept in mind and stressed the Program's firm commitment to consultation, though it be classified as "desirable" or "complementary." He reiterated the view expressed by national program leaders during the feedback session that payment by CIMMYT for conducting trials would be inappropriate and said that the Program would make creative and effective adjustments in response to budget restrictions.

Though the role and scope of international testing are evolving, he said, its objectives remain unchanged. He foresees an increase in testing by regional programs and a need to support those efforts and coordinate them with work at headquarters. Regional staff should provide input on the targeting of germplasm. He said that international testing presently has access to more resources now than at its inception and must find ways to use them most effectively.

Finally, Dr. Paliwal said that notes from the internal review would be circulated for comment, and raised the possibility of expanding the scope of the subsequent external review to cover germplasm development as it relates to international testing.

Evaluation, Management and Utilization of Maize Germplasm and Breeding Systems

C.O. Gardner, Foundation Professor Emeritus since 6/30/89, Foundation Professor prior to that time.
M.A. Thomas-Compton, Assistant Professor
W.A. Compton, Professor
B.E. Johnson, Assistant Professor

This is the final report of work accomplished under the particular grant and research project listed above. The broad objective as to promote collaborative research between the Plant Breeding Group, department of Agronomy, Institute of Agriculture and Natural Resources (IANR), University of Nebraska at Lincoln (UNL), and the Maize Research Staff at the International Center for Maize and Wheat Improvement (CIMMYT) at El Batan, Mexico. Dr Linda Pollak, USDA-Iowa State University has also been a collaborator on the classification of international environments. Because of the complementarity of the two research groups, it was possible to achieve goals that neither group could have achieve individually. We were able to provide the expertise in breeding systems, quantitative genetics and statistical procedures needed to enhance the CIMMYT program and make valuable use of a vast amount of CIMMYT research data accumulated over the years. As a consequence, research programs of both organizations were greatly strengthened, exchanges of germplasm took place, and collaborative programs were developed. Under the direction of Dr. Ronald Cantrell, numerous beneficial changes have taken place in the CIMMYT maize program during the course of this project, including the addition of a statistic geneticist, Dr. Jose Crossa, who had been trained in our maize-breeding program at UNL.

In order to adequately assess the effectiveness of the international maize improvement program and to provide recommendations as to how it might be improved, the first step had to be retrieval, careful study, and detailed analyses of masses of accumulated, but relatively unused, data from "International Progeny Testing Trials" (IPTT's), "Experimental Variety Trials" (EVT's), and "Elite Variety Trials" (ELVT's). Dr. Jose Crossa and Dr. Hiep Pham were exceptionally helpful in locating the files and in data analysis work. Without them the job would have been much more time consuming.

As this "final" report is being written, we are still very much involved in continuing some analyses, interpretation and publication of studies involving CIMMYT data. However, major objectives of the originally proposed research have been accomplished. In this final report, we have attempted to summarize some of the major accomplishments in relation to each stated objective.

Objective 1: To extract, interpret and make use of information accumulated in CIMMYT data files over at least a 10-year period of recurrent selection and intefnational testing of maize.

The initial and main thrust continuing throughout the period of this grant was the retrieval, analysis and interpretation of data accumulated over a decade of international testing. This involved the three types of tests listed above (IPTT's, EVT's and ELVT's). Special emphasis was placed on analyses of 12 populations undergoing full-sib family recurrent selection for up to 7 cycles. In each population in the program, 250 full-sib families were grown in two replications in a 16 X 16 simple lattice design in 6 international environments each cycle of selection. Initially, forty percent (100 families) were chosen and recombined each cycle to form the selected population to initiate the next cycle of selection. Later the selection cycle was extended and a complex system involving intra-family selection and inbreeding (sib-mating or selfing) followed by further selection and intermating to produce half-sib families which were used to develop 250 new full-sib families for the next cycle of testing and selection (See Pandey, et al., 1986) the complexity of the latter procedures makes it impossible to estimate expected progress from the intra-family selection. Hence we have concentrated on the progress expected from full-sib family recurrent selection.

The numerous analyses performed and studied have led us to the following important conclusions:

1. There is no evidence to indicate that genetic variability in any of the twelve populations had been reduced (Table 1). Over several cycles of selection, one would expect frequencies of favorable alleles at each locus to increase in the improved cycles and a reduction in genetic variability should occur. It is not surprising that genetic variability has not decreased. The populations are very broad based with considerable initial genetic variability, and initial frequencies of favorable alleles may have been less than 0.5. In addition, the selection intensity (100/250 or 40%) was very low, traits other than yield were considered, and the maximum number or cycles of selection was only 7. Testing sites were generally "chosen" as the first countries requesting to grow the specific set of 250 FS progenies each cycle, but one location was always in Mexico. The environments were extremely variable and never the same from cycle to cycle. Some tests were poorly conducted and had high coefficients of variation so the data were considered unusable, some were never reported, and others were reported too late to use in selection. Expected maximum gains were not large (Crossa and Gardner, 1989) and realized gains were even smaller (Pandey, et al., 1986, 1987). Yet gains were obviously being made in resistances to biological and environmental stresses.

2. Genotype x Environment interaction components (G X E) were larger than genotypic components in most populations (Gardner and Crossa, 1989). This makes progress from selection difficult and suggests the need to classify international testing environments and to subdivide them into more homogeneous subsets for selection purposes. What is unusable G X E interaction in a selection program aimed at a very broad spectrum of environments, becomes usable genetic variability in a more narrowly defined range of environments. In fact, greatest progress from selection should come from within national programs where the target population of environments for which selection is practiced can be narrowly defined. As national programs develop as trained plant breeders become available, CIMMYT broad-based, broadly-adapted maize populations should be very useful germplasm resources for use in extraction of locally adapted varieties and of adapted inbred lines for use in hybrids.

