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9. ABSTRACT The discussions center on three major topics: <ol style="list-style-type: none"> 1. Identification of critical production problems of maize technology for the 1970's, and thus better focus on CIMMYT's planning. 2. Assessment of progress in National maize production programs, especially their potential for increased maize production; and a clear definition of the services they may need. 3. Suggestion of programs for Maize Improvement that merit attention in other institutions, including activities of scientists, policy makers, and educators. 		
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WELCOME

On behalf of CIMMYT, welcome to Mexico and El Batán. And, on behalf of the Maize staff, in particular, we would like to express our appreciation for your attendance here at the Symposium on "World-Wide Maize Improvement in the 1970's and the Role for CIMMYT."

Our topic could scarcely be more current or relevant; during recent days we have all read, seen, or heard about--or witnessed first hand--some of the world's food production and distribution problems. The United Nations, Government leaders--all of us--are reacting to the sharply increased demands of scarcity. Hopefully, during this week, we can work jointly in alleviating some of these problems as they relate to maize production. Our aim here is to achieve systematic assessment, which is heavily dependent upon your responses. As an extension of our own process of examination and discovery, we seek your contributions--information, perspectives, resources, and ideas--which have proved useful to you and which may give us specific leads, thoughts, and suggestions.

Our discussions will center on three major topics:

1. Identification of critical production problems of maize technology for the 1970's, and thus better focus on CIMMYT's planning.
2. Assessment of progress in National maize production programs, especially their potential for increased maize production; and a clear definition of the services they may need.
3. Suggestion of programs for Maize Improvement that merit attention in other institutions, including activities of scientists, policy makers, and educators.

Our plan is to present some of CIMMYT's current philosophy and planning related to restraints in maize production. The maize staff and the discussants for each topic will analyze our research approach and how we hope to assist in world food needs. Discussion will cover our approach here at CIMMYT headquarters, our international involvement, and some of our views on strategies for national programs.

The discussants will perform a central role in the Symposium; we urge you to participate freely and to help us develop a dynamic plan that CIMMYT might consider for its role during the remainder of the 1970's and beyond. We feel that CIMMYT has already matured and gained immensely in the process of gathering together the people and information for this program. And, by the closing session of the Symposium, we hope that we will have arrived at a broad consensus regarding our three Symposium objectives, with additional input from each of you (see Sections 14 and 15).

These objectives, again:

1. To help focus CIMMYT's planning on the most critical maize production problems.
2. To assess national programs and define services needed in the developing countries.
3. To suggest additional ways that our institutions and staff can work together.

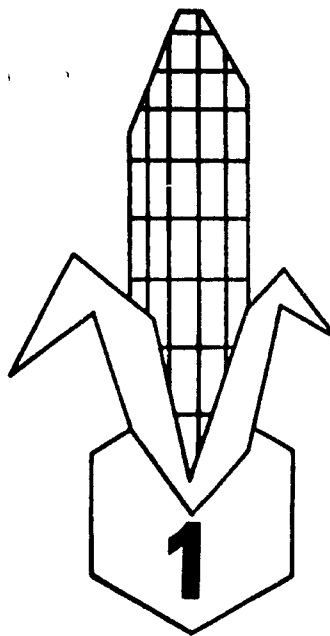
As we open up these options during the Symposium, it seems likely that we will be reminded daily of the urgency of our task--that of expanding the physical limits of the world's food production.

The CIMMYT Maize Staff

EDITOR'S NOTE: Each of the Symposium presentations and discussion has been edited to achieve some consistency of style, with every effort given to retaining the original thoughts and philosophies of the individual contributors. However, precedence has been given to accuracy and speed of distribution, rather than to format considerations. Hopefully, quicker availability to users will offset any lack of formality in make-up. Quotes or reproduction of this material should be cleared with the specific author or discussant.

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**THE ROLE OF MAIZE IN WORLD
FOOD NEEDS TO 1980**

by
Haldore Hanson, CIMMYT

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**THE ROLE OF MAIZE IN
WORLD FOOD NEEDS TO 1980**

by

Haldore Hanson

1.1 INTRODUCTION

My paper will discuss four topics that can help us plan a maize program for the next five or ten years. These are:

- (1) Population growth
- (2) Trends in food production
- (3) The protein problem
- (4) Fertilizer supplies

At the end of the paper, I will suggest some guidelines for a maize improvement program.

Many other ideas could appropriately be included in this opening paper. I hope the discussion period will enable our Lead Discussant, Dr. Paarlberg, and members of the audience to introduce additional ideas.

1.2 POPULATION GROWTH

I begin with population growth, and I shall do so with some history, dating back to the discovery of agriculture. This history is relevant to our present Symposium. Some of the pressures on population growth today began at least 9,000 years ago, as you will see.

One scientist at CIMMYT has suggested that it was neolithic woman, not neolithic man, who discovered agriculture and this discovery was an impetus for later increases of peoples. The reasoning goes like

this. In the days of the hunting culture, the women gathered wild grain, berries, and roots. These women were very close to nature, and it was probably a woman who hit upon the idea of cultivating plants. Perhaps she saw some seeds she had dropped on the ground outside the cave germinating and growing. Possibly the idea of a kitchen garden came to her on a day when her husband the hunter, armed with a club or a rock, failed to bring home any meat.

At any rate, the domestication of cereal grains took place about 9,000 years ago, occurring independently for rice in Eastern Asia; for wheat and barley in Western Asia; for sorghum in East Africa; and for maize in Mexico and Guatemala.

If speculation is correct that agriculture owes its origin to a woman, there must have been several women who got the idea about the same time, each for a different crop on a different continent. They left no written record.

Demographers of our time believe that the world contained about ten million people at the time agriculture began. From that point onward, a more reliable food supply made life more secure, and people began to multiply more rapidly. As their food supply increased, so did the people. Eventually, the population began to double and redouble in ever shorter periods.

For example, at the time of Christ there were an estimated 250 million people in the world. This population doubled in the following 16 centuries, reaching 500 million people about the year 1650. Another doubling of population required only two centuries; thus, we find one billion people by 1850.

Only 80 years were required for the next doubling and in 1930 world population had reached two billion. Today, we have almost doubled that figure again. World population stands at 3.8 billion. People continue to increase at the rate of 2% a year, and at this rate, we shall double the human race again in 38 years, or a little beyond 2000 A.D. The developing countries have an even higher average growth rate of 2.5%, and they will double their populations in 25 years or less.

These figures suggest that 25 years from now, developing countries will consume twice their present food supply, just to maintain themselves on today's inadequate diet.

Here at CIMMYT we speak of our work as a holding operation, a way to buy time while the world slows its population growth rate. A logical question is: What is the probability of lowering birth rates in the next two or three decades?

This Symposium is not the place to go into detail on population forecasts. But some reputable demographers are cautiously optimistic about slower growth rates. They cite the following evidence:

- (1) Birth rates are already declining. They began falling during the 1960's in many developing countries.
- (2) When birth rates decline in developing countries, the rate of decline seems to be more rapid than that found in North America and Europe, 100 years ago. In general, the higher the birth rate, the faster the rate of fall.
- (3) The climate of opinion is more favorable today toward family planning, and the technology of contraception is better.

Despite these encouraging factors, the problem of population continues to be the most severe problem confronting the human race. No agricultural technology can keep pace for very long with a 2.5% growth rate in developing countries. In the longer perspective, zero population growth is necessary; any indefinite rate of growth, no matter how small, will lead to disaster.

For several decades more, the plant breeders and the agronomists can provide technology to stay ahead of population growth, possibly to the end of the century. But time is running out.

Our task in this Symposium is to discuss how the maize crop can make maximum contribution to world food needs while population doubles in the next 25 years. Our focus is primarily on the last half of the 1970's. Population growth will be a major concern in this Symposium.

I turn now to the next topic: trends in food production.

1.3 TRENDS IN FOOD PRODUCTION

Over the 20-year period from 1954 to 1973, there has been an upward trend in the per capita production of food throughout most of the world. (Africa has been one exception.)

In industrialized regions such as North America, Western Europe, Australia, etc., food production per person increased about 1.5% annually, for 20 years. In the developing areas of Asia, Africa, and Latin America, the increase was slower: about 0.5% per person per year.

These gains are stated in food per person. That means that farmers were producing enough food for a rising population, and there was some left over to provide for slightly greater consumption. As a group, even the less developed countries were making progress. The average family in a developing country in 1974--though still not well nourished by world standards--has slightly more food on the table than did the families of their fathers and grandfathers.

These general trends do not tell us all that we want to know about differences between countries, or differences between social classes. There are still poorly nourished people in all parts of the world. These imbalances are caused by climate, by poverty, by inadequate movement of food, and sometimes by poor public policies. Statistical food indices are based upon general averages and tend to conceal special problems.

(It is customary for speakers who generalize from statistics to protect themselves by recalling a joke. I am reminded of the fellow who placed one hand on a hot stove and one foot in a refrigerator; he was very uncomfortable, but by statistical average, the temperature was fine.)

One circumstance concealed by the long-run averages is the impact of regional drought. For example, there was a severe drought in India and Pakistan in 1965-1966. And there was a temporary decline in world food production in 1972 when droughts occurred in the Soviet Union, China, South and Southeast Asia, and Australia. We know, now, that the droughts of 1972 caused only a 4% decline in cereals production for the world as a whole. Yet, a fluctuation of this small size brought about massive shipments of food grains between continents, doubled the price of wheat, tripled the price of rice, and emptied much of the world's storage bins of grain available for sale.

While we are observing the ups and downs of the weather, it is appropriate also to observe the ups and downs of the newspapers that write about food supply. The Indian drought of 1965-1966 was described in the newspapers as a disaster of such magnitude that it suggested the human race could no longer feed itself. Three years later, the dwarf wheats from Mexico had made a good beginning in Asia, and the same newspapers swung 180 degrees, praising the Green Revolution as the answer to all food problems. Next, came the 1972 droughts, and the press declared that the Green Revolution was a lie, a fraud, and a public relations gimmick which had been invented by IRRI and CIMMYT.

Now, in 1974, we are undergoing still another reappraisal: food stocks are low, fertilizer is in short supply, and the press is speculating on another disaster.

Obviously, those of us who work on agricultural technology must generate our own emotional stability, place our confidence in science, leave the weather to God, and let the press follow its own crystal ball.

Actually, food production in 1974 appears to be back on the long-run trend line, moving gradually upward as in the 1950's and 1960's. But that is small comfort to the peoples of sub-Sahara Africa whose cattle are dying in the fifth year of a regional drought.

Now let us see what has been happening to maize, wheat, and rice, the three cereals which provide over one-half the total calories and over one-half the total proteins for all the peoples in developing countries.

In total world production, wheat is the largest food crop, followed by maize and rice. In the developing countries, the order is different: rice is first, followed by wheat and maize. In other words, maize is the second ranking food crop in the world, and the third ranking food crop in the developing countries, as is shown in the table below:

Production of Cereals -- 1972

<u>Cereal</u>	<u>World Production, (Millions of Metric Tons)</u>	<u>Developing Coun- tries (Millions of Metric Tons)</u>
Wheat	348	79
Maize	301	62
Rice	295	161
Barley	152	19
Sorghum-millet	90	42

Source: FAO Production Yearbook 1972.

The decade of the 1960's was a successful period for production of major cereals in Asia, Africa, and Latin America. Wheat production rose 50%. Maize production rose 50%. Rice production rose 40%. All these gains compare to a 30% population growth in the same areas. This confirms an earlier statement that the developing regions, as a group, were making progress.

But, when we analyze how these gains of the 1960's were achieved, the results are not reassuring: about one-half of the gains are attributable to the use of more land, and about one-half to increases in yield per hectare.

Developing countries used 30 million additional hectares for cereals at the end of the 1960's, compared to the beginning of the same decade. Some of this additional land was taken away from legumes, some from oilseeds and pasture crops; it is possible that the strenuous effort to increase cereal grains actually lowered the quality of the diet for proteins and vegetable oils.

The yields per hectare of the major cereal crops failed to keep pace with population growth, and here lies the implication for the 1970's. Among the three leading cereals, only wheat yields advanced at a rate equal to population growth during the 1960's.

By contrast, the average yield for maize in developing countries rose only 10% in the 1960's, compared to a population growth of 30%. Rice yields also fell behind. The average yield of rice rose only about 15% in the 1960's, against a 30% population increase.

If we look more closely at maize yields, country by country, the picture suggests even more problems for the 1970's. Economists at CIMMYT have made a study of 55 developing countries in which maize is a major food. The study shows the following dismal facts about the decade of the 1960's:

First, 45 of the 55 countries in which maize is a major food failed to increase their maize yields at a pace equal to their population growth in the 1960's.

Second, 20 of the 55 countries were importing maize at the end of the 1960's.

Third, only eight of the 55 countries achieved average maize yields of 1,500 kg/ha., or higher, and the other 47 countries were below 1,500 kg.

Obviously, here is evidence of the need for better technology.

We need to agree on the importance of raising yields. Most developing countries have nearly exhausted the possibilities for additional cropland. The world has few remaining major areas of underutilized land, and each of those areas poses its own problems. One such area is in tropical Africa, centered on the Congo basin, and two are in South America, centered on the Amazon basin, and the llanos or high grasslands. These vast, underpopulated areas are lacking in roads and railroads; lacking in the amenities of cities, schools, and hospitals; lacking in agricultural services necessary for development. Production in these areas will require billions of dollars in new investment, and the time required for such investment will contribute little to food production in the 1970's.

If the developing countries are to produce more and better food in the near future, the food must come from higher yields.

Before leaving this topic of long-run trends, we should take note of two excellent forecasts which are available on the world grain outlook to 1980.

In 1971, FAO published a major two-volume set of agricultural projections for the period of 1970-1980 (FAO, 1). The study was published before the 1972 droughts and before the present fertilizer shortage. It concludes that by 1980, the average "shortage" of food will be somewhat less than at present; but, "the absolute number of people who are short of food may be much the same as today." The study also finds that "diets would become more diversified in both high-income and developing countries."

Another set of projections for the period of 1970-1980 was published in 1971 by the U. S. Department of Agriculture (USDA, 2). The U.S. projections are still being revised.

Like the FAO, the U.S. Department of Agriculture concludes that nutritional levels for the developing countries will improve during the 1970's, on a per capita basis. Assuming normal weather conditions, the projections are that the production of cereals will increase faster than consumption; thus, there will be a rebuilding of grain stocks, and a downward pressure of prices. These projections do not take into account unusually poor years, like 1972, or unusually good years, like the late 1960's.

The U.S. Government analysts expect the world demand for coarse grains, including maize, to increase faster than the demand for wheat and rice, because of the increased use of grain for livestock and poultry feed.

Developing countries will continue to import substantial quantities of wheat and feed grains, despite increases in their own production.

I will leave further comments on long-range projections to Dr. Paarlberg, the Lead Discussant, who supervises research on this subject.

1.4 THE PROTEIN PROBLEM

We now turn to the next topic: What is happening to protein and to the quality of the human diet?

In the mid-1960's, it was fashionable to talk about a world protein shortage or protein gap. Now, we know there is no shortage in an absolute sense, only inadequate distribution. If all the dietary protein consumed in the world today were distributed on a basis of need, there would be sufficient protein to provide a protein-adequate diet for everyone and to leave a surplus of 70%. Put another way: there would be an oversupply of protein in the world today, if it were somehow distributed according to bodily requirements. But several factors are skewing the distribution of protein.

First, the industrialized countries are consuming 80% of the world's protein. These countries contain only 20% of the people. There is a high correlation between the level of individual income and the level of protein consumed. The average North American or European is eating six times more protein than the average person in Asia, Africa, or Latin America.

Second, within developing countries, the upper third of the income groups puts a much larger serving of protein foods on their dinner tables than does the lower third. In other words, those with higher incomes in Asia, Africa, and Latin America show the same tendency to invest more income in protein foods--especially in meat.

A third form of imbalance is less obvious: this is a problem that may occur within the family. Modern nutritional studies have established that children to age six, and nursing mothers, require a higher proportion of protein in their diet. But that is not how the typical family eats. At the family dinner table, it is the working adults who get the largest protein share. And it is the youngest children and nursing mothers who find themselves at the foot of the table, both literally and figuratively.

A final imbalance of protein relates to those suffering from disease. Medical researchers have found that people suffering from intestinal diseases like diarrhea, and those recovering from severe fevers like malaria, require a higher proportion of protein in the diet. These infections and fevers are most common in the humid tropics, especially among the poorer people. Thus, we find a greater need for protein among a population group that now has the least access to protein.

Now we ask ourselves: Can the agricultural scientist do something that will provide a better protein diet for peoples in developing countries, including the lower income groups?

Here at CIMMYT we believe the agricultural scientist can make a contribution. Our reasoning begins with the present sources of protein.

Today the world obtains about 50% of its dietary protein from cereals, about 20% from legumes, and about 30% from animal products.

We should define the terms. Cereal protein comes from wheat, maize, rice, sorghum, barley, and a few other grains. Legume protein comes mainly from crops such as soybeans, dried peas, and dried beans. Animal protein comes from meat, eggs, milk, and fish.

As already stated, for the world as a whole, cereals now provide 50% of protein, legumes 20%, and animal products 30%.

If we narrow our interest only to the developing countries in Asia, Africa, and Latin America, animal products contribute only 10% of protein, and cereals over 70%. Thus, we see that rice eaters in Asia, wheat and barley eaters in the Near East, sorghum eaters in tropical Africa, and maize eaters in Latin America, are getting two-thirds of their protein from the cereals they eat.

Animal protein takes more land to supply 100 people with an adequate protein diet than do legumes. Scientists are working on better ways to produce meat, milk, eggs, and fish; but so far there is no sign of a breakthrough to produce animal protein, with less land.

Legumes are much lower in price than animal products. But the crop yields of legumes are relatively low, and farmers have actually been reducing the land devoted to legumes.

That brings us back to cereals. Is there anything the scientist can do to improve cereal protein?

You are familiar with the traditional or normal levels of protein in the three major cereals: rice 7%, maize 9%, and wheat 12%. Those are rounded figures. One hundred years of work on cereals breeding has not significantly changed the quantity of protein in these crops.

But there are some new findings which affect the quality of protein, and these findings can change the amount of protein which will be digested and retained by the human body. At the risk of oversimplifying, I will recount several recent developments.

Nutritionists have known for more than 50 years that animal protein is more beneficial to the body than protein from legumes or cereals. But until the 1950's, scientists did not have the laboratory techniques to study the difference.

Now we know the difference. Protein quality depends on the distribution of amino acids. There are 20 amino acids that make up protein. Eight of these are called "essential" because the body cannot

synthesize (or manufacture) them. Therefore, these eight must be obtained in the diet to permit digestion of protein. The other 12 amino acids are called "non-essential" because the body is able to manufacture them. The eight "essential" amino acids must not only be present in the diet, but they also must be present in a certain ratio. If one essential amino acid is below its proper ratio, the body can absorb only part of the available protein. Judged by this new standard, animal protein can be said to have a higher quality, because a higher percentage of the protein can be used by the body. Cereal protein is said to have a lower quality.

During the 1950's, new laboratory techniques for protein analysis were developed, permitting more precise measurement of amino acids. It soon was found that the protein of cereals was relatively low in one essential amino acid, lysine, when compared to meat, thus providing a major reason for the lower utilization of cereal protein.

Several new classification systems for protein were developed. One is called "Net Protein Utilization" or NPU. NPU shows the amount of protein in a food that the body will digest and retain.

Measured by this new standard, the hen's egg is almost a perfect protein food, because over 93% of its protein can be digested and retained in the body. Other foods are now rated by this same system, as shown in the following table:

Relative Utilization of Protein from Different Sources

<u>Food Source</u>	<u>Total Protein %</u>	<u>Net Protein Utilization % (NPU)</u>
Eggs	12.8	93.5
Casein from milk	99.0	79.6
Beef	19.5	76.7
Rice, whole	7.5	70.2
Wheat, whole grain	12.2	65.2
Maize, whole meal	9.2	51.1
Soybeans, after oil removed	52.5	58.0

Source: Inglett, Symposium: Seed Proteins, 1972.

The development of new ways to classify protein started a new era of plant breeding. If 100 years of cereals research had achieved no significant change in the quantity of plant protein, was it now possible to raise significantly the quality of protein, and thus to increase the protein taken up by the body?

This brings us to opaque-2 maize, the story of a mutant gene, which many of you know.

In 1914, researchers in Connecticut put some laboratory rats on a strict diet of maize, and all the rats developed acute signs of malnutrition. The scientists then added a little lysine and tryptophane to the diet, and the rats recovered quickly. This identified the two amino acids which were the source of protein trouble in maize, but laboratory techniques of that period did not permit the measurement of the amounts of lysine and tryptophane in maize. Hence, maize breeders could not yet breed for quality of protein.

In 1935, a mutant gene was identified in maize which gave the kernels an opaque appearance. The protein significance of this opaque-2 gene, as it was named, could not be identified; again because the laboratory techniques were not yet available. But the gene was used as a marker in breeding.

In 1963, a group of scientists at Purdue University learned something much more important about opaque-2. Using an amino acid analyzer, they found that maize carrying the opaque-2 gene also carries 70% more lysine and 100% more tryptophane than normal maize. These were the two amino acids identified 50 years earlier as principally responsible for the low efficiency of protein in maize.

Opaque-2 maize was tested as feed for animals and as food for humans. It was found that maize carrying the opaque-2 gene had a protein utilization rate of 90 (that is, NPU 90), compared to the traditional maize which had a utilization rate of about 50 (NPU 50).

The implications are exciting. If this opaque-2 gene could be transferred to a world maize crop of 300 million tons (1972), this crop would contain 27 million tons of protein (9% of 300 million tons), and 90% of that protein would be utilizable, instead of 50% in normal maize. This is like adding another ten million tons of protein to the world's supply, and it would cost nothing additional to grow the crop--nothing more to distribute the crop.

I will end this story here. Other speakers are scheduled to talk about the difficulties of transferring this opaque-2 gene to better plant types, plus the difficulties of introducing to maize eaters a new quality of maize in which the higher nutritional value cannot be seen with the naked eye.

My purpose in this discussion of protein was to emphasize that protein distribution is one of the most important food problems in the world today. Because the poorest countries and the poorest peoples are already receiving a large fraction of their protein in the form of

cereals, cereal scientists have the opportunity to provide a major change in the world's protein distribution--without changing the diet, and at no increased cost to the customer.

I will now turn to our next topic: fertilizer supplies.

1.5 FERTILIZER SUPPLIES AND USE

In 1973, the price of nitrogen and phosphate fertilizers doubled and even tripled in some parts of the world. Many fertilizer importing countries, such as India, have not been able to fill their fertilizer orders in 1974.

The significance of fertilizer as a topic at this Symposium is obvious. The recent agricultural revolution was built upon new varieties of wheat and rice, and their recommended production practices. These varieties are more efficient in their use of fertilizer. But without fertilizers, they are not much better than traditional varieties.

We know that one million tons of nitrogen fertilizer, nutrient weight, will produce an additional nine or ten million tons of grain, if properly applied to high yielding varieties. Therefore, a shortfall of one million tons of fertilizer can mean a drop in production of nine or ten million tons of grain.

In this Symposium we need to formulate answers to three questions about fertilizer: How long will the present shortage last? Will the present high prices come down? Should we change our recommended technology which now is dependent upon chemical fertilizers?

I will suggest one set of answers to these questions, based upon information from the TVA, or Tennessee Valley Authority in the U. S. A. You know that TVA is a major research organization for fertilizer products and for design of fertilizer factories. TVA has served as consultant to 30 foreign governments regarding their fertilizer needs and production plans. TVA publishes a World Fertilizer Market Review, and the latest review was issued in April 1974 (T. V. A., 3). The FAO, the World Bank, and other international institutions look to TVA and its Fertilizer Review as an important source of information about future markets for fertilizer.

CIMMYT invited the Director of the TVA Fertilizer Service, Dr. Don McCuge, to visit Mexico a few weeks ago to meet with the CIMMYT staff. I will offer you a picture of the fertilizer outlook, as it emerged from those talks.

First, the fertilizer industry is a cyclical industry, a boom-and-bust industry -- like agriculture itself. A period of over-expansion in the world-wide fertilizer industry occurred in the mid-1960's, and about 1968, there was a substantial over-supply and a drop in prices. The industry reacted by building almost no new factories for five years, starting in 1968, and some old factories were closed.

Next, widespread drought occurred in 1972, causing a slight drop in world food production, actually a drop of only 4% in world cereals. But this small change brought violent reaction in world grain trade. The price of wheat and maize doubled, and the price of rice and soybeans tripled.

Next, governments were forced to draw down their food stocks after the 1972 drought. Naturally, they sought to rebuild their grain supplies the following year by importing more fertilizers. At the same time, farmers in the exporting countries, like the U.S.A. and Canada, also sought to take advantage of high food prices by buying more fertilizer. This pushed the demand for fertilizer in 1973 to an historic peak, beyond the capacity of the industry. So prices of fertilizer products doubled and tripled.

Now what is the outlook?

TVA estimates that a fertilizer shortage will continue until new factories are built, sufficient to meet the new level of demand. The shortage of phosphate fertilizers is expected to continue two more years, to 1976; the shortage of nitrogen fertilizers to continue four more years, to 1978.

Meanwhile, some 30 or 40 new factories are under construction or under negotiation, to operate in Canada, the Caribbean, the Persian Gulf, Eastern Europe, the Soviet Union, China, and Indonesia. As new factories come into production, the shortage of fertilizer will gradually disappear. The next four years will be a period of privation, but the end of the shortage is in sight.

The outlook for prices is not so good. TVA does not anticipate fertilizer prices will ever again return to levels that existed before 1972. This is because the industry is drawing upon more expensive raw materials, more expensive labor, and will operate in some developing countries where efficiency of operation may not be as high. No one likes to predict future prices, but we may be safe to plan on prices 50% higher than those before 1972.

And what is the outlook beyond the present shortage?

Raw materials are adequate for nitrogen, phosphate, or potash fertilizer. The world is still flaring (or destroying) more natural gas at the well head than it is using in the entire nitrogen industry. Raw materials for phosphate and potash are plentiful, but new mines will need to be opened.

It is quite possible that expansion in the industry, beginning in 1974, will produce another glut by 1978, similar to the glut of 1968.

Looking farther ahead, TVA sees no reason why the fertilizer industry cannot increase its product as rapidly as agriculture demands it, up to the year 2000 A. D. and beyond. If population doubles, and food production doubles, the fertilizer industry can double or more than double. The plans for food production can continue to rely upon chemical fertilizer to 2000 A. D. and further.

But there is one limitation: the economics of fertilizer has changed, perhaps permanently. Prices will remain higher than in the 1960's. National programs for maize production must reassess the recommended levels of fertilizer. And research centers like CIMMYT must help to test more efficient fertilizer products, and search for more efficient fertilizer practices which will increase plant utilization of nutrients.

Our scientists at CIMMYT have discussed the impact of the fertilizer situation on maize production. Let me share with you some premises about future fertilizer use, as CIMMYT sees them.

- (1) Farmers are now wasting much of the nitrogen fertilizer they apply.

For example, in the temperate zone, the maize crop and other food crops now take up only 50% of the nitrogen applied in the form of fertilizer. The other 50% is lost. In the tropics only 25% of the nitrogen applied to food crops is taken up, and the other 75% is lost.

Much of the loss in the tropics is caused by farmers who broadcast their fertilizer, instead of turning it under.

Another waste is caused by farmers who do not control insects and diseases. Plants that are fertilized, and then damaged by insects and diseases, cannot pay back the cost of the fertilizer.

Lack of weed control in the tropics is another fertilizer waste. The weeds sometimes take up more fertilizer than the crop.

Problem soils can cause fertilizer waste. Zinc deficiency in the soil, for example, inhibits the uptake of nitrogen by the plants. This can be corrected.

Many steps to reduce waste of chemical fertilizer are well known. But, making these changes on the farmers' fields will require a large effort by national extension programs. If all these changes were possible, we might eliminate half the fertilizer losses; in other words, we might produce twice as much grain per hectare with today's fertilizer. This would help pay the higher costs.

- (2) There are new fertilizer products and new ways of applying fertilizer which may prove useful.

For example, a pelleted fertilizer coated with sulphur is being tested in Asia. This is a slow-release product which makes the nitrogen available at approximately the time that the plant is ready to take up the nutrient. Planners of this product claim it will increase the uptake of nitrogen by 33%.

Another experimental approach is a foliar spray for nitrogen. India is testing the application of urea as a spray on the crop leaves. Under some circumstances, this gives a greater response in grain than the same amount of urea applied to the root zone.

Both the slow-release pellet and the foliar spray deserve more study, in order to make more efficient use of nitrogen.

- (3) Some scientists advocate greater use of natural nitrogen. This could mean more legumes in the crop rotation, more composting, more use of house and barn manures on the fields. All these sources of natural nitrogen should be reassessed, in comparison with higher cost chemical fertilizer.

But CIMMYT staff believe that organic agriculture, using natural sources of nitrogen, can play only a marginal role in world-wide agriculture. Natural nitrogen does not offer an effective alternative to chemical fertilizers in the 1970's.

- (4) "Radical research" may produce new sources of plant food by the end of the century. We will mention some radical solutions here only as options which could become important beyond the 1970's.

Some legumes, we know, have the capacity to form an association between their roots and soil bacteria. The bacterium transform nitrogen from the air into ammonia and nitrates in the root zone.

Question: Can this ability of the legume plant to feed itself be transferred to other crops such as wheat or maize? The answer is beyond today's horizon.

There are other plants which help produce their own food. In rice paddies, both algae and bacteria are able to fix nitrogen from the air and deposit it in the root zone of the rice plant. In sugar cane, bacterium feed upon the sugars in the roots, and in return, they deposit nitrogen products which are used to feed the sugar cane. Perhaps the strangest example is the pine tree, which is able to grow in pure silica sand with no visible nutrients, because a fungus known as mycorrhiza lives upon the pine roots and fixes nitrogen from the air.

No scientist has yet learned how to domesticate these nitrogen-fixing processes and to transfer these benefits from one crop to another. Perhaps we shall see this happen by the end of the century.

I now leave the subject of fertilizer and turn to my last topic: some guidelines for a maize program.

1.6 SOME GUIDELINES FOR MAIZE IMPROVEMENT

The term "guideline" is used here to suggest a broad framework. The guidelines on my list are only those which emerge from the topics we have just discussed; they are conclusions relating to population, to food trends, to protein, and to fertilizer. I shall state ten guidelines, and your discussions will probably produce others.

- (1) On Population Growth: The developing countries will double their population in the next 20 to 25 years. A stable world population cannot be expected in a shorter period. Thus, developing countries will require at least twice as much food before their populations level off. The demand for more food is already strong in the 1970's, and rising at more than 3% a year.
- (2) On Trends in Food Production: During the 1960's, the developing countries managed to increase their production of cereals at a rate above 3% a year. But half this increase was made possible by a shift of more land to the cereal crops; this cannot continue. More land available for cereals is unlikely in most countries. Future food increases must come from more intensive use of existing crop land, and higher yields. That means better technology.

- (3) On Food Imports: Countries short of food cannot hope to solve their problem by imports alone. Food will continue to move from surplus areas like the U.S. A., Canada, and Australia to deficit areas; however, this alone will not solve a food problem of the magnitude that is now upon us. Foreign exchange will not be enough to buy the food. Foreign aid will not be enough to subsidize the food. Each country will need to produce its own food supply, to a large degree.
- (4) On Better Technology: The Green Revolution is not a finished product that requires only to be marketed on a larger scale. The new technology for food production is in its infancy. There are many unsolved problems in plant breeding, in plant physiology, in plant protection, in agronomy-- all topics for this Symposium.
- (5) On Protein Supplies: Lower income groups of the world must rely--increasingly--upon cereal protein to balance their diet. But cereal protein, especially in maize, has been of poor quality due to a poor balance among amino acids. Thus, there is urgency to develop quality protein maize, and to spread its use.
- (6) On Fertilizers: Present shortages should be ended by 1978. Beyond then, it should be possible to produce enough fertilizer for world agriculture. But prices will remain high, and the economics of fertilizer will compel us to find more efficient ways to use fertilizer. Every national program will need to re-evaluate its recommendations on fertilizer. And research centers like CIMMYT must join in the study of ways to increase plant efficiency in the uptake of nutrients.
- (7) On Cropping Intensity: As more food is required from each hectare, there will be wider use of multiple cropping, mixed cropping, relay cropping, and other ways to grow more crops each 12 months on the same land. National programs will give more study to farming systems. And a center like CIMMYT must contribute to the study of cropping intensity, especially through its outreach projects.
- (8) On More National Programs: During the 1970's, there will be need for more national maize programs. As an arbitrary number, we estimate that every country which grows 100,000 ha. of maize will need a national program. These programs will require more trained scientists.

(9) On "Radical Research": The "conventional" research which we are now using--that is, crossing plants within the same genus--may produce enough variability to keep crop yields rising for another 25 years, until 2000 A.D. But the staff at CIMMYT believes that if population continues to grow beyond the end of the century, we shall need some "radical" research--crosses between genera--to produce new kinds of variability. "Radical" research must begin now if it is to deliver new products to the farmer and the dinner table, within 25 years.

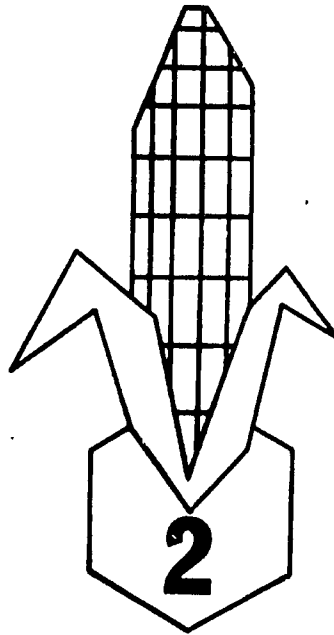
(10) On a "Network of Collaborators": Our plans for the future are so ambitious, and the range of problems so great, that success will come only through a network of scientists, world-wide in scope. There will be hundreds of scientists in national programs working, as the military say, in the front lines. Only a small role can be played by an international center like CIMMYT.

We expect to collaborate with governments, and in doing so, we must use methods that are persuasive to policy makers, yet politically acceptable. We expect to collaborate with outside scientists, and in doing so, we must find methods of collaboration which are professionally rewarding to them.

Successes will undoubtedly come; and credit for those successes must be shared by all who participate. That is the basis of a successful network.

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2.0

**WHAT LIMITS
WORLD MAIZE PRODUCTION?**

by

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2.0

WHAT LIMITS WORLD MAIZE PRODUCTION?

by
Ernest W. Sprague

2.1 INTRODUCTION

2.1.1 MAIZE: SOME PLUS AND MINUS FACTORS

Maize has a great deal going for it as a cereal crop. We need few reminders of its versatility as a crop and as a food. We know that maize grows over a wider geographical range and over a wider range of environments than any of the other cereals. Thus, in a world-wide context, maize is exposed to more hazards and is a higher risk crop in general than the other cereals.

We know that, under good management, maize produces yields equal to or superior to the other cereals. And with no management, it produces an average of about one ton per hectare, as does wheat or rice with the same level of management.

Experimental yields vary from very high to satisfactory at sites throughout the world, and several countries have been extremely successful maize producers, which suggests that maize has excellent adaptation and capability. Virtually every major maize producing country is reporting yields from micro plot data that are three to five times higher than the national average in these countries. Yet, national average yields have not changed very much in the last ten years, except in a very few countries.

The present world food and fertilizer shortages have pushed grain prices to record levels on the world market, a factor of increasingly grave concern to national governments. Under pressure of mounting food needs, many governments are for the first time asking serious questions about means of accelerating food production. Although the concern may appear to be fairly recent, the

conditions limiting production have existed for years--centuries in some cases.

In some of these countries, farmers are condemned for not adopting the new varieties and practices--the extension services are condemned for being ineffective. In turn, the farmers are very skeptical of government promises, and extension personnel are critical of research. In this kind of loaded situation, the likelihood of irrational analysis and decision making very probably outweigh the probability of constructive, positive action.

Against this background, then, What Limits World-Wide Maize Production? Can we isolate some of these restrictions and examine them? Having examined the barriers, can we adapt some of our present technological and management know-how for use in needful countries? A basic aim of this paper is to size up the forces opposing maize production in hope of getting a step ahead of some tricky opposition. Even half-stride gains are welcome in the race against hunger.

2.1.2 SOME BASIC QUESTIONS

The remainder of this presentation--and of this Symposium--will highlight some of the questions asked daily by farmers, maize researchers, production management people, and by national agricultural policy makers. Thus, the Symposium deals with two major topics: (1) the technological aspects of maize research and production and (2) policy, organization and management. My paper touches only briefly on technical subjects; dealing primarily with problems of a management and staffing. Dr. Johnson's presentation to follow (3.0) will set the stage for discussion of the more technical aspects of the Maize Improvement process.