3. There is no evidence to indicate that populations selected for performance over a broad spectrum of environments become more stable as measured by the magnitude of their G X E interactions (Table 2).

4. Some progress from selection for broad adaptability in international programs has apparently been achieved (Pandey, et al., 1986, 1987). Such progress seems to be more from the elimination of deleterious genes, shorter plant height, higher harvest index, and increases in frequencies of favorable genes controlling disease, insect, and stress tolerances rather than from an increase in frequencies of genes impacting directly on yield in the absence of stresses.

5. An examination of expected genetic gain in relation to the number of testing sites and the number of replications per site indicated that good data from 2 replications at each of 6 sites, as is currently being used, is satisfactory. More replications could not be justified, and it is unlikely that quantities of seed and operating budgets will permit more locations. It is very important that sites chosen return reliable data. With information on only 3 locations expected gains are greatly reduced.

Since there was no apparent decrease in genetic nor in G X E components of variance, we considered ways of best estimating these parameters for each of the 12 populations. Mean values across all cycles, pooled estimates combining all cycles, and weighted mean estimates (weights used were the inverse of the variance of each estimate) were all calculated. The three types of estimates are shown for genetic components of the 12 populations in Table 3. The weighted mean estimates seemed to eliminate extremes and was considered to be the most precise estimate; hence, it was used to estimate mean yield and genotypic, G X E, and error components for each population, and to predict expected progress from full-sib family selection in each (Table 4).

From these analyses, it was suggested that for recurrent selection programs, the international testing sites appropriate for each population and the professional personnel at that site need to be carefully considered in choosing the 6 sites to be used for each particular population. This should insure good, reliable data and make the selection program more efficient and effective. A clear definition of the target population of environments for which a cultivar is being bred is essential, and it is important to obtain the best possible data on the progenies being evaluated and selected in the program. Experimental varieties extracted out of each population (developed by recombining the ten best families at each testing site and the ten best across all sites) can then be distributed to any country wishing to evaluate the varieties.

Objective 2. To study corn-growing environments used in CIMMYT's international maize testing program to develop a more efficient classification of environments, and to design efficient systems for conducting international work.

Leadership for this phase of the work was undertaken by Dr. Linda M. Pollak, USDA and Iowa State University, and Dr. Hiep Pham who was head of CIMMYT's international testing program. After evaluation of a great many IPTT's, EVT's and ELVT's from the CIMMYT data files, it was quite clear that there was not only great variability among international testing sites and in the quality of data collected and returned, but also great similarities among some sites within the total set. A questionnaire was developed and sent to the scientist in charge of each site to provide detailed information about agroclimatic data at that site. This information was compiled and multivariated analysis techniques were used to classify the environments into subsets of similar ones. This work has been completed for the African Continent (Pollak and Pham, 1989) and is nearly completed for the South American continent. In addition, we are in the process of classifying testing sites according to yield data to see how well this classification corresponds to the classification based on climatological and physiological data. This classification of potential international testing sites is a valuable source of information in running any international testing program.

Objective 3. To examine genotype X environment interactions and stability parameters to gain a better understanding of genotypes, environments, and their interaction, and to evaluate progress realized in efforts to breed for broad adaptability an stability.

G X E interactions have been examined in many analyses and have already been discussed under objective 1 above. There is little evidence to indicate that breeding for very broad adaptability has reduced the magnitude of G X E. Exposure of genotypes to many different disease situations, insect pests and environmental stresses, which affect yield in recurrent selection programs, have undoubtedly led to greater stability in the presence of those diseases, but because of the extreme variability among testing sites in any one cycle, G X E remains large.

Crossa et al., (1990) used an additive main effects and multiplicative interaction model (AMMI) (Gaouch, 1988) to analyze data from two of CIMMYT's international maize cultivar trials. Increase predictability, greater precision in estimating yield means, and greater insight into genotype x environment interaction were realized. The AMMI model identified a different highest yielding genotype than did treatment means in 72 percent of the environments.

Methods of measuring stability of genotypes has been considered, and, from a breeding standpoint, the repression method of Eberhart and Russell still provides the most usable information. It is suggested, however, that curvilinear responses be examined along with linear responses in examining G X E interactions. This will sometimes help explain large deviations from linearity. A variety that performs well in a poor range of environments yet has the ability to respond geometrically to improved environments may well be the ideal one. In many developing countries, it is better for a farmer to grow a variety that provides him some food every year and lots of food in good years than to grow one that has a high average yield over years, but which may be subject to crop failure in some years.

Westcott, who spent a year with the Biometrics group at CIMMYT, reviewed methods of measuring stability (Westcott, 1986), and he suggested a geometrical method which was applied by Crossa to CIMMYT data to identify genotypes with greatest stability. Three manuscripts were developed from this work and were submitted for publication (Crossa, Westcott, and Gonzales). The method has not been widely used by plant breeders, and there is no evidence to indicate that this method will identify a variety that will product some grain in extremely bad years, which is needed for survival. Further studies are needed.

Objective 4. To develop methodology to use in selecting for stability of performance over a range of environments, and to determine the range of environments that can be tolerated in breeding strategy aimed at maximizing yields in developing nations.