As a first step, then, we can seek to identify the problems as the farmer sees them and not just as the research personnel see the problems. Why are the superior varieties not adopted? Are they unreliable in large-scale production? Are they too early or too late to fit the farmer's cropping system? Do they require a level of management beyond his capability or beyond the availability of inputs.

Has research been overly concerned with looking for the variety that gives maximum yield under experiment station conditions? Has the real issue been neglected--a dependable and stable performing variety that fits the farmer's system at a management level he can provide and can double the yield of the farmer's present variety?

The extension services around the world have often been less than successful. Have they had the right things to extend? Do

they have the necessary qualifications, if they had a successful production package to extend? Are the recommendations well founded by determination on farm field situations, or are they an attempt to translate experiment station responses to farm conditions?

In many situations government policies do not support or encourage accelerated production. Policies on fertilizers, pesticides, and other inputs are clumsy and unsatisfactory. Policies on irrigation often work against, rather than for, increased production. Pricing and marketing of product and inputs are often a hindrance.

There are, then, it seems, three basic issues: (1) setting up the technological know-how for farmers via maize research and production people, (2) the facilities and support for these operations, and (3) government policies and incentives that will encourage and promote maize production. As mentioned, my paper focuses on the latter.

2.2 CRITICAL NEEDS

The questions asked above about the technical factors limiting maize production usually focus on a few basic needs, most of which will be discussed thoroughly later in the Symposium. One of the clearest needs is that of getting improved production technology to the farmers. The local varieties (farmer variety) are often not very responsive to fertilizer and improved management. And, almost without exception, the improved varieties and hybrids developed by national research programs are much too tall and lodge badly under higher levels of management. It is most discouraging for farmers to labor through the process of growing a crop only to find at harvest an entanglement of plants with a considerable amount of grain loss from rodents and spoilage while it is lying on the ground.

In addition to the lodging, most of these varieties and hybrids, although very responsive to fertilizer, are not efficient converters of fertilizer into grain. This is due in part to the low grain-to-stover ratio and to a high number of barren plants in the population. In other words, these varieties and hybrids do yield well under experiment station management, but yields do not hold up with reasonable management under farm conditions.

Many of these varieties which seem to perform well only at the experiment station are substantially later in maturing than the local varieties. True, these later varieties mature within the time span required between harvest of one crop until the planting time of the next. But the extra week or two needed to mature the "improved" variety serves as a deterrant to farmers, as it adds substantial pressure to his timetable that he follows in his total

cropping system. Shouldn't such varieties be analyzed from the standpoint that maize is a rainfed crop? Under rainfed conditions the variety must fit the period of most favorable or reliable moisture conditions. If rains start early, 1 variety is needed; if rains start later another variety is probably required. When maize is grown in association with other crops, are there additional limitations?

Many of the varieties demonstrated to the farmer have grain characteristics that differ from his local variety, a factor which often deters adoption. This is particularly true in areas where a portion of the crop is marketed and the local marketing system discounts the price offered for the slightly different grain type.

Seed and seed distribution seems to be a continuous problem to most countries. To a great extent, this is because the national seed programs have overly sophisticated seed certification and seed production policies, but do not have adequately developed storage and distribution systems. Often these national programs operate on the theory that systems of Europe, the United States, etc. should be copied as a guarantee that the farmers will be getting high quality seed. Such a rationale ignores the fact that for generations the farmers have been saving their own seed from harvest to the next planting. Rapid spread of outstanding wheat and rice varieties has occurred where the seed moved from farmer to farmer and the farmers saved their new seed in the same way that they had for generations.

Generally speaking, governments have discouraged the private sector from entering into seed production and distribution. Instead, such governments have involved themselves in the business and laid down restrictions that would discourage even the most venturesome people who might be interested in the seed business as investors. All of this has been done with the good intent of protecting the farmer from unscrupulous seed dealers.

It is difficult to know how successful the private sector might be in maize seed production and distribution. Systems in the United States and Europe would not necessarily be successful in most of the developing countries, as the volume of sales contacts would be extremely high as compared to the volume of seed sold. Also, it would be very difficult and expensive to manage transportation and storage adequately dispersed to reach the millions of farmers (most having no more than one hectare of maize). In other words, operational overhead for distributing and selling would be high.

In most countries, little if any production agronomy research has been associated with the improved varieties and hybrids, and for all practical purposes, absolutely no on-farm testing. Why,

then, should one expect the farmers to rush after a new variety that he has not seen, has not been shown how to manage, and for which he probably could not get seed if he were interested in trying it?

The questions of developing resistance to maize insects and diseases, certainly one of the most vital, need only be mentioned here. The implications of the work for maize improvement seem obvious.

Pricing policy--or no policy--has often worked against the promotion of improved varieties and improved management. In many cases, the farmer does not have a guaranteed floor price, so at planting time maize prices are very high. At harvest, however, he is forced to sell his crop because he needs the cash and because he has inadequate storage. The result? His price is low and his extra yield is offset by the extra expense for inputs. He gains little for the greater risk that he took through higher investment.

In other situations, the governments have subsidized fertilizer as an incentive for increased use. Such approaches have not worked well and will no doubt work less well for the next few years because of the chronic shortage of fertilizer in all countries.

The objective in subsidizing fertilizer is to help keep costs down to the consumer. In the first place, this logic is questionable when 70 to 80% of the consumers are also the producers. When fertilizer is subsidized, and in short supply, there is immediately an opportunity for black marketing. Fertilizer allocated for food crops is thus rerouted to sugar, tobacco, and other high value crops. Some of these situations are ideal for smuggling fertilizer from the subsidizing country to a neighboring country that does not subsidize.

In a similar fashion, when the subsidies do work as intended, that is hold down prices of food grains, an ideal situation for smuggling food grains from the low-price country to the neighboring countries where food grain prices are higher emerges. The irony of this is that the producing country then loses both ways: the fertilizer for food grain, and the food grain after it is produced.

Basically, the impact of most national maize research programs has been disappointing. On the other hand, most nations that have developed superior varieties or hybrids have been able to plant 15 to 20% of their maize producing area with the superior yielding varieties. In these countries, the increased yields have more than paid for the cost of the research. So let us not look backward with despair, but look forward with imagination and optimism.

CIMMYT'S MAIZE IMPROVEMENT PHILOSOPHY IN OPERATION

Having discussed some of the pros and cons of current maize production, this paper seeks to think through the production problems to see if we can't find ways of conducting more effective and relevant research and introduce some new thoughts and strategies. The emphasis here is on organization and management.

2.3.1 IDENTIFYING PROBLEMS

Technological needs can be met by research, and there is no question but that maize production can be greatly increased. Every country, however, including the most advanced, needs to reevaluate their research and production programs. They need to define these objectives and research must be sharply focused on those objectives.

Less advantaged countries should not look at the more advantaged countries and feel a compulsion to pattern their range of activities after those of the wealthier countries. In the first place, there is little to indicate that the advanced countries are using their applied research funds in the most efficient way, nor is there anything to argue that affluent countries should have the same approach to their objectives that the less affluent countries should have.

In general, research and production programs are plagued with a chronic shortage of funds. By the same token, money per se is rarely the first limiting factor. Rather, management and choice of uses for the money (as viewed in its broadest sense) is usually an initial barrier.

The need for determining priorities and efficiently operating the programs goes all the way through the system. Therefore, every country should determine what type of research and production program will be required to genuinely meet the national requirements. Until this is done, duplication will continue on the one hand and gross neglect on the other, with needless waste of monetary and human resources and few benefits to the rural community or the nation.

2.3.2 DESIGN OF NATIONAL PROGRAMS

Basically, it seems fair to say that most developing countries do not have suitable maize research and production set-ups. So the question becomes: Can we recommend a system for those coun-

tries to help them focus their maize production activities? I believe that we can, bearing in mind that each country's needs will differ.

In my opinion, national research and production programs should be commodity oriented; that is, with staff representing all disciplines working together as a team. Each of the presentations at the Symposium is designed to give a thorough account of how the various disciplines can complement the others within such a program. Dr. Johnson's presentation, to follow next (3.0), will discuss the maize improvement concept and breeding input more comprehensively. My aim here is to provide only a general overview, with each succeeding paper to provide its own disciplinary viewpoint.

Breeding programs range from non-existent to grossly over-involved to irrelevant to national needs. There are exceptions, of course, and many nations--particularly during the last 18 months--have begun to look for ways to structure an improvement program that will best meet their needs.

As suggested previously, my opinion is that none of the developing countries with small farm holdings should be working with hybrid development. Fortunately, a number of countries with more advanced research programs abandoned their work on hybrids and shifted to population improvement programs. This, however, brings up another problem of how to direct population improvement programs toward varieties. Unfortunately, few countries are actually doing so, although their stated objective is to provide superior varieties to their farmers.

These programs are not to be overly criticized. The vast majority of work at the population level has been done in the United States and was directed toward development of breeding methodology and not for development of superior varieties for commercial production. Thus, the experience of the breeders and the research findings do not set examples for varietal development that can be followed by breeders in other national programs. It is not surprising that, in most cases, too many different genetic materials are being studied--with inadequate testing and precision. Too much effort is going into combining ability--a hangover from hybrid work. The concept of gene transfer is either not well understood or not practiced; and the integration of breeding, plant protection, and production agronomy rarely exists. How, then, can these concepts be brought into closer working relationships?

2.3.3 OVERALL RESEARCH AND PRODUCTION STRATEGY

Every national program, large or small, should be organized in such a way that there is a flow system from one activity or function to the next until a reliable production package reaches the farmer.

From a planning standpoint, there are three basic categories of countries:

Category One: where maize is an important crop over a large acreage. Such countries may be adequately staffed, or even over-staffed. However, there is in general a severe lack of competently trained staff. This is often overlooked because the staff academic record would suggest a high level of qualifications.

Category Two: where maize production is an extremely important part of the national economy, but there are extreme limitations in terms of qualified personnel and resources.

Category Three: where maize remains important, but of a much lower priority than other food crops.

2.3.3.1 Category One Countries

With very few exceptions, all of the countries in this category need a staff of about 55 people. Four to six members of this staff should have Ph.D. -level training and education, about 16 should have the equivalent of a M.S. degree, with the remainder having Bachelor-level experience. This staff would include breeders, entomologists, pathologists, production agronomists, and production economists, working as a team under the leadership of a coordinator or director of the maize research and production program.

If a nation plans to move into an on-farm testing program, it will be essential that staff be especially trained for this function. This is essential because of the lack of agronomists, as well as a general lack of understanding of what effective on-farm testing is, or how to go about it. Funds (either internal or external) can usually be found to support training for a few production agronomists. But, to get the greatest impact, large numbers of extension staff must also be trained in maize production techniques. Because of time, money, and distance problems, however, it is almost impossible to train these people outside their country. Thus, as soon as a national program has developed to sufficient depth, a national "in-service"

training program should be established for extension staff.

There are several countries that have extension training centers. By and large, they have not had an impact on production because the training is developed around extension methods and the trainees are not knowledgeable in production techniques. These programs must be reorganized around production programs and conducted by expert production agronomists.

Some countries need more experiment stations; however, there are many countries with far more experiment stations than are necessary. Unfortunately, there is a strong tendency for each station to work towards autonomy and independence, and thus duplication. With the present critical food situation, it is doubtful if a country can afford the luxury of operating experiment stations because of local political pressures. Instead, national governments must come to grips with their genuine requirements.

Rigorous decisions might mean closing stations, but would allow more adequate staffing and funding for those stations that are required. In the eyes of administrators, establishing an experiment station might seem an answer to their problems, but a new station does not always offer a solution. Modern approaches to crop improvement and production require stations representing major climatic areas, not political regions. Research at the farm level, as will be discussed later, will do far more for agriculture than a large number of ill-managed experiment stations.

Countries in Category One should usually have one national headquarters experiment station in a location where genetic materials from any environment in the country will grow and set seed successfully. They also should have a regional testing station in each of the major agroclimatic regions.

The research program should generate families to be tested at the national headquarters, as well as at the regional stations. It is not important where progeny are generated; in fact, they can be generated anywhere that the genotype will grow. The location of the tests, however, is extremely important, as is the precision of the test for yield, disease, and insect reaction, etc.

From the progeny testing, experimental varieties should be formed and likewise tested at all of the stations. This process, if properly conducted, will generate varieties that are adapted to all of the agroclimatic regions. Equally important, these varieties will be widely adapted and should demonstrate long-term stability or dependability of performance.

Research programs should also provide the progeny trials and experimental variety trials to the other nations cooperating on a regional basis. Further, they should test progeny and variety trials from the regions and other sources (international programs, etc.)

After elite experimental varieties are identified, two years of data are available: first data on the families and second data on the experimental varieties formed from the progeny. The elite experimental varieties should then go to on-farm trials composed of two to five varieties and located over the regions that the experiment station represents. Such trials will provide trustworthy data. Equally important, the extension staff and farmers will share in all aspects of the decision-making processes involved in the release and promotion of the variety.

As we have said, for this system to work, the right type of genetic material must be selected for the breeding program at the outset. First, the variety must meet the farmer's needs. Obviously, satisfactory yield is of utmost importance, but by no means is yield the only significant criterion. Other essential aspects are: grain type, satisfactory levels of tolerance to disease and insects, maturity, standability, uniformity, and dependability. The population chosen for improvement must then carry genes that will allow all of the characters to be built into the variety.

Production agronomy work, so essential to the total process of developing an economically viable production package, is usually one of the weakest links in national research and production programs. In other words, a reliable network is not available for diffusing technology to meet the farmer's needs. The traditional system of formulating recommendations from experiment station data and expecting the extension service and farmer to adopt has not proven successful in most countries.

2.3.3.2 Category Two Countries

These countries have the same need for accelerated maize production as the countries in Category One. They are, however, extremely limited in qualified personnel, facilities, and resources. Their staffing pattern and experiment stations network should be similar to that described for Category One countries.

Substantial time and cost is required to develop the staff and facility described and these countries cannot afford to wait. Thus, they should not attempt to generate progeny, but should be satisfied with testing progeny and experimental varieties coming from stronger national, regional, and international programs. If appropriate progeny and varietal trials are provided for testing in these countries, they

can very quickly determine varieties that will be substantially better than the locally grown varieties. It is important that all of their testing be done with a high degree of expertise.

Like the countries in Category One, they must give high priority to developing on-farm testing teams, if the superior varieties they identify are to have substantial impact on national production.

2.3.3.3 Category Three Countries

These countries should have relatively small staffs and should test only experimental varieties coming from national, regional, and international programs. But, they must develop the on-farm testing system, with superior varieties and production techniques to use as rapidly as possible. If such countries devote a large effort to maize, they will misuse their total agricultural research and production resources.

Unfortunately, most countries, regardless of size or stage of development, tend to believe that the first thing they need is a breeding program. The so-called "more mature" countries are devoting proportionally much more of their resources to breeding than to any other aspect of technological development. This costly effort is, in part, an historical hangover and reflects a lack of understanding of how to most effectively capitalize on modern breeding systems in cooperation with regional and international programs. Perhaps there is also the desire to develop their own varieties as a matter of national pride.

Such problems often stem from the isolation of the national research staff, who may not be adequately in touch with their colleagues from neighboring countries and the international network of maize research and production workers. Additional training and travel opportunities would help overcome these difficulties.

2.4 DEVELOPING AGRICULTURAL PERSONNEL

Previous discussions have touched very lightly on some of the technological needs, as well as organizational and policy problems that can affect maize production. This section shifts to a specific demand found within all categories of countries--the critical requisite for trained personnel.

Looking ahead through the 70's and beyond, perhaps the development of well-trained men and women is the single most es-

stantial factor in maize improvement and is certainly a slow and continuous process that cannot be overlooked. Thus, my discussion here seeks to provide both a rational and specific recommendations for fulfilling some of the current needs in agricultural education and training. CIMMYT's own training functions are set aside for later presentations.

2.4.1 SOME BASIC CONCEPTS

We can say that our human development is conditioned by two main factors: our genetic capability and the opportunity we have to reach our full potential. The first we are born with and can be changed very little with current knowledge. The second--opportunity--is usually related to the economic status within which the individual is born. Unfortunately, the economic status of the rural people, particularly in the developing countries, is generally below the level allowing a full opportunity for education. Thus, we are faced with the fact that most of the people who receive advanced education and training are drawn from urban centers--and this includes agricultural graduates. One of the basic questions then (and a major limitation in staffing) is: How do we go about developing people for service in agriculture who have had no association with agriculture during the first fifteen to twenty years of their lives, other than through the food they eat. Far too often, such a student's first association with agriculture occurs in a classroom; via a professor who may have had only an academic exposure to the problems of agriculture, with virtually no direct involvement in solving agricultural production problems.

It seems to me that we now have two areas for discussion: First, how do we train the present generation? Secondly, how do we train the generation that follows? Obviously, the more urgent need today is the present generation; therefore, the paper focuses primarily on that issue.

2.4.2 PREPARING YOUNG SCIENTISTS

The development of young scientists is a costly and time consuming process. For this discussion, I plan to start with the student's first year at an agricultural college. (However, in terms of motivation, prestige, career course, the process must begin much earlier) We can begin by asking: What does the student need, and how does he get it?

I think we all agree he needs a sound education in the basic sciences, the agricultural sciences, and considerable exposure to the social sciences. In addition, as a solid foundation from which to be able to develop, he will need to assimilate a good deal of practical field and laboratory experience. This sort of direct experience is often called an internship or apprenticeship. After such a basis has been acquired, he will be in a position to learn through personal experience; acquiring and gaining additional depth in a continuing process throughout his career.

On the surface, such a system of education seems quite simple. Most universities and colleges probably feel that they are providing the background a student needs. In general, however, I disagree. My experience suggests that most universities are simply not adequately preparing students to give the world what it needs in agricultural research and production. In far too many cases, students are being taught by professors who are poorly qualified. True, these professors may have the required academic degrees and years of teaching experience, but these per se are not an adequate measure of qualifications. And let me add, quickly, that this dilemma is not unique to any part of the world. Perhaps it is best to fault the educational process, rather than any segment.

Since an agricultural scientist is basically the product of his education and experience, we need to give much more attention to the undergraduate and graduate study programs. We must find ways to improve the educational system so that it will turn out better qualified young people.

Here are some of the problems we must struggle with. In the first place, teachers and professors traditionally receive very low salaries. Thus, the educational system cannot often afford the best talent. Further, academic roles within a civil service system are usually fixed, with rigid salary scales and increments that prevent the possibility of promotions for merit. When the excellent, good, fair and poor members of the academic staff are treated identically, mediocrity is usually the product.

In many institutions, agricultural teaching is done by professors who are not engaged in research; who have no access to modern libraries. As a result, they often teach from notes taken when they were students. For some of the basic courses this aspect is perhaps not too serious, if the professor took his course from a good teacher. In other words, the anatomy of a plant does not change; basic genetics at the undergraduate level has not changed much, etc. But advanced courses of the applied sciences do change, and they must be revised continually to be really effective. Courses

such as production agronomy, plant breeding, production economics, must use examples that fit the current local situation. Unfortunately, this usually is not the case. The material and examples are outdated and, even worse, are often related to an agriculture totally different from that found in the student's native country. The problems here involve: What information inputs are available? From whom? How translate for student?

So, in preparing young people, we must first improve the teachers and their information. Incentives must be found to motivate teachers. They must be involved in dynamic research programs. They must be thoroughly familiar with the problems of agricultural production, and should know farmers and the farmer problems, if their teaching is to be relevant to a country's needs. Let me give an example or two to illustrate the present situation. For the most part, in the developing countries, agricultural research is conducted by the Ministry of Agriculture. Their colleges and universities are doing very little, if any, agriculture research and almost no research of an applied nature. Often, however, young scientists and administrators from the Ministry of Agriculture have opportunities to travel, or study as participants in in-service training programs, etc. Such activities are directed towards improving the knowledge and experience of the individual. But, the classroom professor usually has far fewer chances to travel; and if he does, he generally visits another university having the same orientation as his own. Many universities have research responsibilities, of course, but frequently the research lacks relevant to the needs of the country. My suggestion is that professors and teachers be provided opportunities and motivated to travel and participate in dynamic research and production programs keeping them up to date on the latest in applied research. This concept also implies that research and field people should have some access to classroom and lab work, for a two-way flow of information.

In addition, I believe we should develop teaching programs which require the student to think through and apply the new knowledge he has gained. His work should focus on the needs of his own country. Unfortunately, the system most commonly used today simply throws a series of "facts" at the student. If he can memorize the material and regurgitate this to the teacher, he will probably be "Number One" in his class. Within such a system, he receives no guidance or reward for recognizing the principles involved; or for his ability to marshall facts and data and translate them into a solution of problems. In my opinion, such academic experiences limit the potential of both the student and his native country.

A student must acquire a practical education, plus on the job training and experience, before he can be productive in solving problems in his chosen field. During his undergraduate preparation, such problem-oriented training should involve application of his newly acquired knowledge, plus a strong motivation to acquire additional information through reading, discussion and thinking. Such experiences demand precision on the part of the student in his thinking, in the implementation of the exercise, and in the interpretation and reporting of results.

Students also should become thoroughly familiar with experimental techniques. Since applied agricultural research must be field-oriented to be effective, students should learn good field techniques. Students could be given an opportunity to work as research assistants during the breaks in the academic program. In my opinion, such work experiences should be a requirement for the degree. It is imperative that the student work with a scientist who fully understands the importance of high quality field research; that is, good seed bed preparation, good stands of plants, good water control, careful recording of data, etc. With such training, the student soon learns that the best statistical analysis known will not improve poor data or foggy thinking. Such concepts can only be learned by direct participation on the part of the student. As an extra dividend, the student can learn much about experiment station management and operation via the same process. In my view, this lack of direct experience is the weakest link in applied agricultural research, and generally is given far too little attention by both the researcher and the administrator.

Obviously, a Bachelor's degree does not, in itself, prepare an individual to serve as a research scientist. But if he has had the experience, basic courses, etc. described above, he is qualified to be a first rate assistant in a dynamic research and production program. He will have enough of the concepts and skills to understand the why's and wherefore's of what he is doing, even though he will not be able to analyze all of the biological, economic and social implications.

After the receipt of the basic academic degree, what then? When the young scientist starts out as an assistant he should be assigned a role with a well defined responsibility in the overall research and production program. But, he must also be given sufficient guidance to allow him to effectively perform the functions that are required. His education in conduct of research is just beginning.

Much of CIMMYT's philosophy in regard to subsequent educational training is presented by Dr. Violic (11-0), and time

permits only a brief mention of some of the other crucial aspects of education.

It is very apparent to most of us that education and training cost considerable amounts of money. At present it is estimated that graduate study costs on the average \$ 7,500 U.S. equivalent per year. An M.S. program requires a minimum of two years and a Ph.D. program normally requires three and a half years. Thus, the total average cost for an M.S. and a Ph.D. degree will be about \$ 41,250. Such an expense must be considered carefully. If the wrong scientist is chosen, or if he was a wise choice but is not subsequently placed in a position where his education can be exploited, the investment cannot yield the expected dividend.

However, we must remember that even with the best education and training, people very quickly become isolated unless there is a system whereby they can keep abreast of new developments. This is best done by maintaining ongoing contact with other scientists, both within their country and the world-wide network of scientists in their area of interest. Thus, opportunities to move out occasionally as visiting scientists to see and participate in foreign research and production programs is essential. It is also essential for foreign scientists to periodically visit the National program.

2.4.3 RECRUITING QUALIFIED STAFF

There are many different systems used for recruiting young scientists. Unfortunately, the system usually is designed to fit a governmental policy that often renders the system ineffective.

In addition, no matter how carefully the system screens the candidate, mistakes will be made. Far too often such mistakes are not rectified and the organization, over time, accumulates dead wood. One system that I believe would avoid this problem would require that young staff working in research, production and administration would work one year for the employing agency with no commitment on their part or on the part of the institution for future employment. At the end of the year the outstanding candidates would be selected for the vacancies in the system.

In many countries eager to rapidly staff programs it is found that there are insufficient qualified graduates to meet the needs. This leads to employing a number of people of less than desirable capability. After these people are on the payroll, in most systems, it is impossible to dismiss them. The real tragedy here lies in the fact that they are not only inadequately filling positions,

but that, with time they may be promoted into higher positions. There they not only are less and less productive themselves, but preclude the development of effective leadership in the scientific cadre below their level.

I therefore ask the question, Is it not time to remove the agricultural research, production and administration personnel from the traditional civil service system? It seems to me very unfortunate that scientists are employed, promoted, etc. through the same system used for the more routine clerical positions of government.

If there are no means for removing recruiting from the traditional civil service system, it is probable that there will be no efficient way of guaranteeing that positions will be filled by the best candidates. Can we, with the present and future world food problems, afford to continue dealing with agriculture in the same inefficient bureaucratic way?

2.4.4 ESTABLISHING INCENTIVES AND BUILDING ATTITUDES

The attitude of the individual is often the difference between success and failure. Although attitudes are individual qualities, changes of poor to good attitudes and the stimulation of good attitudes is done through good leadership. Poor or indecisive leadership will most certainly dampen the spirit and attitude of the subordinate staff.

Energetic people must be fully occupied mentally and physically or they will become dissatisfied. They should have a little more responsibility than that which they can comfortably handle. If they have leadership capability, they will respond favorably to an overload. If, however, the young scientists are treated as second class citizens they most certainly will lose or fail to develop a positive attitude. This must be avoided at all cost and one mechanism that can overcome this problem is a built-in system of incentives. These incentives may take many forms; contrary to popular opinion, money is only one such incentive and not necessarily the most important.

2.4.5 ESTABLISHING A SENSE OF RESPONSIBILITY AMONG SUBORDINATE STAFF

Mankind seems to respond to challenge by instinct, and this instinct can be either stimulated or dampened depending on

how a staff is handled. As with all aspects of human nature, the opportunities that people have and the leadership that they work with are crucial.

The responsibility for developing young people who will have a sense of pride, initiative and be able to provide leadership lies with the senior staff and administrative system of each particular organization. As senior staff, we often criticize the failures of our subordinate staff without analyzing our role in such failures. If we are truthful, the problem often lies not with the young scientist or administrator, but with the senior people and the administrative system.

Many times the system provides a mechanism for punishment for mistakes, but few or no rewards for excellence. This is a reverse incentive. Imagine how frustrating it is to the young energetic scientist or administrator who works hard to fulfill his responsibility only to be punished for minor mistakes.

To establish a sense of responsibility in subordinate staff, the senior research and administrative staff must provide adequate and timely leadership. Unfortunately, all too often, people with inadequate qualifications and capabilities have been promoted into the top positions. Most systems do not include a mechanism to release them or to reassign them to other positions where they could be effective. Such staff often have an inferiority complex and, through a natural instinct for survival, never let the talents of the younger staff emerge. This leads to a kind of institutional suicide.

If a sense of total team effort is established among the subordinate research and administrative staff, they will automatically be more productive. They will perform their duties with a zeal and integrity. Not only will they be more productive in their routine duties, but they will quickly develop the skill of discussion with their superiors and colleagues.

When younger well trained staff have become capable of making decisions, they must not only be allowed to make them but encouraged to do so. In reality, most young (and too many senior) administrators are afraid to make decisions. Why? A no decision - no punishment; wrong decision - severe punishment attitude prevails in many institutions. The art of procrastination seems to have reached a level of perfection in such administrative systems. Individual procrastination, plus the further stifling delays resulting from resorting to committees, is often the rule rather than the exception. It is just such a system that results in fertilizer being available two months after the crop is planted; in floor prices not being announced

before planting, or not defended at harvest (as far as the farmers are concerned) because of delay in governmental decision making processes.

Just such bottle necks have rendered most, if not all, public national seed corporations ineffective --a liability to the nation and a hindrance to the supply of quality seed to the farmers. The same situation applies to many government fertilizer factories where delays in decision making and availability of money on time have resulted in government plants running at less than full capacity and at an efficiency far below standard--frequently 60-65% of rated capacity. This situation generally results in fertilizer priced substantially above world market prices.

2.4.6 PREVENTING PERSONNEL DRAIN

The greatest deterrent to the "Brain Drain" existent in many developing countries is an opportunity to work freely and productively in a dynamic system which has adequate facilities. Assuming this requirement has been met, a reasonable salary within the income stratification of the society is normally acceptable.

Different countries try different strategies. Few are totally effective if the above requirements are not met. In far too many situations young people are required to sign bonds, contracts, etc. to provide service to the country for a number of years equal to that they are sponsored for training. In my opinion, such an approach does not set the stage for respect and loyalty to a particular country, or dedication to solving the chronic problems of that nation.

Clearly some people accept positions in other countries or in other institutions within a country simply for economic gain. I believe, however, that this group constitutes a very low percentage. The majority leave their home institution because opportunities elsewhere provide a freer hand and more responsibility with better facilities.

It must be recognized, however, that there are far too many countries where salaries (again tied up with civil service) are not adequate to maintain a scientist and his family. In such situations, one of two things inevitably occurs. Those who can find employment outside will leave the country, and those who cannot, or for personal reasons choose not to leave their country, will work at more than one job. Either situation is undesirable. The first represents a complete loss to another nation, which often is not in desperate need of the talent. In the second situation, the

individual is not dedicating his major efforts to handling the responsibility for which the investment was made in training and education. Governments must come to grips with this problem, and it is another strong argument for removing agricultural research, production and administrative staff from the standard civil service system.

If staff recruitment in such areas were to be removed from the general civil service system, real thought and effort would need to be given to designing a reliable and workable system. Some countries have separated their Government agricultural work from the remainder of Government employees, only to find in a few years that an equally undesirable bureaucratic system has evolved. This accomplishes little.

Basically, developing people is not so complicated if all of the pieces of the puzzle are put together. In my opinion, this can be accomplished if a government firmly makes a decision to do so. Further, I believe, that in the long run, progress would be made at a more rapid rate than can possibly be expected with the pattern of events that occur today. If a government were to decide to make the necessary changes and launch a deliberate effort to systematically develop its agricultural research and administrative staff it must first make a thorough appraisal of present and long-range staff requirements. I do not know of a single so-called developed or underdeveloped country in which adequate planning has been done in this regard.

Some of the more advanced countries are, however, prime examples of over staffing, duplication of effort, and lack of coordination. Under such conditions their accomplishments are the product of mass force and effort not of efficient management of human and monetary resources.

Less developed countries, unfortunately, tend to look to one or more of the advanced countries for a pattern to emulate. The world (not to mention some of the individual nations) cannot afford that luxury today.

Other countries show other products of inadequate or non-realistic planning. In these countries, inadequately qualified people fill positions for which they are totally unsuited. Since they are not qualified, the task laid out by the planners is not accomplished. This leads to the appointment of still more unqualified people and the job is still not done. These nations are caught up in a numbers game with people and limited funds. The funds are limited because they are paying too many people to do a very poor job.

Political pressures have forced most governments to try to attack a wide range of problems within their country. No doubt this may be necessary politically, but it results in a dissipation of resources and human talents to the extent that very little is achieved in any one field. How much longer can the world afford the luxury of such political decisions?

This brief discussion on the need to train and use our scientists and resources in the most efficient manner highlights the urgency for governments to develop staff development programs in an organized and systematic way, even if this means changing systems, releasing senior people who are retarding factors, etc. The need is so great and the hour so late that these steps must be taken if each nation is to bear up under its responsibility for food production.

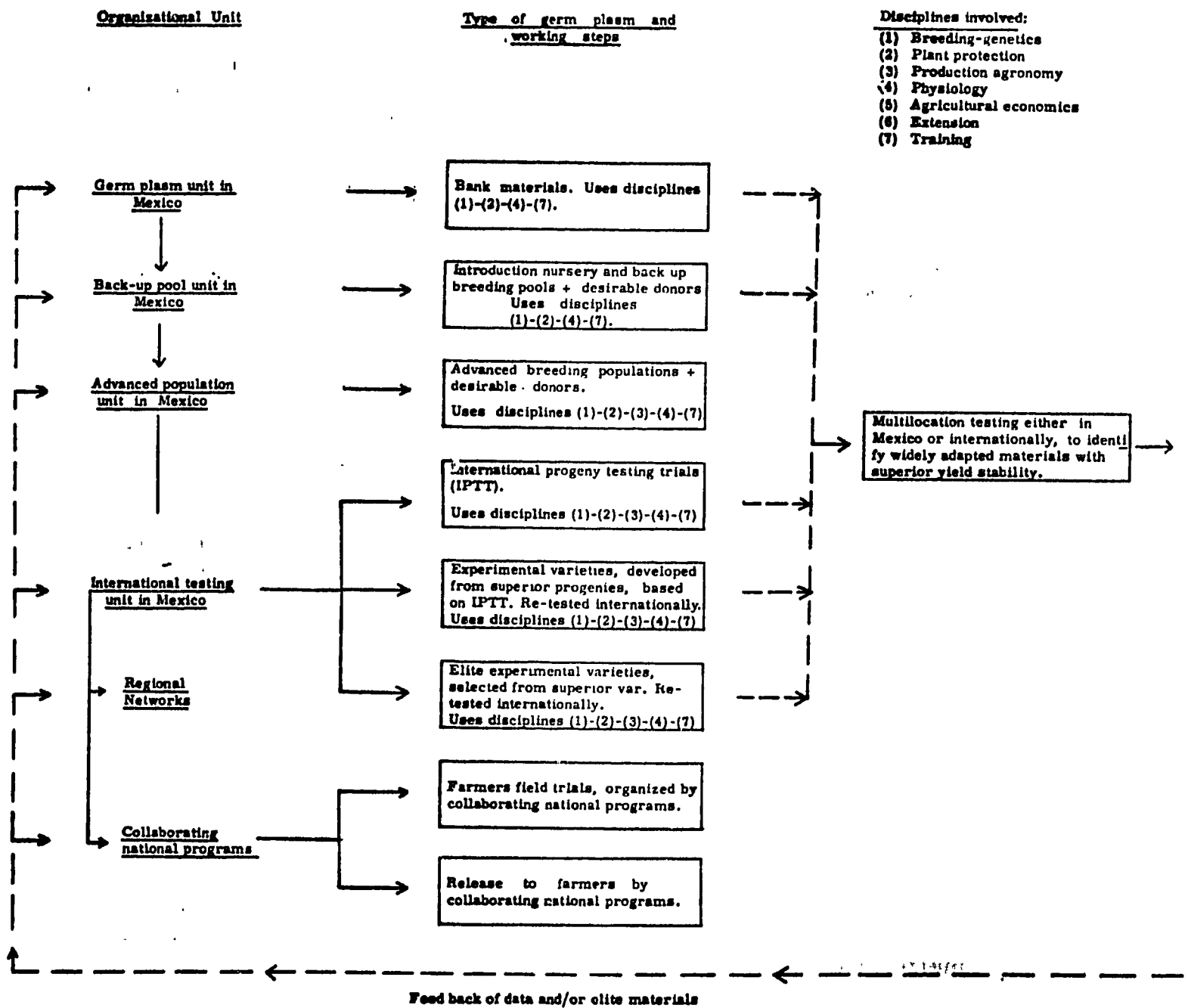
2.5 FUTURE CONSIDERATIONS

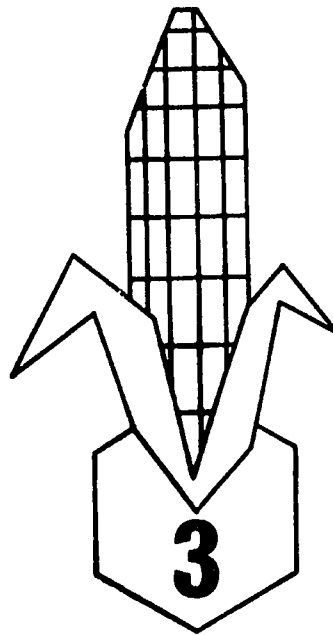
We have spent a considerable amount of time traveling and discussing with individual national programs their problems and how CIMMYT might organize its efforts to be most useful. My discussion of factors limiting production and changes in program strategy required to overcome these restraints, reflects the attitude of most of the maize research and production staff that we have worked with over the last two years.

The strategies and projections that will be discussed are a joint effort of the CIMMYT collaborators and staff--we believe that this has evolved into a system of research and collaboration that can be extremely useful.

The presentations to follow will describe our maize improvement program and how it is geared for boosting world-wide maize production.

Fig. 2-1 Structure and working steps in CIMMYT's maize program in Mexico and in collaborating network of regional and national programs.