This objective overlaps Objective 3 to a large extent. Is seems clear that selection for a narrower range of environments will lead to maximum progress in yield improvement and stability in developing countries. This means that selection programs designed to breed varieties for specific subsets of environments within each country are essential in order to achieve maximum gain. Improved CIMMYT populations and pools plus other germplasms stored in CIMMYT's germplasm bank should provide the essential resources needed in tropical and subtropical areas. Well designed experiments to compare within country selection compared to across country selection have not yet been designed. Pandey et al. (manuscript submitted) did try to compare across environment selection with single environment selection but the experiment was not designed to answer the critical question: How does progress from selection in a narrowly defined set of environments compare to that from selection in a broad range of environments when the evaluation is done in the narrowly defined set? They simply compared two populations from single cycles of selection, one developed by recombining selected families based on means of several international environments and a second one based on means of a single environment. These paired populations were tested in several environments including the single environment. All advances from one cycle to the other were based on means over all environments, which means that the population being improved was not being selected for specific adaptation to the single environment. Hence, the critical question has not yet been satisfactorily answered.

Objective 5. To evaluate the use of broad-based, broadly-adapted breeding populations compared to more narrow-based, narrowly adapted ones as germplasm resources for maize improvement in a limited set of definable environments found in one area (region, state or country).

Relatively little has been accomplished on this objective, particularly in relation to varietal development. There is much to be said for using broad-based population as long as the germplasm going into the population is reasonably well adapted to a specified set of maize production environments within a country. We would like to incorporate as many of the most favorable genes at each locus as is possible and use intense selection pressure to eliminate deleterious and undesirable alleles as fast as possible without losing the most desirable ones.

Where the ultimate objective is to use improved populations as resources for inbred line and hybrid development, the situation may be quite different. In this case, it is important to have at least two germplasm resources that exhibit considerable heterosis when crossed with each other from which to extract complementary inbred line. Detailed studies of diallel crosses made among many of CIMMYT's broad-based population revealed that heterosis was lacking (Crossa, et al., 1990; Beck, et al., 1990). The maximum was only 20 percent. On the other hand, in some older data on diallel crosses made among races or varieties of maize in Mexico, which was recently summarized by Crossa, et al. (in press), much higher levels of heterosis values were found. Likewise, in many other countries including the USA much higher heterosis values have been found. It is a common practice in the USA for commercial hybrid corn companies to maintain two or more populations which exhibit considerable heterosis in interpopulation crosses. Hence, where inbred lines and hybrids are the ultimate goal, it seems wise to develop populations based on heterotic patterns of resource germplasm.

Objective 6. To evaluate available information on gene pool formation, maintenance, and utilization and to plan new experiments needed to provide additional information in order to do a more effective job of introgressing alien germplasm into adapted materials for maize improvement.

CIMMYT personnel maintain a large germplasm bank, and CIMMYT breeders have made extensive use of this germplasm in developing a large number of germplasm pools and improved populations for use in national programs where the primary goal is varietal improvement. At the University of Nebraska, we have a long history of introgressing tropical, sub-tropical and other alien germplasm into our adapted populations, and we have made considerable use of CIMMYT materials. We have also carefully studied the results of diallel crosses among CIMMYT improved broad-based population. In addition we have done theoretical statistical genetic work on integration of unadapted germplasm into adapted populations, and we have used molecular marker genes to study crossing over and to identify useful chromosome segments in the unadapted germplasm. We have also suggested the use of molecular markers to increase the efficiency of selection in adapted x unadapted crosses.

Further work is obviously needed to develop complementary populations of use in hybrid programs, and some such work is already under way at CIMMYT. One way to do this is to form new populations based on heterotic patterns, because existing populations show relatively little heterosis when crossed with each other. Another way would be to use an existing improved population or some combination of such populations and divide the seed into two lots. Reciprocal recurrent selection could then be applied to separate these two sub-populations into two heterotic groups for use as sources of inbred lines to be used in hybrids. Comstock suggested such a procedure many years ago, although to our knowledge, it has not been tried because it might take several cycles to get divergence. Reciprocal recurrent selection using inbred testers as suggested by Russell and Eberhart (1975) should be an effective way of separating the two sub-populations. However, two such highly heterotic inbred lines are not yet available in the CIMMYT program.

Objective 7. To study the role of linkage and recombination in introgressing useful non-adapted germplasm into adapted germplasm for maize improvement.

One of the major problems in the utilization of exotic germplasm is that while it may possess some valuable favorable genes that one would like to transfer into adapted material, such genes are invariably linked to undesirable genes at other nearby loci. Day-length sensitivity and temperature sensitivity are always a problem when tropical or sub-tropical germplasms are used in the USA Corn Belt. Likewise, use of Corn Belt germplasm in the tropics is hampered by day-length sensitivity and lack of sufficient resistance to disease and insect pests found there. To the extent that these undesirable traits are controlled by major genes, the use of molecular markers provides a new technique to locate such genes on the chromosomes, and hopefully, to manipulate them more effectively in selection programs. CIMMYT has now developed the capacity to utilize molecular maarkers. Likewise molecular markers are being used in our own program.

Variation in recombination frequencies between linked genes has implications in breeding programs. Work of Tulsierum et al. (in press) at this University, indicates that wide ranges of recombination exist among families for chromosome regions studied. It is suggested that crossing over may be controlled by a single gene in some regions and by multiple genes in others. They also found differences among populations, some of which had Mexican and Caribbean germplasm incoorporated. Environment did not seem to affect recombination rates.

Objective 8. To evaluate breeding systems currently used in the recurrant selection programs for maize improvement at CIMMYT in relation to others available including the inbred-hybrid system, and to determine the role that each might play in a comprehensive international program keeping cost effectiveness in mind.