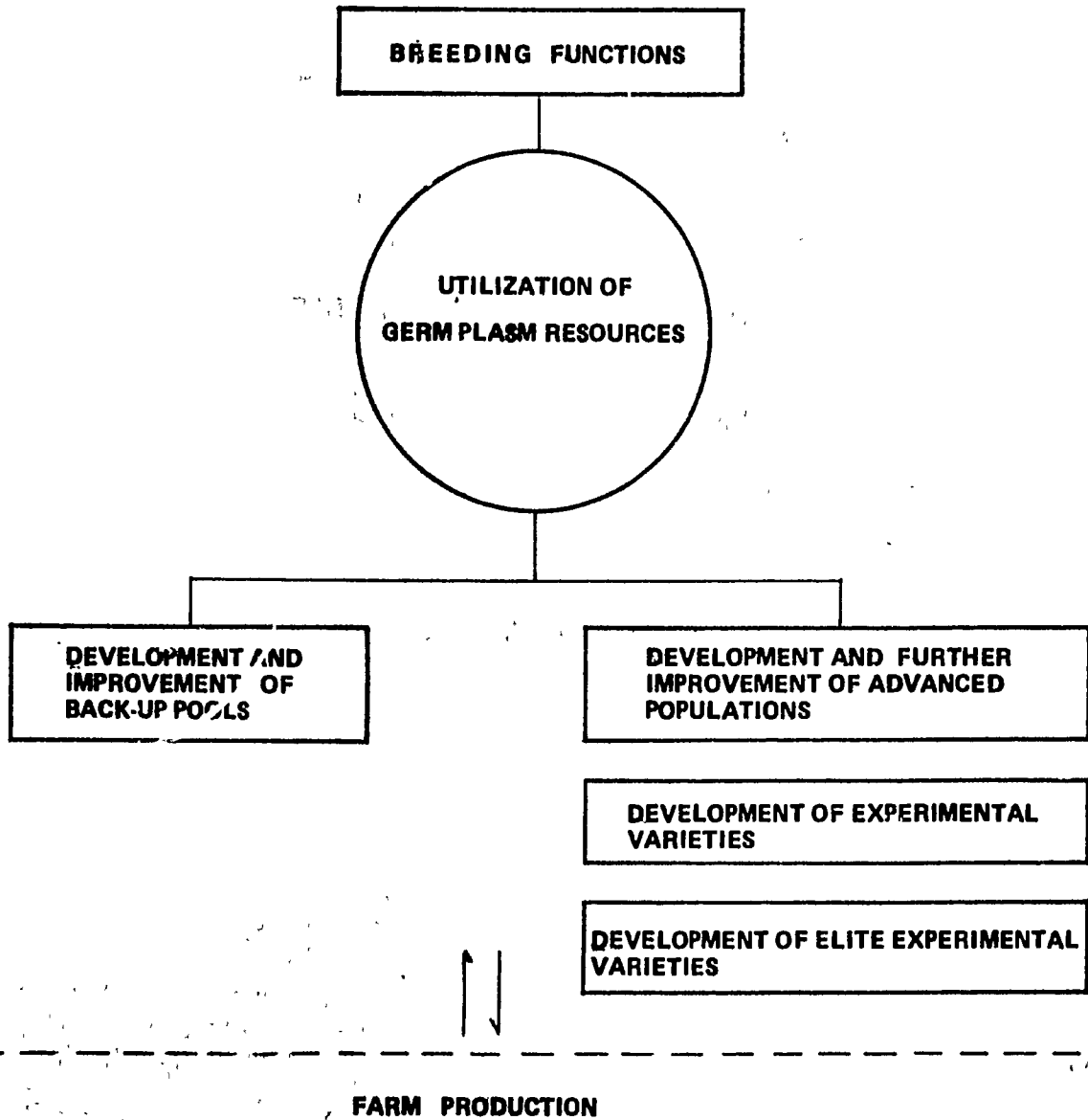


MAIZE IMPROVEMENT

by
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**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



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3.0

MAIZE IMPROVEMENT

by

Elmer Johnson

3.1 INTRODUCTION

The CIMMYT Maize staff works within a framework of interlocking disciplines and procedures that might be called the "Maize Improvement" process. Maize Improvement is viewed as a global concept that spans disciplines from breeding and genetics to training and economics -- all of the topics presented at this Symposium. Thus, the Symposium is organized to show these components in operation, with examples of how their interdependent operations are expected to be used to increase the productivity of the maize species.

As indicated by previous speakers, the maize improvement program attempts to focus on what happens in the producers' fields.

After all, it is in the fields of farmers where the problems of production exist. The solutions to those problems must be utilized in the producers' fields, if improved production is to result. The job of research in maize improvement is to devise practical technological packages of varieties and practices that can be delivered in useful, workable form to the farms where they can be applied. Part of the research job can be done on experiment stations, but results must be verified on the farm to assure their applicability.

3.1.1 MAIZE IMPROVEMENT: BREEDING

Within the overall framework of maize improvement as defined for this symposium, breeding is the component that deals with the development of varieties that are better suited to meeting man's food needs. Maize improvement in the sense used here includes not only the development of better varieties through breeding, but also the appropriate technology for control of pests, diseases, and weeds, the efficient use of fertilizers and the integration of the crop into associations and sequences of crops that make most productive use of the land. Since

efficient production is a basic consideration, it follows that the farmer must incorporate a great deal of interrelated information into his farming practices. Research results must be translated into the simplest, most clear cut terms possible and put within reach of the farmer, if they are to be useful to him.

The implications of this translation into maize production in terms of national maize program organization, training of personnel, economic significance, extension activities, and related topics are covered in other sections of the Symposium. This paper will deal primarily with two essentials related to varietal development: (1) varieties suitable for both the agronomic conditions and the grain utilization requirements encountered in the field, and (2) varieties that can be delivered quickly and easily to producers (Slide 3-1).

3.1.2 OBJECTIVES: BREEDING

A basic breeding objective is to develop materials with broad adaptation--varieties or populations with adequate genetic variability to permit their production under a reasonable range of different environments. They must, however, be sufficiently uniform in plant size, maturity and kernel characteristics to be readily accepted as varieties for production. These varieties should have a minimum of variety-associated constraints to their rapid multiplication and distribution. Final specific selection for use as varieties is considered to be the responsibility of the local and national programs.

Before the programs make their selections, they must take into account many mutually dependent factors. For example, the yield potential or capacity of crop varieties to produce grain as measured in experimental trials is generally much greater than actual production obtained by farmers in most countries. Experimental maize yields in trials on experimental plots are often many times that realized by the farmer, and national maize production figures fall far short of those yields that would be projected on the basis of reported variety yield potentials. What, then, are the restraints that prevent the farmer from obtaining commercial production at levels closer to those reported for experimental yields?

Consideration must be given to such restraints in the developments of improved varieties insofar as the characteristics of the varieties themselves may constitute limitations. Such characteristics can include not only the traits of the variety itself (in terms of management requirements and limitations), but in terms of seed production and distribution requirements, as well. For example, the yield advantage of classical maize hybrids as compared with the open pollinated

populations from which they are derived is well known and documented. But the practical problems of delivering hybrid seed every planting cycle to a large enough segment of the total number of producers in many countries are such that the hybrids make almost no impact on total national production. Thus, the essential aspects of adequate seed production and distribution systems for the hybrid seed becomes a limitation in the utilization of the hybrid and its potential production.

Restated, then, the objectives of the breeding program are as follows (Slide 3-2):

- (1) Development of varieties characterized by:
 - (a) Short plant height
 - (b) Good standability
 - (c) Efficient, high grain yields and high proportion of grain to total dry matter
 - (d) Early maturity
 - (e) Broad adaptation, dependable production over range of varied environments
 - (f) Tolerance to field hazards of insects and diseases
 - (g) High quality protein in grain
- (2) Distribution characteristics
 - (a) Open-pollinated varieties to avoid bottleneck of hybrid seed requirements
 - (b) Sufficiently uniform to be used immediately as varieties
 - (c) Sufficiently variable to allow local selection modifications

3.2 FRAMEWORK FOR CIMMYT'S MAIZE BREEDING

3.2.1 BREEDING WORK AREA

The CIMMYT maize program is visualized in terms of its potential contribution to world grain production. More specific defi-

dition is required to provide a framework for organizing the breeding program. In general terms, the area for which better varieties are sought lies roughly between the latitude boundaries of 30° north and south of the Equator (10.5 to 14.5 hour day fluctuation at 30° Lat.), where effects of day lengths are comparatively unimportant (Table 3-1). A wide range of micro-climates is included within these latitudes, varying in temperature and moisture regimes, as well as in the associated pests and pathogens of the species. Improved varieties must be capable of performing satisfactorily under such conditions. Additionally, utilization requirements must be met in terms of grain type, color, texture, and quality, etc.

In practical terms, specific varieties suitable for each of these many conditions cannot be developed. It follows that the improved materials generated in the breeding program must be capable of performing satisfactorily over a range of environments, or in other words, be broadly adapted. To organize materials in a practical way, arbitrary assignments have been made of the factors involved in the environments combined with the characteristics of the crop. Within the latitudes of 30° north and south of the Equator, a second major classification into highlands and lowlands is considered as dividing the maize crop into two general categories for which varieties must be developed. This division is essentially one of temperature, in which highland types (cool conditions) are those grown under night minimum temperatures (generally below 17 to 18° C), whereas those of lowland types (hot conditions) do best at minimums above this figure (Table 3-1).

Schematically, the basic maize types required can be shown as (Slide 3-3):

<u>Environment</u>		<u>Maturity</u>		<u>Color</u>		<u>Texture</u>		
Highland		Early		White		Flint		
and	X	Medium	X	and	X	and		
Lowland		Late		Yellow		Dent		
	2		X	3	X	2	X	2 = 24 types

To this group should be added at least an early and medium flouly type for highland areas plus two or more for temperate, or higher latitude, conditions. Thus, a total of at least some 27 or more different types must be projected.

3.2.2 STRUCTURE OF BREEDING

The statement of objectives in terms of characters that are

to be modified suggests that present materials are at least partially unsatisfactory. This is accepted as a point of departure. It is further accepted that, of the materials that are available, some are better for one trait, whereas others are superior for other traits. (If any one variety is sufficiently desirable for a series of traits, it should be chosen for immediate use until a superior one is identified or produced.)

Having discussed the general framework for breeding operations, more specific points can be given for structuring the breeding, selection, and distribution mechanisms, including (Slide 3-4):

- (1) Use of broad genetic bases within which to conduct selection as a prerequisite.
- (2) Formation of basic breeding pools is guided by the identified specific attributes that are desired, rather than by racial or other classification.
- (3) Recognition that the inclusion of certain components in the compositing of attributes also results in the dilution of gene frequency of those attributes in admixture with other varieties that do not contain them at similar frequencies, and subsequent selection must be performed to re-establish acceptable frequencies.
- (4) Assumption that most of the agronomic traits are multi-genic (and may be treated as quantitative, probably largely additive gene action).
- (5) Use of large numbers of plants is necessary for adequate selection.
- (6) Assumption that practically any desired recombination imaginable can be achieved of the genes that make up the maize species.
- (7) Use of appropriately diverse environmental testing sites to identify as accurately as possible the superior genotypes which are to be recombined. Adaptation to diverse environmental conditions can be gradually achieved through successive recombinations of superior genotypes identified at each of a series of sites representing the area for which adaptation is sought. The selection process itself may be simultaneous at the series of sites (preferable) or by rotation through different sites.
- (8) Selection and recombination in successive cycles.

- (9) Measurement of progress in selection toward a goal should be in terms of time and effort required, rather than by percent gain attributable to a single cycle of a given procedure.
- (10) Selection of plants based on progeny (Progeny: offspring. Progeny test: evaluation of performance of offspring as measure of breeding value of their parents) performances insofar possible. Selection based on progeny performance requires some form of family (Family: A group of individuals bearing a certain genetic relationship to each other by virtue of common descent) structure arrangement of the population under selection:
- (a) Full-sib (Full sibs: as used here describes a family of individuals having both parents in common; may result from either selfing or from crosses of two individual different plants) continuous recurrent selection is preferred where recombinations are made from remnant seed.
 - (b) Modified ear-to-row (half-sib) (Half sibs: as used here describes a family of individuals having one parent in common, i. e., the progeny from an open pollinated ear.) mass selection may be preferable where actual selected surviving plants produce the seed for the succeeding generation.
 - (c) To provide sufficient seed to enable the desired selection pressures at several simultaneous sites necessitates reciprocal full-sib crosses.
- (11) Choosing of approximately 25 to 50% of the families under test in a given population for intercrossing to derive the subsequent set of families. Individual within family selection is exercised at two levels:
- (a) Best plants at pollination time (three to five plants per family).
 - (b) Only the best of these plants saved at harvest (discarding less desirable plants and families so that approximately the same total number of families are generated and saved each cycle).

Assuming the the eventual improved varieties should contain as many of the desired attributes as possible, the initial breeding stage involves the assembly of these desired attributes into a broadly based

genetic "pool". The definition of such a pool as used in this discussion is essentially that given by Lonnquist (1).

Formation of a germplasm pool should be the compositing of available material collections reasonably well adapted to the area for which improved populations are sought. If endosperm types are an important consideration, only those varieties embodying desired types would be used. The compositing of a number of varieties would result in increasing the genetic variability and assure greater ultimate selection potential. Opportunities for incorporation of exotic germplasm into the pool should not be overlooked. Population improvement is dependent upon the accuracy with which the selected parent plants can be evaluated, the sample size, and selection intensity. It is assumed that adequate genetic variability exists within the population for which improvement is sought. This can be assured through the development of composites comprising a range of diverse materials.

This definition is expanded, however, to include the potential of adding other materials with desirable attributes as they are identified and developed. The pool is thus considered as an open repository to receive new genes over an indefinite period, rather than as a closed breeding unit population.

One such basic pool is contemplated for each of the 27 different types that have been enumerated as being required as a minimum to meet the presently defined needs for different kinds of varieties in the world. Thus, it is expected that the number of pools will remain relatively the same, although new germplasm and selection for an array of characters will modify the pools continually.

These basic pools now vary in stages of development from early formation in some cases to relatively advanced development in others. Unequal emphasis in their development relates partially to the greater importance of certain types as compared with others, and partially to the disparity of progress possible with lowland types with two growing cycles per year as compared to the highland types with only a single growing season.

For purposes of systematic handling of breeding materials, a regular sequence of steps has been established. The initial stages of introduction of materials, evaluation of bank collections, and the formation and development of pools has been assigned the name "Back-up Unit" in the program (Fig. 3-1). This phase of preliminary mixing and selection supports the more refined and advanced materials, which

have been assigned the name "Advance Unit". The Advance Unit contains the populations (For convenience in identification within the program, those materials which are sufficiently developed to be considered as potentials for generating families that can be selected to form varieties for production are being called "populations". This term is applied to those materials in the advance unit under systematic progeny selection, and may be applied to back up materials as they are promoted to this category. In general practice, however, the terms "pools" and populations have tended to be used interchangeably; the definition as used in the program is an arbitrary one for convenience sake.) that are further refined through systematic progeny selection into the experimental varieties, some of which are graduated into the production field.

3.3 BACK-UP GERmplasm UNIT

The backup unit is the source of materials which are to be funneled into the progeny testing procedure of the advanced unit. New materials, either previously unknown or those reported to contain specific desirable traits, are received and evaluated. Germplasm bank collections are evaluated. Advanced unit materials may be combined with each other and with other newly identified attributes, and then evaluated. (Slide 3-6)

Methodology employed in development of the pools will be that deemed most practical for handling the traits under consideration. Mixing Generations of germplasm will be mixed either in mass bulks or in modified ear-to-row mass selection (2). Large populations will be grown in handling quantitative traits, and selection will be conducted either alternately or simultaneously at more than one environmental site. At all stages of development, selection is a staff function involving all disciplines. For the most part, the back-up materials will be grown at CIMMYT stations in Mexico.

3.4 ADVANCED UNIT

The advance unit portion of the breeding program strategy has two very important purposes: (1) The selection of materials under diverse environmental conditions is focused directly toward the development of broadly adapted varieties and (2) The distribution of progeny trials to potential areas that might use these specific materials provides a mechanism for their systematic introduction, or availability, to those areas. The identification of superior families at each of a series of differing environmental site conditions, followed by their systematic recombination over a period of successive cycles, is expected to be effective in making populations more widely adapted. (Slide 3-7)

Three separate phases are involved in the international testing and distribution of materials. Phase one: consists of variety tests to identify which varieties (or populations) are most suitable for a given location. Phase two: after the above identification, progeny trials of the indicated materials are undertaken. Phase three: Selected superior progenies are then recombined as judgment indicates to provide the experimental varieties. These are decided in conjunction with the local program that would use the variety for production.

To provide a standardized operational procedure, the Advance Unit materials are arbitrarily handled in progeny sets of approximately 250 each. Thus, progeny trials are conducted in 16 x 16 lattice design trials and with the practical limitation of two replications at each of six different environmental sites. The six sites are chosen with one at a CIMMYT station in Mexico and each of the other five in a different country. The intent is to conduct the progeny trials of a given population simultaneously in six different countries.

At the CIMMYT site in Mexico, two replications will be devoted to yield comparisons, and one replication each to disease nursery, insect nursery, and agronomy high density plantings. When possible, all the materials will be artificially inoculated with leaf diseases, stalk rots, and ear rots--as well as infested with insects. Thus, the related supporting disciplines are involved in the routine of developing the improved populations as an integral part of the program.

In order to conduct progeny trials of this type, adequate seed must be provided. To do so, the progenies are generated by means of reciprocal hand pollinations of selected individual plants. From 25 to 50% of the families in progeny trial are selected, and the pollinations are made among families chosen in this way (replanted with remnant seed from the previous cycle). Several plants in each family are thus individually crossed to other plants in other families (each with a different family). Seed from these pollinations is divided as follows:

- (1) 100-seed reserve (for emergencies and to combine into experimental varieties)
- (2) 25 seeds for next nursery planting
- (3) 25 seeds for disease nursery
- (4) 25 seeds for insect nursery
- (5) 35 seeds for high density planting
- (6) Remainder of seed for yield trials at up to six different sites in different countries.

Advanced materials have been assigned population numbers 21 through 48 inclusive. (Numbers 1 through 20 are reserved for experimental variety trials, bank entry evaluations, etc.). At least in the beginning, progenies will be generated in Mexico during the winter (December-April) period and grown in progeny trials during the summer season, so that one cycle of selection is completed each year. (Very likely a small number of materials will be handled in alternate seasons of the year to provide the same service to locations on the other side of the Equator.) (Slide 3-8)

A few rows of an opaque counterpart is planted adjacent to each advance population. This is back-crossed to the parent population during the progeny generating cycle. These crosses are sib-mated during the progeny trial period in the summer, and the opaque-2 segregate kernels again planted adjacent to the recurrent parent for the next back-cross. In this way, each advanced population is simultaneously converted to its opaque-2 equivalent.

In 1973, 34 progeny lattice sets of 16 x 16 were sent to one or more locations in countries other than Mexico. The number of sites varied from one to six for each of these materials. Data available was used to select the families for intercrossing to produce the progenies to be used in 1974 plantings at the several international sites.

Thus, the advanced unit materials are not only those that are relatively most uniform and homogeneous in characteristics (so that they are suitable for immediate increase as varieties); they are also systematically distributed to several countries simultaneously so that they are widely and continuously available to national programs.

The progeny and varietal testings are conducted in conjunction with regional and national programs as cooperating sites. Such programs thus get a detailed look at each set of progenies and have available a series of alternatives for utilization of the germplasm represented. Reserve seed is maintained in order to permit the following options:

Option One is that the total array of families representing a population gives a broad picture of that population and its relative suitability for the site--or a direct utilization simply by bulking the families and multiplying as a variety.

Option Two is that of choosing a few of the outstanding families from the population with which to constitute an experimental variety, obtain reserve seed, and multiply this as a variety. An example of this in operation is shown in Annex 2.

(In those cases where the material is found suitable for possible commercial use, experimental varieties are extracted from a population. Potentially an experimental variety might be derived from the ten best progenies as evaluated at each of the test locations, plus an additional one based on mean performance of progenies over all the test sites. Such a procedure has a potential of seven experimental varieties from a given population grown at six test sites. The first generation of experimental varieties derived in this manner is now being increased.)

Option Three is that if one or more families are sufficiently outstanding to be considered as possible hybrids for use, they can immediately be developed from reserve seed of parental families.

Option Four is found in those cases where more than one population is grown and superior families from each can be identified and used as hybrids per se, combined with families from other populations into experimental varieties or checked as possibilities for hybrids of families across populations.

Option Five is that one or more of local program materials can be added to the set of potential combinations as variety crosses, selected family based composites, or hybrid combinations.

An additional level of evaluation of materials is contemplated in further tests of the experimental varieties. As the experimental varieties are developed, they in turn are organized into variety trials that will be grown over a much larger range of sites than at present. These are projected for about 25 sites with four row plots and four replications. Such testing allows an opportunity for more precise comparisons of experimental varieties themselves, and also provides a means for the identification of the most suitable materials for individual sites. Based on such varietal evaluations, a given site might select a different material than that which was originally used in progeny testing; whereas other sites, without progeny trials, could choose the materials to be established as progeny trials from the varietal trials.

Finally, the elite experimental varieties can be identified, both for use as commercial varieties at specific sites and for further study in relation to dependability of production over ranges of varied environments. As quickly as elite experimental varieties are determined, on-farm trials should follow to verify the suitability for production. (Slide 3-9)

Any test site with the technical resources to generate progeny can fit those progeny into the procedure. Programs without the technical capacity to do their own breeding work can still grow the progeny sets that are developed elsewhere, and thus have available materials under selection that otherwise would not be obtainable. The station generating progenies (CIMMYT, in most cases) should visit the progeny trials in progress to maintain continuous monitoring of the materials and evaluate the validity of the trials. In the course of such regular visits, the suitability of materials can gradually be documented and new and desirable materials identified and channeled back into the base breeding program. This systematic two-way flow of materials should provide continuous testing and improvement of materials, as well as their immediate availability for cooperating maize programs wherever they may be located.

3.5 SOME CONSIDERATIONS FOR THE FUTURE

Remaining for conjecture and clarification are at least three major areas of concern. These can be listed briefly, but could be discussed at great length. They are:

1. The architecture, size and grain-to-dry matter ratio found in tropical maize varieties.
2. Disease problems such as streak virus, downy mildew and others that are certain to be encountered.
3. The implications of restrictions on seed movement among scientists cooperating in breeding programs.

There are other problems related to many other restrictions, such as marketing, fertilizer supplies and various political problems, but the three points enumerated merit special attention from the breeding stand point.

Rather than trying to make shorter and more manageable varieties from the undesirable tropical maize types, why not use such more efficient plant types as are available in the temperate regions? The "Corn Belt" maize is the prime example. For an immediate answer, anyone who has grown them can verify their susceptibility to the insects and diseases of the tropics. They are usually killed outright, or nearly so.

For a longer range answer, an attempt is under way to introduce enough tropical germplasm into the temperate materials to enable them to survive. The thought is that gradually a germplasm complex can be built up with a different size and architecture (as well as physiology) of plant. Preliminary results are encouraging.

Downy mildew has been a serious problem for years in Southeast Asia, and appears to be spreading in the area; reports from Argentina, Central America, the United States, and Africa suggest potential losses of huge magnitude can occur in the countries unless resistant materials are developed. Streak virus has long been a damaging disease in Africa, and though it requires the appropriate coincidence of inoculum source, vector, and susceptible material, it can be very effective in ruining plantings. At the very least, it severely limits times when maize can be planted in many areas.

In the case of both downy mildew and streak virus, it appears that reasonable genetic resistance has been identified. In both cases, it is suggested that improved levels of resistance be sought and that resistance to both be incorporated into varieties as quickly as practicable. To do this will require cooperation of testing sites in the selection of materials, and these sites of necessity should be in the areas where the diseases now occur. Ready interchange of materials among cooperating scientists is most desirable.

And this brings up the third major concern. To the extent that restrictive barriers to the rapid interchange of seeds are imposed in the form of quarantines and other prohibitions or delays; to that extent the breeding programs will be hampered. Certainly, there is no argument against realistic attempts to prevent the unnecessary spread of pests and pathogens. On the other hand, it is hard to conceive that carefully treated, selected seeds in the hands of competent scientists can be considered as major threats when compared to the benefits accruing from them in the form of improved varieties. In many cases, the whole side of the house is left open to massive movements of commercial grains with little thought as to the spores they may carry, while the mail box is barred to registered letters carrying experimental seeds.

REFERENCES

- (1) LONNQUIST, J. H. Genetic variability in maize and indicated procedure for its maximum utilization. *Ciencia E Cultura*. V. 19. No. 1. 1967.
- (2) _____ . A modification of the ear-to-row procedure for the improvement of maize populations. *Crop Sci.* 4:227-228. 1964.

TABLE

<u>Table</u>	<u>Title</u>
3-1	Rough estimates considered in classifying maize germplasm

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>
3-1	CIMMYT's backup germplasm unit
3-2	CIMMYT's advanced germplasm unit
3-3	Scheme for making parallel improvement in opaque-2 and "normal" <u>advanced population undergoing full-sib family section</u>

SLIDES

<u>Slide</u>	<u>Title</u>
3-1	Maize breeding--Visualized in terms of contribution to world grain production
3-2	Objectives
3-3	Basic maize types
3-4	A basic food factory system
3-5	Breeding
3-6	Back-up Unit
3-7	Advance Unit seed requirements
3-8	Advance Unit time schedule
3-9	Experimental varieties

Table 3-1.

Rough estimates considered in classifying maize germplasm

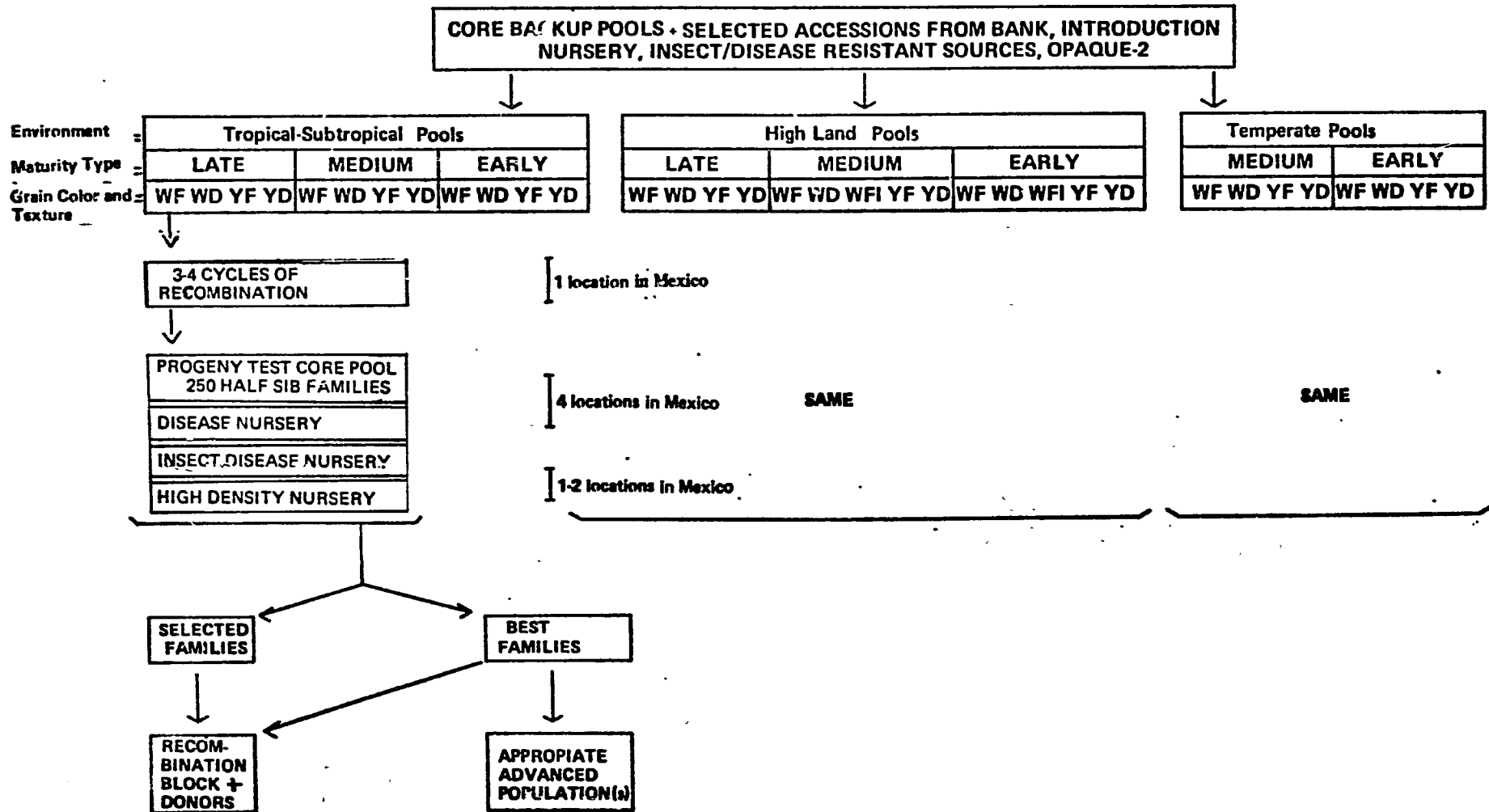
CLIMATE	MATURITY		RANGE
	Early	Medium	Late
Tropical - Subtropical			
Altitude (meters above sea level)	0-1600	0-1600	0-1600
Latitude	30° N-S	30° N-S	30° N-S
Temperature (Mean of growing season)	25° - 28° C	25° -28° C	25° -28° C
Days to silking (main season)	< 50	> 50 < 60	> 60
Duration of crop growth (in days)	< 100	> 100 < 120	< 140
High Land			
Altitude (meters above sea level)	1600+	1600+	1600
Latitude	30° N-S	30° N-S	30° N-S
Temperature (Mean of growing season)	15° - 17° C	15° -17° C	15° - 17° C
Days to silking	< 70	> 70 < 95	> 95 < 120
Duration of crop growth (in days)	< 130	< 190	< 240
Temperate			
Altitude (meters above sea level)	0-1600	0-1600	0-1600
Latitude	30° -40°N-S	30° -40°N-S	30° - 40° N-S
Temperature (Mean of growing season)	20° -22° C	20° -22° C	20° - 22° C
Days to silking	< 60	> 60 < 75	> 75
Duration of crop growth (in days)	< 120	> 120 < 150	> 150

< = Less than

<math>\leq</math> = Up to

> = More than

Fig. 3-1. CIMMYT'S BACKUP GERmplasm UNIT



WF= White Flint
 WD= White Dent
 YF= Yellow Flint
 YD= Yellow Dent
 WF= White Floury.

Fig. 3-2. CIMMYT'S ADVANCED GERMLASM UNIT

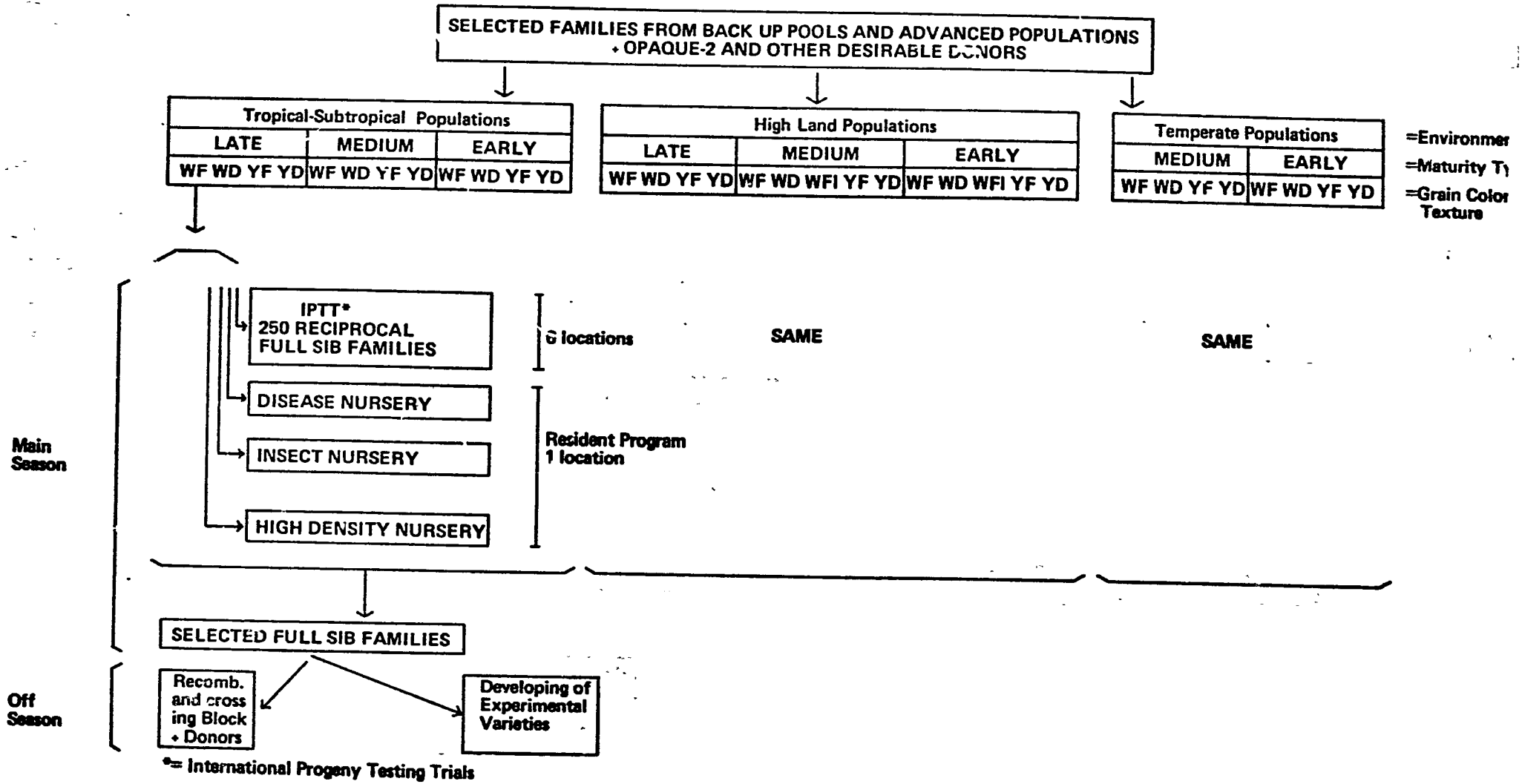
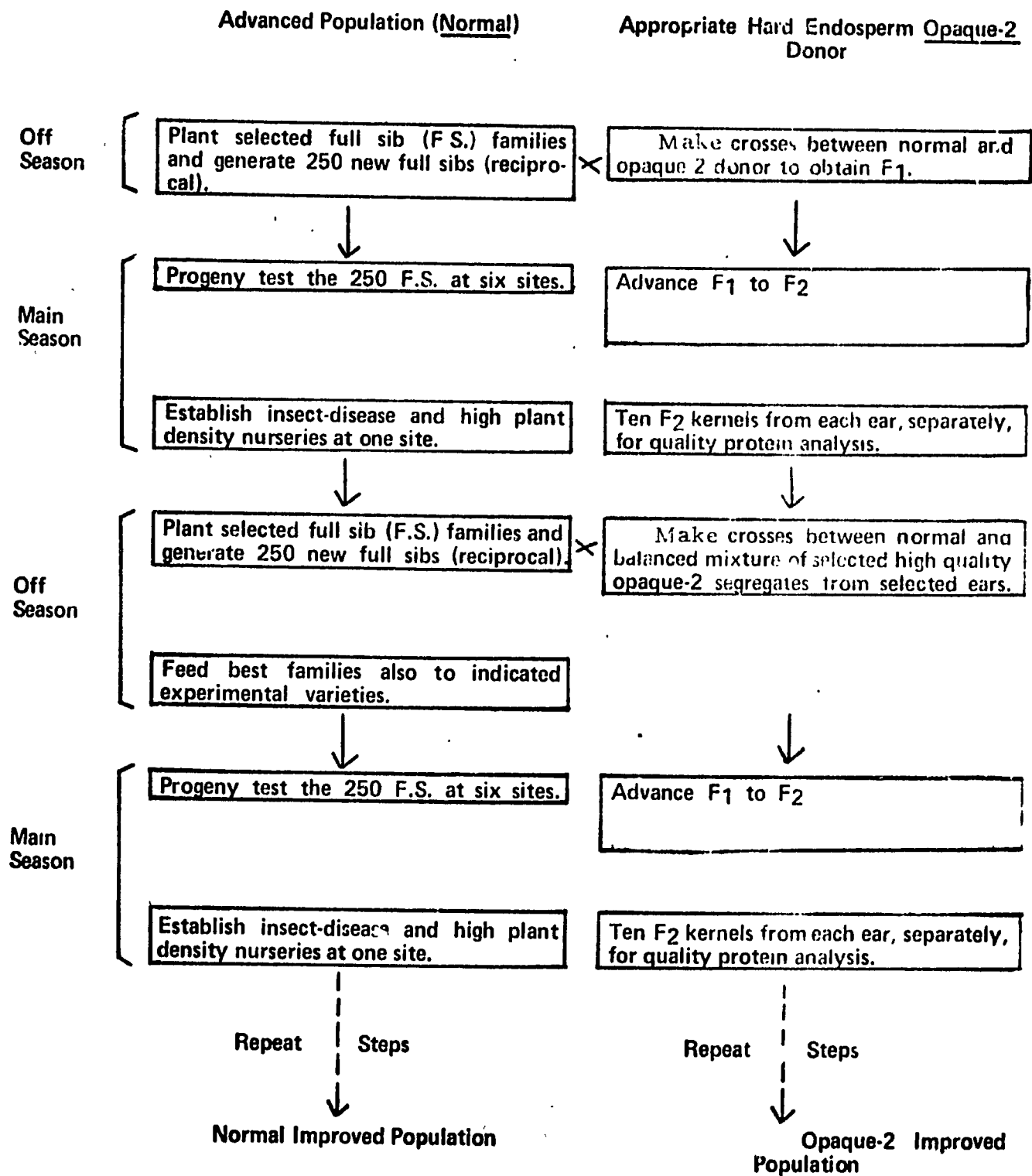


Fig. 3-3 Scheme for Making Parallel Improvement in Opaque-2 and "Normal" Advanced Population Undergoing Full Sib Family Section.