CIMMYT personnel in the maize program have done an excellent job of evaluating their breeding systems, and numerous changes have taken place under the direction of Dr. Cantrell and Dr. Paliwal. The full-sib family recurrent selection system is no longer the only system being used for population improvement. The merits of inbreeding and S_1 family recurrent selection, as well as combinations of different systems have been recognized and numerous changes have occurred in the program. An inbred-hybrid system was initiated and has been in operation in recent years, and the need for development of new heterotic groups has become apparent. Individual breeders now have more latitude in choice of breeding systems to use, which should definitely enhance progress; yet it is very important to have and integrated program and an interchange of ideas and materials between all breeders, including those involved in the germplasm bank. Promising S_1 lines identified in population improvement programs or directly from germplasm resources should be fed into the inbred line development program for further inbreeding and evaluation.

Objective 9. To evaluate improved populations as sources of inbred lines for use in hybrids where hybrid maize production might be feasible.

At the University of Nebraska as well as at other universities, inbred lines extracted from improved populations have been found to be superior in hybrids compared to those extracted from comparable original base populations. Hence in developing countries where hybrid programs are developing, the continued improvement of populations through recurrent or reciprocal precurrent selection should not be neglected. Attention to heterotic patterns in the formation of any new populations must be considered. Improved populations with high interpopulation heterosis will be useful sources of new inbred lines needed to supplement a pedigree breeding program.

Objective 10. To evaluate germplasm and develop breeding methodology for specific environments such as minimum tillage, reduced nitrogen availability, aluminum toxicity, low rainfall, etc.

At the University of Nebraska, we have studied genotype-tillage method interactions, nitrogen uptake efficiency, aluminum tolerance and drought tolerance. There is reason to believe that recurrent selection systems already developed, especially S_1 family selection, will be effective in proving populations that will perform well under adverse conditions as long as selection is done under those adverse conditions.

Summary

Although work of this type is never really completed and we will continue to analyze and interpret CIMMYT data for some time, we feel that a great deal was accomplished during the four years of this USAID/USDA support. We believe that we were able to provide useful expertise in the areas of plant breeding, quantitative genetics, and statistics to the CIMMYT maize staff, and we also participated in CIMMYT's training program for leaders of maize research in developing countries. At the same time, we were given access to valuable data for the analyses done and to some excellent germplasm for use in our maize improvement program. We were also given nursery space and assistance for evaluation and improvement of some germplasm resources used by our international students in their dissertation research. In all it was a very useful and mutually beneficial collaborative program which definitely will be continued but on a somewhat reduced scale. Without travel money, we will be somewhat restricted in what we can do.

The Maize Program in the 1990s: An Overview*

R.L. Paliwal

The Maize Program's primary mission is to assist national agriculture research systems (NARSs) in developing 1) improved germplasm for favored and marginal environments, and 2) appropriate research and production technologies for maximizing efficiency in the use of resources and sustaining natural resources. The Program carries out its mission through four main activities: 1) germplasm development, 2) crop management research, 3) training, and 4) dissemination of information. The products of this work are superior germplasm, appropriate technology for maize production, more efficient research techniques, more skilled human resources, and improved information systems.

The urgency of these tasks is heightened by expected trends in maize demand. Based on an annual population growth rate of 2% and 2.6% average growth in per capita income, CIMMYT's Strategic Plan estimates that until the year 2000 demand for maize in developing countries will increase at 3.5% annually. Assuming that the area planted to maize is extended at the rate of 1%, yields will have to increase at a rate of 2.5% to keep pace with demand. According to a recent reevaluation of circumstances affecting CIMMYT's Strategic Plan, the demand for maize is likely to increase at a faster rate than was anticipated earlier, requiring a higher rate of growth in production.

Research and Development Strategies

Our efforts to assist national programs in achieving this rate of growth are guided by 10 basic strategies, nine of which I will explain briefly below, followed by a more detailed discussion of the tenth strategy.

1. *Focus on mega-environments for prioriity setting*—In view of our global responsibilities in germplasm development, we focus on the requirements of maize *mega-environments* in planning and priority setting. This concept has proved to be an effective tool for managing the resources available for germplasm development.All of the 30 mega-environments we have delineated are international, and many are transcontinental. The number represented in particular countries is highly variable. Mexico, for example, contains 13, Thailand 7, Zimbabwe 4, and Bostwana only 1. To further refine the current characterizations of mega-environments, CIMMYT recently added to its staff a specialist in geographic information systems. In addition, we are beginning to delineate mega-environments for targetting specific agronomy-crop management research (CMR) activities.

Some of our germplasm development activities are directed not so much toward mega-environments as toward certain countries and areas where the prospects for utilization of the germplasm are brightest. That is the case for our work on quality protein maize (QPM) germplasm and on hybrids.

2. *Basic germplasm/intermediate products for further refinement*—The Maize Program develops improved germplasm that matches the broad requirements of the mega-environments. National program scientists then further refine this material to fit the conditions of particular production areas or *micro-environments*. We currently have improved germplasm for almost all the 30 mega-environments

* Presentation to the Program Committee of the Board of Trustees, 4 April 1991

worldwide. Cooperating country researchers have played an important role in improving this material further, particularly as participants in our international testing system, and they have skillfully fashioned it into final products for release to farmers. This strategy, in which released germplasm is named by national programs rather than by CIMMYT, has proved very effective at maintaining these programs' interest in cooperating with us.

It may sometimes happen that our improved, broad based germplasm fits almost perfectly one of the various macro-environments of which a mega-environment is composed and is released for production in that environment. Such cases are entirely coincidental and are not part of CIMMYT's strategy. An important exception to this approach is our work on QPM germplasm, which we try to develop in such a way that, with little modification, it can be released to farmers. Even in these cases, however, we encourage national programs to name the materials they intend to release. We are anxious to ensure that our efforts in hybrid development are also handled according to this strategy.

3. Germplasm sources of stress resistance—The Maize Program's work has from the start been influenced by the fact that in most of the developing world's maize growing environments the majority of farmers cannot afford high levels of inputs. We do not expect this circumstance to change soon. Though high input maize production may become more prevalent in favored environments, it will continue to be the exception rather than the rule in most areas of the tropics.

Given the predominance of low input agriculture in developing countries, our maize breeding program is geared toward the development of germplasm that is highly efficient in the use of farmers' scarce resources. It has the potential to respond to optimum conditions but also performs well where inputs (such as water and fertilizer) are not available or farmers cannot afford them. In this work we focus on disease and insect resistance as well as tolerance to drought and other abiotic stresses, such as aluminum tolerance in acid soils. Our resistant germplasm, particularly to insects and abiotic stresses, is intended to serve as source material, from which scientists in national programs can transfer desired traits into locally adapted varieties.

4. Flexible approaches in developing germplasm products—Many national maize improvement programs receiving our germplasm are concerned mainly with the development of improved open-pollinated varieties (OPVs). Nonetheless, a growing number are expanding their efforts in hybrid development, particularly for favorable environments and specially in counties that have considerable experience with OPVs as well as reasonably effective seed industries. In response to this gradual shift in the priorities of our clients, we are employing flexible methodologies whose products are equally suitable for the development of OPVs, synthetics, or various types of hybrids.

5. New techniques in germplasm development—The Maize Program is committed to exploring the possibilities of using new tools emerging from current research in molecular biology. By applying some of these, we hope to increase the cost-effectiveness of our breeding for complex traits, such as insect resistance and drought tolerance. Molecular marker aided selection is one promising approach for improving our efficiency in handling traits that are costly and time-consuming to develop through conventional approaches.

6. Conservation and utilization of genetic resources—We continue to examine the possibilities of introducing new genes into maize germplasm through wide crosses with its wild relative (e.g., *Tripsacum*) and are also exploring the possibilities of maize transformation, using sources such as the soil bacterium *Bacillus thuringiensis*. Nonetheless, we recognize that the genetic variability in maize provides an ample basis for continued gains in stress related traits and yield. Thus, in addition to maintaining and evaluating our large collection of maize landraces and wild relatives, we also assist national maize germplasm banks in managing their maize holdings and actively seek means of making genetic resources more accessible and useful to maize breeders.

7. ***International testing***—Testing of improved germplasm internationally at sites representing the developing world's major maize mega-environments has been and will continue to be one of the Maize Program's key strategies, both for the purposes of maize improvement and germplasm dissemination. Currently, we are examining the issue of how to handle international testing of the diverse array of germplasm being developed in our headquarters and outreach programs without placing too heavy a burden on cooperators.

8. ***Strategic crop management research (CMR)***—We realize that our comparative advantage lies more in the development of germplasm than in CMR. Even so, the Maize Program has gradually invested some of its resources in the latter for various reasons. One is that changes in growing practices have not kept pace with genetic improvement of the crop, making it more difficult for farmers to realize the higher yield potential of new genotypes. A second reason is our interest in improving certain traits for which the genotype interacts closely with particular aspects of crop management. To develop germplasm that is especially well suited to intercropping and other multiple cropping systems, for example, we must have direct experience in the relevant areas of CMR. A third justification for the Maize Program's increasing commitment to CMR is the need to sustain production growth in the face of steadily increasing populations; more intense pest, disease, and weed problems; declining natural resources; and diminishing availability of high quality land. In answering these challenges, the Maize Program will increasingly emphasize strategic CMR designed to remove major production constraints, preferably in ways that are broadly applicable across a given region, and will assist national program scientists in adaptive research aimed at tailoring proven technology to specific sites. Much of our strategic agronomy research will be concerned with achieving more sustainable and less environmentally damaging agricultural production. As in the past, our maize agronomy research will be concentrated mostly within the regional networks, will be conducted in cooperation with selected national programs and will feature close collaboration with the Economics Program.

In connection with this strategy, we are concerned about TAC's possible recommendations to the CGIAR that the system be reorganized into global germplasm development and ecoregional centers. Our main worry is that this new structure could result in germplasm development being divorced from CMR activities, a circumstance that could be detrimental to both.

9. ***Close and direct interaction with NARSs***—The Maize Program's approaches in germplasm development and CMR are both predicated upon strong support of cooperating national programs. We provide this service partly through consultation, chiefly within our regional programs, and also through training offered at CIMMYT headquarters and in the regions. The three basic functions of our regional programs are to: 1) improve germplasm for traits of regional importance at locations that are particularly suited to this purpose, 2) carry out crop management research, and 3) consult and interact directly with NARS staff. As in the case with our strategy in CMR, TAC's recent thinking on restructuring the CG system has important implications for our approach to interacting with national programs. It appears that responsibility for strengthening NARSs would be transferred to the ecoregional centers. Such a change would severely handicap our research programs and therefore need to be carefully reviewed.

Decentralization of CIMMYT Maize Breeding Activities

In addition to the approaches mentioned above, a tenth strategy of decentralizing breeding activities, where expedient, figures importantly in the Maize Program's efforts to generate improved germplasm. Over a 25-year period, this work has passed through two main stages and has now begun to enter a third. The first was centered on our headquarters in Mexico, while the second was characterized by a significant decentralization of some of our breeding activities. The third will take this trend even further and will involve a new and more challenging role for selected advanced national programs.