Slide 3-1.

MAIZE BREEDING

Visualized in terms of Contribution

to

World Grain Production

- 1. Must develop more suitable varieties for agronomic and consumption conditions**
- 2. Must fit into practicable procedures for making varieties available to producers**

Slide 3-2.

OBJECTIVES

A. Plant characteristics of variety

1. Short plant height
2. Good standability
3. Efficient - high grain yields and high proportion of grain to total dry matter
4. Early maturity
5. Broad adaptation - dependable production over range of varied environments
6. Tolerance to field hazards of insects and diseases
7. High quality protein in grain

B. Distribution characteristics

1. Open-pollinated varieties to avoid bottleneck of hybrid seed requirements
2. Sufficiently uniform to be used immediately as varieties
3. Sufficiently variable to allow local selection modifications

Slide 3-3.

<u>Temperature</u>		<u>Maturity</u>		<u>Color</u>		<u>Texture</u>	<u>Total*</u>
Highland vs. Lowland		Early Intermediate Late		White vs. Yellow		Flint vs. Dent	
2	X	3	X	2	X	2	= 24 Types
* Early Floury and Intermediate Floury Highland							= 2
Temperate (or more)							= 1
							<hr/>
							27 Types
							<hr/> <hr/>

Slide 3-4.

A Basic Food Factory System

Germplasm Resources → Breeding ^{/1} → Farm Production

1. Present varieties

1. Evaluations

1. Farm Trials

2. Bank collections

2. Selections

2. Production

3. Genetic stocks
(mutants)

3. Combinations

4. Mixing

4. New traits

5. Recombination

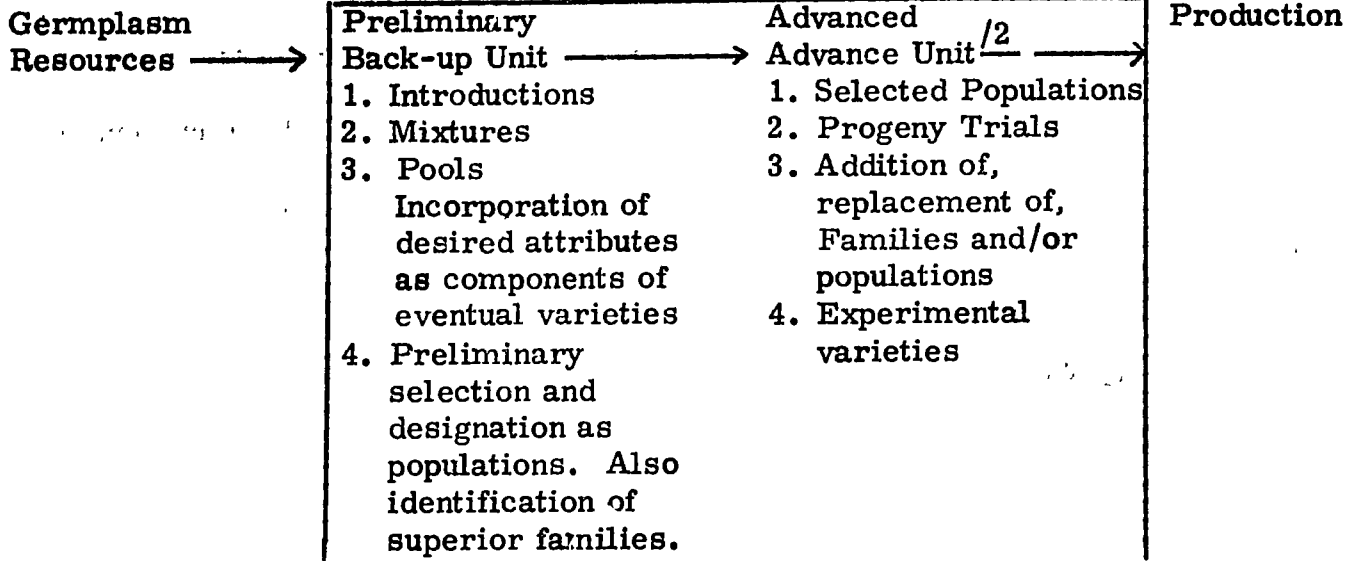
5. Related species

6. Continuing
Selection

/1 For further detail

Slide 3-5.

/1 Breeding



/1 /2 For further detail

Slide 3-6.

Back-up Unit

Components of Pool:

1. Disease Res.
2. Insect Res.
3. Yield
4. Texture
5. Color
6. Maturity
7. Etc.

Develop to Population:

1. Crossing
2. Mixing
3. Recombination
4. Selection
5. Yield Trials
- a) Poza Rica
- b) Tlaltizapan
- c) Obregon
- d) Batan
- e) Toluca

Advance Unit:

Selected populations or families move to indicated Advance Unit Material (Variety)

Slide 3-7.

Advance Unit Seed Requirements

1.	5 locations outside of Mexico:		
	2 reps. x 33 seed x 5	= 330	seed
2.	Yield Trial CIMMYT 2 x 33	= 50	"
3.	Insect Trial	= 25	"
4.	Disease Trial	= 25	"
5.	Agronomy Trial	= 35	"
6.	Subsequent Nursery	= 25	"
7.	Reserve (Emergency + Expt. Var.)	= 100	"
	Total	590	"

Slide 3-8.

Advance Unit Time Schedule

(Selection)

Center

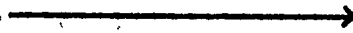
Other Countries

Planting Nov. -Dec.

Different
environments

Harvest Mar. Apr.

Shipment April



Planting May-June

Harvest Sept. -Oct.

Planting Nov. Dec.



Data Nov. -Dec.

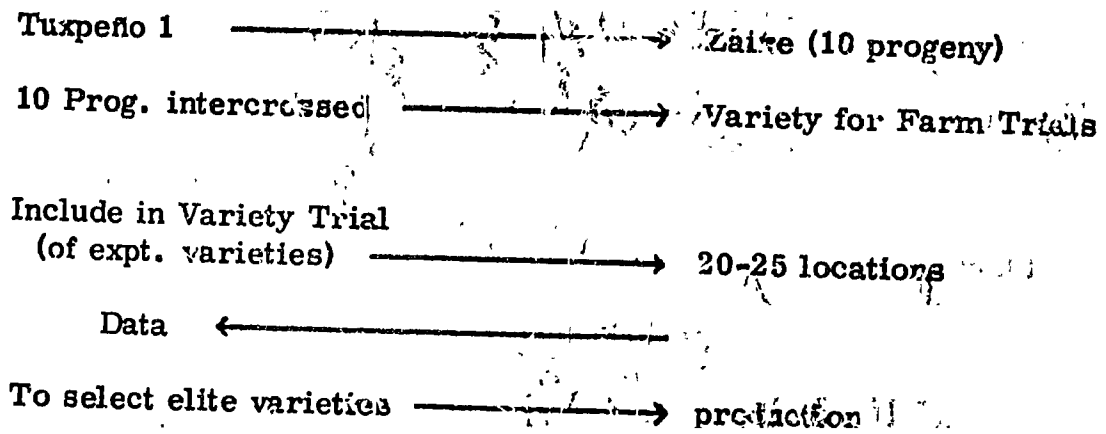
Pollinations Feb. (intercross only selected progenies)

Continuous process so long as indicated of recombination of
selected genotypes.

Slide 3-9.

Experimental Varieties

Center



ANNEX 3-1

In order to give a general perspective of how improved varieties can be developed and fed into national production programs, an example is provided in Annex 1. This letter, in essence, sums up the operation of the system. The ten superior progenies in a set under selection were identified in the area where the improved variety is to be grown. Reserve seed of those same progenies is then recombined to form an open pollinated variety for further trials on farms in the area and for distribution. A systematic interchange, evaluation and recombination of maize germplasm can provide a continuous flow of materials to cooperating programs, as exemplified by the letter (Annex 3-1) from Zaire.

PROGRAMME NATIONAL MAIS
MINISTERE DE L'AGRICULTURE

B. P. 3673 — Station de Kisanga — LUBUMBASHI, Rép. du Zaïre

N./Ref.: 041/74

V./Ref.:

Lubumbashi, le 20 February

19 74

Dr. S.K. Vasal
CIMMYT
Apdo-Postal 6-641
Mexico 6, D.F.
MEXICO.

cc: - Dr. E.W. Sprague

- Dr. E.C. Johnson -

Dear Dr. Vasal,

At Gandajika, Zaïre, we tested 234 families of Tuxpeno planta baja C 11, origin PR 73 A, 20 ~~#~~. The material proved to be excellent. The progenies yielded up to ten and eleven tons per ha, which is much more than even the local hybrid produces. Moreover, the Tuxpeno material was the only material which did not lodge after one heavy rain storm.

It was decided to use the ten best progenies immediately as a variety for the area. To have seed available already by September 1974, we will use the open-pollinated ears harvested from the best progenies and multiply these under irrigation.

For September 1975 we would like to have a variety based on the remnant seed of the best progenies. I suppose that the progenies could be recombined at CIMMYT. We would like to receive the recombined seed for multiplication in Zaïre not later than November 1974, if possible earlier.

As soon as possible we hope to send the data sheets of the trials, conducted at Gandajika, to Mexico for analysis.

Attached, please find the list of selected Tuxpeno progenies. They are: 4, 79, 11, 93, 130, 174, 180, 196, 214, 221

With best regards,


Frans de Wolff

ES-PDW/VVD.-

ANNEX 3-2

Considering the problems of management of the typical tropical maize varieties, we arbitrarily decided to put high priority on developing a range of materials with substantially reduced plant height as the first phase of effort in the breeding program. In attempting to develop shorter plants, three different approaches were employed:

- (1) Use of genetic dwarfs (major genes such as Br1, Br 2, Br 3, Pigmy, Tassel ear, Dwarf 1 short, Dwarf 1 tall, etc. for conversion to shorter types
- (2) Employment of available short materials (which generally also were very early maturity and low yielding) to cross with taller productive types in hopes of recovering short plants with good yield
- (3) Recurrent selection within tall materials to gradually reduce plant height over an extended period of selection. This assumed the existence of great genetic variability for the trait in the form of multigenic (quantitative) systems.

All three approaches provided shorter plants, but were associated with different kinds of problems. In general, the genetic dwarfs also produce undesirable side effects, such as excessive leaf width, erratic height, uneven development and a tendency to delay maturity. In the case of the crosses of short with tall types, the resulting progenies tended to be intermediate in most characters, including yield.

At this point, it appears that the recurrent selection within tall materials has resulted in the development of the most satisfactory plant types. A broad range of such reduced height germplasm has now been developed, one population of which is presented for more detailed comparison in Tables A-1, A-2 and A-3. Table A-1 lists the performance of four such materials that have undergone selection for shorter plants. As can be seen in the table, height of both plant and ear was drastically reduced, maturity became somewhat earlier, lodging was reduced and yield was obviously maintained. In fact, yield appears to have been improved, although this may be, at least in part, a reflection of reduced losses, rather than improved productive capacity.

In table A-2, the Tuxpeño selection (in 7th cycle of selection) was compared in performance in El Salvador with the original tall variety,

a brachytic 2 dwarf conversion of the same and a local check. Again the short plant selection (planta baja) appears to be superior. Further confirmation is provided in data from farm field trials conducted in the Veracruz, Mexico, coastal area near Poza Rica, in 1973. Table A-3 shows the results of these farm trials, so far as yields are concerned. The short plant Tuxpeño selection (Tuxpeño 1) was the highest yielding at 75,000 plants per hectare and still in second place at 50,000 plants per hectare. The commercial hybrid recommended at present for the area is H-507.

Following the development of shorter materials, an effort was made to improve their yield. Table A-4 gives the results of two cycles of selection in three different populations, of which one is a brachytic 2 dwarf. Apparently, the same procedure utilized for shortening plant stature can be employed to subsequently improve yield in such populations.

The Tuxpeño 1 material (previously called "planta baja" selection) has thus been tested in a series of treatments on experiment station trials in Mexico and El Salvador and in on-farm trials in Mexico. It is the same one selected for immediate use in Zaire as a variety for increase there. The evidence suggests that the overall strategy is successful in developing improved materials.

The data on which the experimental varieties are derived is shown for the 10 selected progenies in each of a white and a yellow population to complete the process of development of materials which has been outlined. From here we need to develop information on stability of performance, which is the most satisfactory way of constituting experimental varieties, etc. No final decision has yet been made on what the eventual choice will be.

Table A-1. Short Plant Selections vs. Original (1972)

<u>Material</u>		<u>H e i g h t</u>		<u>Flower</u>	<u>Lodging</u>	<u>Kg. /Ha. Yield*</u>
		<u>Pl.</u>	<u>Ear</u>			
Tuxpeño	C0	277	175	69	3.2	3739
Tuxpeño	C10	212	112	64	1.6	4284
E T O	C0	244	136	67	2.3	3003
E T O	C9	212	99	63	1.4	3308
(Mix. 1-Col. 1) ETO	C0	267	157	67	2.4	3317
(Mix. 1-Col. 1) ETO	C7	213	102	63	1.8	3969
Mezcla Am.	C0	239	130	64	2.4	3613
Mezcla Am.	C5	219	116	62	1.4	3858

* \bar{X} of 3 locations, 4 reps. /loc.

Table A-2. Performance of four maize varieties at four planting densities as shown by grain yields per plot at 15% moisture. San Andrés, El Salvador, C.A. 1972. /1

Densities*	V a r i e t i e s				\bar{X} of Densities
	Tuxp. or. /2	Tuxp. P.B. /3	Tuxp. br2 /4	Taverón	
40,000	3.99	3.79	2.48	2.59	3.21
65,000	4.55	4.77	2.87	3.08	3.82
90,000	4.28	4.57	3.65	3.29	3.94
115,000	5.06	5.13	3.94	3.43	4.39
\bar{X} of Varieties	4.47	4.57	3.23	3.10	3.84

_____ Comparison 5% level.

----- Comparison 1% level.

* Plants per hectare.

/1 Courtesy of Ing. Roberto Vega Lara, Ministry of Agriculture, E.S.

/2 Original tall Tuxpeño variety.

/3 Tuxpeño Planta Baja (short plant selection, seventh cycle of selection).

/4 Tuxp. br2 - bachytic 2 genetic conversion.

/5 Taveron - local variety.

TABLE A-3. On-farm trials held in kg/ha. of grain 15% moisture at four sites in Veracruz 1973B.

Varieties	La Colmena	Rfo Claro	La Isla	Castillo de Teayo	\bar{X}
Tuxpeño 1 (75000 pl/ha)	5290	2656	5701	4285	4482
Tuxpeño 1 (50000 pl/ha)	4338	3172	5587	3463	4152
T 27	3799	2383	5874	3793	3962
Tuxpeño 1 x La Posta o ₂	3965	3142	4265	4171	3885
TC 17	3841	2542	4059	3973	3603
White hard endosperm	3199	1865	4118	4410	3398
H 507	3386	1919	4563	3334	3300
Criollo	----	----	3588	2552	3070
\bar{X} Localities	3981	2526	4719	3747	
LSD 5%	NS	NS	1622	NS	
C. V.	25	24	14	32	

Table A-4

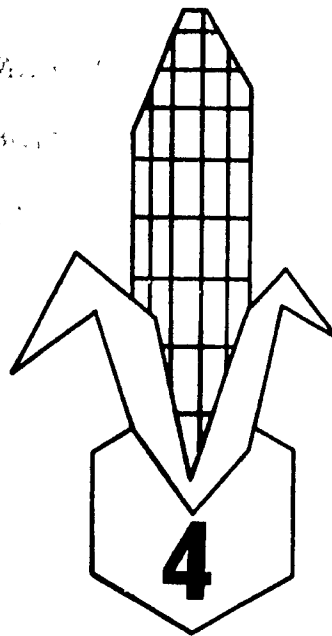
Preliminary Results of Recurrent Full-Sib Selection for
Grain Yield in Three Populations. 1973.

Variety		Days Silk	Height		Ear Rot	Kg/Ha
			Plant	Ear		
SPB	C0	92	252	154	10	3771
	C1	91	225	132	4	4947
	C2	91	219	132	6	5143
CRIS	C0	95	264	164	6	3504
	C1	92	252	148	4	4078
	C2	92	262	153	3	4698
Br 2	C0	94	160	80	14	3269
	C1	94	165	88	10	3651
	C2	93	165	85	7	4224

Table A-5.