Stage 1: Broadly adapted pools and populations developed in Mexico—When the Maize Program was just getting established during the late 1960s and early 1970s, there were relatively few sources of improved germplasm for the major maize production environments of the developing world. Thus, our first challenge was to develop a wide array of genotypes with high yields and resistance to stresses that are important globally and can be handled effectively in Mexico. These materials took the form of a large collection of gene pools and populations. Their development and improvement was the principal activity in the first stage of our maize breeding program, and they still constitute the core of our germplasm offerings. That we were able to generate materials in Mexico for almost the entire range of maize mega-environments in the developing world is a consequence of the country's great geographical diversity, careful selection of suitable experimental sites, and accurate insights that led to effective program planning.

The greater number and diversity of materials being developed by staff based at headquarters has created a need for additional land for our germplasm development activities here in Mexico. We have remedied this problem by leasing a 20-ha annex to our station at Tlaltizapan in the state of Morelos.

Stage 2: Stress resistant germplasm developed in outreach programs—A few years into Stage 1, we realized that, in order to be fully acceptable to many cooperators, our improved populations would require resistance to stresses that could not be handled successfully in Mexico or at least not as effectively as in some other countries. By and large these stresses are not of global importance—as are the rusts and blights, for example—but present major production constraints in particular regions. During the late 1970s, we began special breeding projects in our outreach programs to address these problems and also to expand our offerings in some categories of improved germplasm. By the late 1980s, we had been involved in a half dozen of these projects.

One of the first was an effort to develop corn stunt resistant maize for Mesoamerica in cooperation with two national programs in Central America. This work has resulted in the release of 10 resistant materials in eight Latin American countries. Another on-going project that has its roots in work carried out during the 1970s is our cooperative program in Thailand and Philippines for developing germplasm resistant to downy mildew, which occurs in various parts of the developing world but has been especially severe in Southeast Asia. Several CIMMYT populations have been converted to resistance; two are still undergoing selection; and four new resistant populations are being developed. The products of this work have been widely used by national programs in the Asia region and also have potential for wider use in Africa and some countries of Latin America.

Another effort initiated during the late 1970s in Ecuador focused on improving highland maize with the floury and *morocho* grain types, which are unique to the Andean zone. This activity has now been taken over successfully by a network of national programs in the region. We now have another project in the Andean zone (based at CIAT headquarters in Colombia) whose purpose is to develop germplasm that is tolerant to high aluminum and other adverse conditions characterizing acid soils. Seven populations have been developed and are being improved for this trait.

During the early 1980s, we entered into a joint project with IITA to develop streak resistant materials in Nigeria for sub-Saharan Africa. The project disseminated a sizeable collection of high yielding, streak resistant germplasm throughout the region. During 1986-87, 16 varieties based on this material were released to farmers, and we estimate that national programs released about the same number of varieties during the last three years. Prominent among the new genotypes are products developed from CIMMYT's Population 43 (La Posta), which we improved for streak resistance under the cooperative project in Nigeria.

Two successors of that project are CIMMYT's work at Harare, Zimbabwe and its cooperative effort in Cote d'Ivoire, again with IITA, on streak resistant germplasm. The main objective of the Harare Program is to develop superior germplasm with streak turcicum, and rust resistance for the midaltitutde ecologies of eastern and southern Africa as well as similar mega-environments in other parts of the world. The program is also developing streak resistant, early maturing germplasm for lowland tropical environments, paticularly in eastern and southern Africa. In Cote d'ivore we are focusing on late maturing, lowland tropical materials.

It should be emphasized that the distinct activities of Stages 1 and 2 were designed to complement one another. The breeding work at headquarters has addressed problems of global significance, while the projects in outreach have used materials generated at headquarters and by national programs to deal with specific problems of mainly regional importance.

The breeding activities at outreach locations are handled according to four different approaches, depending on the location and magnitude of the work. One has been to place our staff at stations operated by other international centers (specifically CIAT and IITA) and to make use of their research facilities. A second approach, which we followed in Ecuador and Thailand, was for our staff to work at stations managed by a national program. The third option, which we found appropriate for our work in Zimbabwe, was to set up a new station under the management of CIMMYT staff. In the fourth approach our cooperators have handled the breeding activities at their stations, with our own staff performing more of a coordinating and support function.

Stage 3: A more dynamic role for national programs—The success of this last approach is one of the reasons we are embarking on a third stage in CIMMYT's maize breeding efforts. Its distinguishing feature will be an expanded role for national programs in adapting source germplasm from CIMMYT to conditions in specific maize production areas. The need for such an approach stems from developments in national programs and at CIMMYT. The former are a good deal more experienced and skilled in maize breeding than they were during the early 1970s. At CIMMYT we are now generating a wide range of hybrid oriented products and have developed source populations with insect resistance, some that show improved performance under drought, and others with a decided advantage under acid soil conditions.

Realizing the tremendous potential of some of these materials will be a somewhat more difficult task than the one we faced in the late 1970s at the outset of Stage II. Then, the challenge was to enhance the suitability of our advanced populations in certain regions by improving their resistance to particular stresses, mainly diseases. Handling some of our new products, however, will not be so straightforward, particularly the source germplasm for traits whose improvement is more resource intensive and costly. The challenge then is to establish mechanisms for facilitating the incorporation of new source germplasm into locally adapted materials.

This work requires different skills and in some cases special facilities (to mass rear insects, for example) that relatively few national programs possess. We are now identifying programs with potential for developing these capabilities and are beginning to establish networks, each focusing on a particular problem, such as stem borers or drought. These networks will be a prominent feature of Stage 3 activities.

In performing this task, participants in the stress resistance networks can count on technical assistance from maize staff at our headquarters and in the regional programs. We are confident that they will find the source germplasm and associated techniques to be beneficial and that they will prove to be very adept in employing these new resources. Their success in this endeavor will mark the beginning of a new and very exciting chapter in maize improvement.

Research Focus and Recent Accomplishments

Background information on germplasm development in outreach, hybrid maize, QPM development, maize wide crosses and biotechnology, and CMR has already been provided to the Program Committee. Since those activities will be discussed in some detail during the next two days, they are not covered in this presentation. Instead, I will describe the research focus of other subprograms and review some of their recent achievements.

Lowland tropical germplasm—The lowland tropical mega-environments constitute about 45% of the developing world's total maize area of 80 million hectares. Traditionally, germplasm for the lowland tropics has received highest priority in the CIMMYT Maize Program, and the majority of our most widely used materials are of this type. Since a large portion of the late materials are grown in favorable environments, we strive for high yields and reasonable levels of stress resistance in their improvement. With the early and intermediate populations, we emphasize maturity and yield, so that they will fit intensive multiple cropping systems, and we enhance their suitability of marginal environments.

An impact survey conducted by CIMMYT, though still incomplete, shows that improved lowland tropical materials are being widely used by NARSs and that large areas are planted to germplasm of CIMMYT origin.

Subtropical and midaltitude germplasm—About 17 million hectares of the developing world's total maize area is planted to germplasm of essentially subtropical adaptation. Some 7 million hectares are grown at midaltitudes (900-1700 m above sea level) within the tropics and the rest in lowland areas of the subtropical latitudes. Germplasm development and improvement mainly for the lowland subtropical areas is handled by various staff at headquarters. They are placing special emphasis on resistance to major constraints in these areas, such as northern leaf blight and stem borers. As I have already mentioned, our breeding program for midaltitude areas is located in Zimbabwe, where emphasis is placed on resistance to streak virus. Interest in hybrids for the subtropics and midaltitudes is very high, so we are giving increasing attention to heterotic grouping of material for these areas.

In March of this year, a presentation of the work on midaltitutde and lowland tropical germplasm in Zimbabwe was held at Harare for senior agricultural administrators, Ministry of Finance and Planning officials, maize breeders, seed company employees, and donor representatives from eastern and southern Africa. The participants seemed very impressed with the progress our staff have made, and we are hopeful that this event will contribute to accelerating the use of our improved germplasm by national programs in the region.

Highland maize—Though less important worldwide than lowland tropical and subtropical genotypes, highland maize, with a global area of about 6.2 million hectares, is grown very extensively in certain countries (notably Mexico, Ethiopia, and Kenya), and it occupies 100,000 ha or more in at least a dozen developing countries. The main products of our highland program are improved populations, experimental varieties, and inbred lines for the tropical highlands and tropical highland transition zone. A central element of our breeding strategy has been to introgress germplasm from the subtropical and temperate zones into CIMMYT and Mexican highland materials to improve yield as plant type and lodging resistance, combined with cold tolerance and other useful traits. This germplasm is being used in breeding for various environments where this trait is important.

Crop protection—About the only type of crop protection that is appropriate for most farmers in the tropics and subtropics is germplasm with good pest resistance. Developing such materials is the chief concern of our crop protection subprogram based in Mexico and a goal to which other maize staff at outreach locations contribute importantly, particularly through their work on disease resistance. Remarkable progress has been made during the last four or five years in improving resistance to turcicum leaf blight, the tar spot complex, and maize streak virus.

I am not very far off the mark in stating that the maize Program has dealt successfully with the most economically important diseases of maize. Obviously, one can still find fields showing mild or even severe disease infection in many tropical and subtropical maize growing areas. But these problems persist not because resistant germplasm is unavailable but because it is not reaching the farmers for several reasons.

Until about 10 years ago, many maize researchers did not consider host plant insect resistance to be a feasible goal of breeding for tropical and subtropical maize germplasm. Yet, through painstaking efforts, the Maize Program has developed germplasm that tolerates attack by various species of stalk borer as well as fall armyworm. In 1984 we embarked on a new approach involving the development of special purpose populations, in which the main selection criterion is insect resistance. The first products of this work consisted of the Multiple Borer Resistant (MBR) Population, a subtropical material containing many families that show resistance to various borer species. Products of this population, which has reasonably good agronomic traits, are now available to researchers at CIMMYT and in national programs. We have also developed a second multiple borer resistance population of tropical adaptation (referred to as MIRT), and it is now undergoing international testing. In the future we expect to apply much the same approach in dealing with additional pest species. The challenge now is to transfer the borer resistance of the source germplasm into a large number of materials adapted to various mega-environments. Some aspects of this work will be presented in the field visit at CIMMYT's Poza Rica station.

Physiology subprogram and tolerance to abiotic stresses—The main function of this subprogram is to provide breeders with techniques, germplasm, and information that can better enable them to deliver genotypes tolerant to abiotic stresses. Staff of this subprogram have amassed convincing evidence that selection for reduced anthesis-silking interval (ASI) under moisture stress at flowering can significantly improve the performance of maize under this stress at no cost in yield in the absence of stress. A network for development of drought tolerant germplasm is being set up to facilitate the application of results from our research on drought. The staff of this unit are also developing germplasm for general stress tolerance, largely by concentrating on prolificacy and tolerance to high density. In our recent internal review of lowland tropical germplasm development, the need for resistance to waterlogging/flooding was pointed out, and we are considering the possibilities for research on this problem. Another challenge being addressed by this subprogram is development of a methodology for improving the tolerance of lowland tropical germplasm to nitrogen deficiency. Some aspects of this work will be presented to the Program Committee at Poza Rica.

Refinement, International testing, and distribution of germplasm—The wide array of maize germplasm now available from CIMMYT to researchers around the world includes source materials for biotic and abiotic stress resistance, new germplasm for various mega-environments, heterotic groups, and elite populations and varieties. To a limited extent these materials are available in the form of families and lines but more so as reconstituted pools, populations, synthetics, varieties, and hybrid combinations. Our policies on distribution of all categories of germplasm are well defined and have been widely disseminated.

The Maize Program's advanced unit refines elite germplasm and develops open-pollinated varieties and synthetics for widespread international testing and distribution to cooperators. The international testing unit ascertains the adaptability of the germplasm in various maize growing environments, brings this information to the attention of our large group of maize cooperators, and is responsible for making the germplasm available to them. The first announcement of inbred lines available from CIMMYT is ready to be sent out, and more are sure to follow.

Through CIMMYT's international maize testing system based in Mexico, progeny and experimental varieties from the populations have been distributed to more than 100 countries and used in over 240 released varieties and hybrids. Products of many CIMMYT materials have been widely adopted by farmers in tropical and subtropical environments from the lowlands to midaltitudes and highlands.

Germplasm bank—CIMMYT is strongly committed to conserving maize landraces and wild relatives from the Western Hemisphere and to utilizing them in maize improvement. The activities of the bank were presented in detail to the Program Committee last year. We have recently prepared a pamphlet describing the objectives, functions, and other aspects of the bank.

As part of a program we initiated during 1986 for in situ monitoring of teosinte, bank staff visited Guatemala early this year. They found that, unlike the teosinte populations in Mexico, which are relatively stable, those in Guatemala are being rapidly diminished. After their field visits, our staff had very useful discussions with national program scientists to identify measures for presenting the extinction of Guatemala's two teosinte populations.

Last month CIMMYT sponsored a workshop at which the managers of about a dozen maize germplasm banks in Latin America planned a cooperative project for regenerating the thousands of accessions stored in the region that urgently require regeneration. An important aim of the project will be to document the accessions, using new computer software provided by CIMMYT. We hope the project will bring us a step closer to establishing a global network of maize banks, a concept endorsed by participants in the maize germplasm workshop held here in 1988.

Training—Training is a key component of our assistance to national maize programs. It enhances the impact of improved germplasm, CMR methodologies, and other products by enabling developing country scientists to employ these resources more effectively. The core of our training program in Mexico is practical instruction in maize improvement and CMR. For many years we have offered basic courses on these subjects that are designed to equip participants with the knowledge and skills they need to conduct effective, farmer oriented research. We will continue to provide these basic courses in maize improvement and to a limited extent in CMR but have shifted some of our emphasis in training to more advanced courses designed for more experienced, senior researchers in national programs. Other types of training offered at headquarters are visiting scientist, predoctoral, and postdoctoral fellowships as well as limited number of graduate study fellowships supported with extra-core funds. In addition, a large amount of in-country training on numerous topics (such as on-farm research, seed production, and the use of computers in data analysis) takes place within our regional maize programs.

Just as CMR is more pertinent when conducted in the areas where its results will be applied (or at least in similar environments), training in CMR is likely to be more effective if it is decentralized to the regions where participants work. Our efforts to start a regional CMR training course have finally met with success. The first course of this type has been organized as a joint effort between the Kenyan Agriculture Research Institute (KARI), Egerton University at Njoro, Kenya, and CIMMYT. Funded by USAID and CIDA, the course began in early March of 1991, and the response to it was very encouraging. Of the 23 candidates selected, 20 were able to attend, and only seven of these are supported with CIMMYT funds from special-project grants. Apart from being especially relevant to conditions in eastern and southern Africa, the training is expected to promote more active collaboration in CMR, since the scientists conducting the course will be able to maintain close contacts with trainees as part of their regional responsibilities.

Review Procedures—At the last meeting of the Program Committee, we discussed various types and levels of reviews that would be helpful in orienting Maize Program activities. An internal review process has been initiated in the Maize Program, and so far three activities have been reviewed: CMR, development of lowland tropical germplasm, and crop protection, with emphasis on disease and insect resistance. The results of the last two were discussed earlier this morning. We plan to review once every three years. A panel of external reviewers has been set up that will be called upon to examine the scientific and operational details of specific activities according to needs identified through the internal reviews.

Another type or review is that now being conducted by the Program Committee. In addition to discussing specific issues with individuals members of the Committee, we will focus in this review on policy issues and on the general direction of the Maize Program's research. Three categories of activities have been identified for discussion. The first includes activities that have continued for some time but whose impact does not seem very transparent. QPM, wide crosses, and CMR fall into this category. The second group includes work that has reached a stage where guidance from the Program Committee would be particularly desirable. The hybrid program and germplasm development activities in outreach are both of this type. The third set of activities consists of new initiatives, specifically biotechnology research, whose general direction needs to be established.

For each activity under review, we have identified a few key issues, about which the Maize Program will present its views to facilitate discussion. We are certain that this will be a useful exercise and look forward to interacting with the Program Committee in this task.

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International Maize and Wheat Improvement Center
Centro Internacional de Mejoramiento de Maíz y Trigo
Lisboa 27, Apartado Postal 6-641, 06600 México, D.F., México