Expt. Var.: Selection of 10 Best Families

	<u>Tlalt.</u>	<u>Hond.</u>	<u>P. Rica</u>	<u>Obreg.</u>	<u>\bar{X}</u>	<u>Family Total</u>
White	11,396	4,625	5,791	4,600	5,756	37
Yellow	11,127	6,322	5,185	4,539	6,297	31
	From 256 total families: possible diff.					50
Exp. Var.	1	2	3	4	5	



4.0

MAIZE GERMPLASM

by
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AND UTILIZATION**

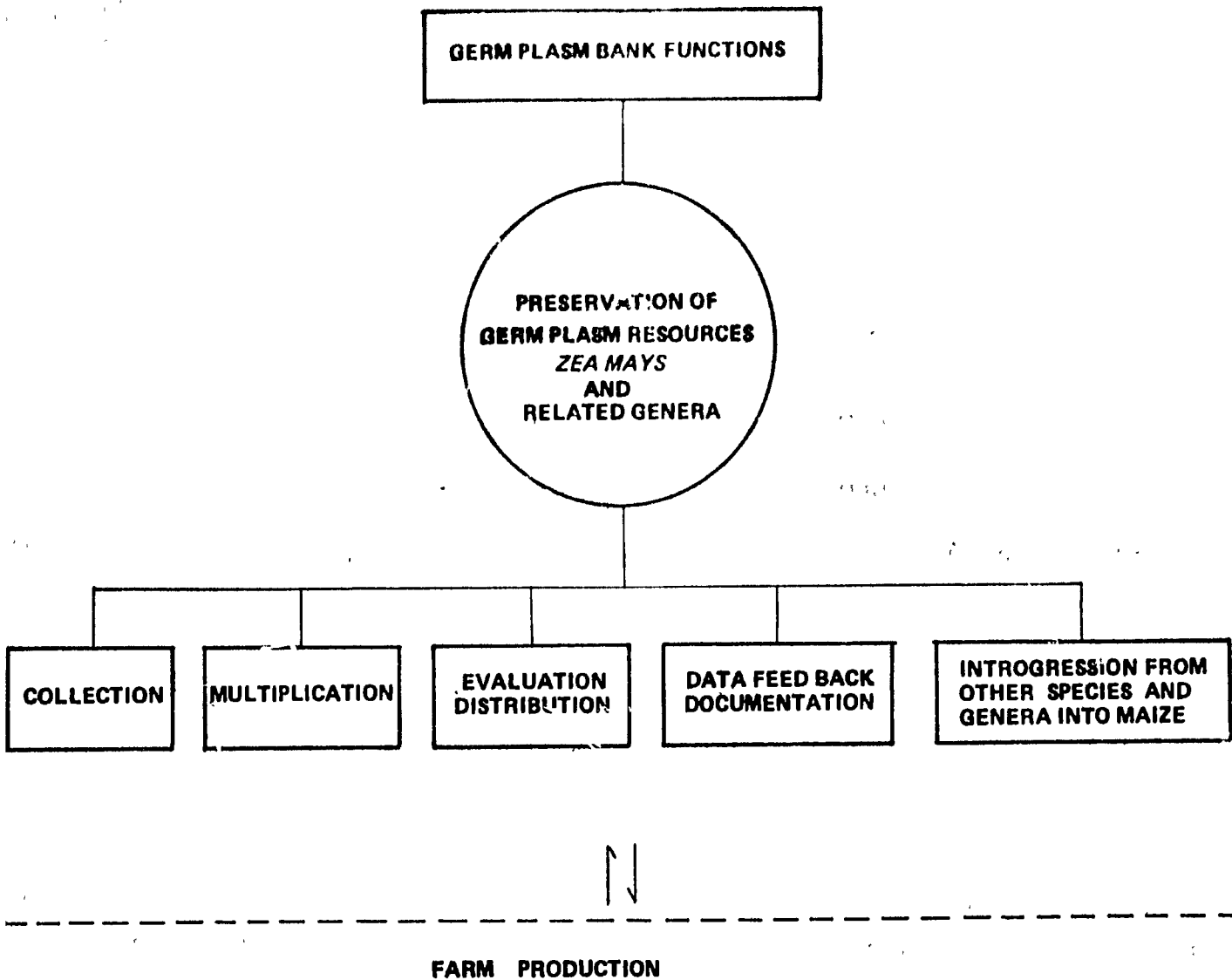
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4.0

**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



4.0

MAIZE GERMPLASM PRESERVATION AND UTILIZATION AT CIMMYT

by

Mario Gutiérrez G.

4.1 INTRODUCTION

The interrelated problems of an exploding world population and dwindling food supplies have been well documented in this Symposium. Brief mention has been made of some of the associated issues, also, including the vulnerability of food crops, the erosion of plant genetic resources, and the need to preserve them now. This presentation focuses on CIMMYT's work in maize germplasm preservation and use. After a brief discussion of purpose and need for the germplasm preservation program, a listing is provided of the current inventory and services performed by the Bank. Subsequent sections outline the Bank's origins and its maintenance program, and some projections for developments over the next six years. A final section discusses CIMMYT's recently initiated work in maize-Tripsacum crosses.

4.1.1 PURPOSE

CIMMYT's maize germplasm bank seeks to preserve some of the existing variability in the species Zea mays L. and related genera. It is essentially a service activity dispensing seeds and information not only to CIMMYT's own maize program, but to breeders and research workers all over the world.

Its functions involve (1) collecting and storing adequate supplies of seed under conditions favorable for maintaining viability; (2) the renewal of seedstocks; (3) the documentation of accessions and their evaluation for potential use in breeding; (4) the preparation of catalogs; (5) the utilization of systems for rapid and efficient information retrieval; (6) the distribution of seeds and information to interested

breeders and research workers; (7) the addition of new accessions to augment the collection and increase its usefulness; and (8) the incorporation into maize of useful traits available in related genera.

4.1.2 NEED FOR BANK

Improved cultivars developed by plant breeders are an essential component of modern agriculture and have played a key role in boosting yield levels throughout the world. In the United States, for example, Sprague (17) reports that maize producers achieved almost universal adoption of hybrid seed by 1956. His calculations, using five-year moving averages to minimize the effects of weather and governmental control policies for the period 1930-1960, show that maize production increased 70%, whereas maize acreage decreased by 30%. Sorghum and sugar beet production reflect similar achievements.

The development of improved cultivars has been accompanied by undesirable effects, also, including the narrowing of the genetic base for the crops grown, which has been intensified by an undue emphasis on crop uniformity both in breeding and in crop husbandry. Pure lines are used as cultivars for self-pollinated crops, whereas cross-pollinating crops such as maize use single, three-way, and double-crosses. In recent years, world wheat production has climbed rapidly, with near continent-wide plantings of a few related, but highly successful, varieties of wheat.

The narrow genetic base and widespread cultivation of a few genotypes has greatly favored the selection and rapid multiplication of disease biotypes to which they are susceptible. Examples of the selection process abound in the literature and only two will be mentioned here: involving (1) a self-pollinated crop and (2) a cross-pollinator.

Self-pollinated Crop: Eighty per cent of the total acreage of oats planted in the U.S.A. in 1945 was grown with derivatives of the variety **Victoria**, whose genotype combined the **Pe-2** gene for resistance to **crown rust** and the closely linked gene for susceptibility to **Helminthosporium victoriarum** (Jochim & Murphy). A severe epiphytotic caused by this pathogen that year produced losses of millions of dollars and forced a shift to Bond derivatives.

Cross-pollinated Crop: A more recent case, which also exemplifies the inherent dangers of uniform plasmatypes is provided by the 1970 outbreak of race T of **Helminthosporium maydis** Nisikado & Miyake in the United States. Maize cultivars with Texas male sterile cytoplasm were grown that year on 46 million acres, or 80% of the total maize acreage--over one trillion plants (4) with a single plasmatype. An

epiphytotic caused by the race T of H. maydis decreased maize production by 15% on a national scale, with heavier losses in the southern states.

Harlan (9) has aptly used the term "genetics of disaster" to refer to the breeding of narrow genetic base cultivars and their planting over vast areas, with the concomitant displacement and loss of gene pools represented by land races, and weedy and wild relatives of the cultivated plants. Land races of a cultivated crop are a product of plant domestication, a lengthy process of natural selection and artificial selection by man. They are characterized by genetic variability and a dynamic equilibrium with their environment, including parasites; thus, they are an invaluable resource for breeding the plants to meet the demands of a growing world population. Unfortunately, cultivation of land races is rapidly falling off due to replacement with improved cultivars of high yield potential but narrow genetic base heavy population pressures, substitution of old farming systems, etc. The replacement of the primitive cultivars by higher yielding strains of better nutritive quality is necessary to increase food production--but such replacement does not necessitate losses of either the primitive cultivars or their weedy and wild relatives.

4.1.2.1 Paradoxical Success

Since progress in plant selection depends upon sources of ample genetic variability, plant breeders and researchers now seem to be confronted with a paradox of their own making--their successful cultivars have been so widely accepted that they threaten to eliminate the very sources of variability which generated their genetic accomplishments.

In meeting the challenges of this paradox, it will be necessary to collect and preserve the land races of our cultivated crops. These land races, together with their weedy and wild forms, constitute a non-renewable resource--necessary for both plant breeding and basic research.

Current calculations are that the world population will double between 1971 and the year 2008--from a level of 3.7 billion to 7.4 billion people--and food supplies must grow at least at a parallel rate. At present, five cereals, two sugar plants, three root crops, three legumes, and two "tree crops" actually feed the world (11). And three of the cereals--rice, wheat, and maize--produce over 66% of the world's seed crop. Plant breeding has been successful in increasing production levels per unit area for these crops, but this addition has been achieved at the expense of reduced genetic

variability and an intensified rate of erosion of the genetic resources. Thus, continued breeding success depends on (1) "banking" of genetic resources still available and (2) widening of the genetic base of tolerance to disease and other pests in the cultivars produced.

4.2 CURRENT BANK OPERATIONS

4.2.1 CIMMYT'S PRESENT INVENTORY

A total of 10,398 accessions are available in CIMMYT's maize germplasm bank (Table 4-1). Over 90% of these are of American origin, but a total of 46 countries are represented in the collection.

Three general types of accessions are recognized: collections, groups, and composites. Groups were formed by recombining two or more collections of similar morphology and geographic distribution during the period 1950-1963, in an attempt to decrease the number of accessions in the bank while preserving the variability available. It was assumed that collections similar in morphology and from the same region were likely to be samples of the same population and that it was not necessary to maintain them as separate entities. One or more collections considered as typical of the members of a given group were preserved as individual entities and the remaining discontinued. Composites have been formed on the basis of traits or racial criteria.

CIMMYT's present inventory includes 9,624 collections; 670 groups involving accessions from Brazil, Central America, Mexico, and the West Indies; and 94 composites. In addition, there are 78 collections of Zea mexicana, 4 of Z. perennis, and a live Tripsacum garden is maintained at Tlaltizapán, including all known species in this genus and involving 103 clones.

4.2.2 SERVICES RENDERED

During the period May 1967 to December 1973, a total of 472 shipments involving 14,783 items was sent to 80 countries (Table 4-2). The largest number (138) of shipments (30.6%) and items (2,853 (21.4%)) were sent to the U.S.A., Mexico, Philippines, India, Pakistan, Nicaragua, and Thailand.

From the seed provided by CIMMYT have come sources of resistance to Puccinia polynora for East Africa (18, 19, 20, 21) to Chilo partellus in Pakistan (1), as well as partial resistance to Spodoptera frugiperda and Sitophilus zeamais in the U.S.A. (28) and in Mexico (CIMMYT News, 2 (7-8): 3, 1967.). In addition, populations supplied by the Bank have been widely and successfully used in breeding programs in different parts of the globe.

4.2.3 PHYSICAL FACILITIES

Facilities for the Bank at El Batán include two cold-storage chambers with a combined volume of 244 cubic meters in which temperature is maintained at 0°C and relative humidity lowered to 45%. Seed dried to 10% moisture content is stored in rectangular base tin-can containers with a pressure lid. Can capacities are one-half or one gallon (U.S.). The open storage racks used are made of galvanized angle iron and mounted on rails to form aisles where desired. As presently arranged, these chambers allow the storage of seed in 10,440 one-half-gallon and 15,120 one-gallon containers, plus 132 drawers 41 x 46 x 18 cm. for small seed lots in envelopes.

4.3 ORIGINS AND MAINTENANCE OF GERMPLASM BANK

Having listed some of the current operations of the Bank, discussion now turns to a description of its fundamental structure and core elements.

Some of the materials available in CIMMYT's maize germplasm bank trace back to collections made in 1943 by the Oficina de Estudios Especiales established by the Mexican Government and The Rockefeller Foundation.

A project was established by the U.S. National Academy of Sciences--National Research Council from 1951 to 1954 to collect, preserve, and study for future use the indigenous strains of maize of the American Hemisphere. This project was directed by a committee composed of leading maize breeders, geneticists, botanists, and administrators and was financed by the United States Department of State through the Office of Foreign Agricultural Relations, and later through the Institute of Inter-American Affairs. Under an agreement with the Technical Cooperation Administration, maize collections were made in all American countries over the three-year period, terminating on June 30, 1954.

Seed Centers equipped with refrigerated seed storage facilities were established in Chapingo, Mexico, and in Medellín, Colombia in cooperation with The Rockefeller Foundation. A third Center was established in Piracicaba, Brazil in cooperation with the University of Sao Paulo. The Plant Introduction Station of the U.S. Department of Agriculture at Ames, Iowa served as a fourth Center for the maintenance and storage of the collections originating in the U.S.A. and Canada.

A total of 11,353 collections were made (5) during the life of the project, and 10,922 of these were listed in a two-volume catalog (12, 13) entitled, "Original Strains of Corn, I and II", published by the U.S. National Academy of Sciences--National Research Council in 1954 and 1955. Of the collections listed in the catalog, 4,351 were stored in the Mexican Bank; 3,945 in the Colombian Bank; 2,380 in the Brazilian Bank; and 246 in the Regional Plant Introduction Station at Ames, Iowa.

Duplicate samples of the collections made in Latin America were placed in stand-by storage for four years at Glen Dale, Maryland under the care of the Plant Introduction Section of the U.S. Department of Agriculture. These were later transferred to the National Seed Storage Laboratory in Fort Collins, Colorado, but not officially accepted because of variable germination, small seed lots, lack of agreement for rejuvenation of viability, and perhaps other reasons (24).

The Mexican Bank was responsible for the storage, maintenance, distribution, and study of the collections from Mesoamerica and the West Indies, whereas the Colombian Bank had a similar responsibility for the collections from the Andean countries (Bolivia, Chile, Colombia, Ecuador, Perú, and Venezuela). The Brazilian Bank's responsibilities extended to the collections from Eastern South America (Argentina, Brazil, French Guiana, Guyana, Paraguay, Surinam, and Uruguay).

The U. S. National Academy of Sciences--National Research Council Project made possible the study and classification of the variation in the species Zea mays L. in the American Hemisphere. A total of 283 races were described between 1957 and 1963 in a series of eleven bulletins (2, 3, 7, 8, 10, 14, 15, 22, 23, 26, 27). The publication (25) that served as a pattern for these bulletins appeared in Spanish in 1951 as Folleto Técnico 5 of the Oficina de Estudios Especiales, Secretaría de Agricultura y Ganadería, México and was translated and published in English in 1952 (26) by The Bussey Institution of Harvard University.

The Project provided only for the collection and storage of seed samples, and disregarded the rejuvenation, evaluation, and distribution of seedstocks. It was not an integral program and the Seed Centers, over the years, met with problems such as lack of continuity of objectives and policies, changes in personnel, breakdowns of refrigeration equipment, power failures, and strikes or civil disorders which barred personnel from the facilities, etc. Timothy and Goodman (24) have recently discussed the current status of the maize collections made under this project.

In 1960, the Oficina de Estudios Especiales of the Mexican Ministry of Agriculture was merged with the Instituto de Investigaciones Agrícolas to create the National Institute for Agricultural Research. All assets of the Oficina de Estudios Especiales, including the maize

germplasm bank and documents pertaining to it, were transferred to the newly created Institute. Duplicates of some, but not all, of the maize accessions in the Oficina de Estudios Especiales collection were obtained by the Inter-American Maize Program and incorporated into its own germplasm bank, which was eventually transferred to CIMMYT. These collections constituted the initial capital of CIMMYT's bank. In 1967, 7,629 of the duplicate samples on stand-by storage at the U.S. National Seed Storage Laboratory (corresponding mostly to materials originally stored in the Brazilian and Colombian Banks) were transferred to CIMMYT. Additions from Central America, Colombia, Ecuador, Mexico, Perú, and the West Indies have been made by direct collection in those areas.

4.3.1 MAINTENANCE PROGRAM

A total of 8,223 accessions have been grown for propagation purposes during the five-year period 1969-1973 (Table 4-3).

Accessions originating at elevations higher than 1,500 m. above sea level are grown in Mexico at El Batán, and those from elevations lower than 1,500 m. or from non-tropical areas, are grown at Tlaltizapán, Morelos.

In general, plots of 408 plants are used, and as many hand pollinations as possible are made by chain mating. This process, in addition to using as many staminate as pistillate parents, facilitates field operations by allowing the easy recognition of plants to be pollinated and of plants already pollinated, thus making detasseling unnecessary to prevent the repeated use of the same plant as a pollinator. All individuals in the plot have an equal probability of being progenitors (no selection is practiced), but diseased and off-type ears are discarded at harvest time. A maximum of 4.5 gallons of seed of each accession is placed in storage. Seed is dried artificially to 10% relative humidity, shelled in bulk, and run through a Boerner sampler twice to subdivide it into fourths (when the amount of seed produced is ample). In turn, each of the fourths is used to fill a one-gallon container and a small sample of each fourth is placed in one-half-gallon can. In this way, all containers of a given accession have a random sample of the seed produced. The seed is treated with an insecticide, weighed, inventoried, and stored in the cold chamber.

Since 1969, from 12 to 15 hectares have been grown annually and nearly 300,000 pollinations have been made every year. The vast majority of the collections grown in 1969 correspond to the duplicate seed samples stored in Glen Dale, Maryland, transferred to the U.S. National Seed Storage Laboratory, and then to CIMMYT

in 1967. These represented collections from the Brazilian Bank, which ceased to function in 1962 (but was recently reactivated). The seed was old, variable in viability, and in many cases, all that could be done then was to restore the germination power for propagation in succeeding years.

A cooperative agreement was reached with the Programa Cooperativo de Investigaciones en Maíz (Universidad Nacional Agraria) and put into effect in 1972 whereby Perú would propagate and increase 1,067 accessions from Bolivia, Chile, Ecuador, and Perú.

The inventory unit is the seed container. Computer listings include: accession number; accession name; racial classification; population type (collection, group, or composite); location; year; crop and plot number in which the seed was produced; mating system followed to produce the seed; number of ears represented in the seed stored; amount of seed in the container; and country of origin of the accession. Containers are uniquely designated with a letter and four pairs of digits which correspond, respectively, to the storage chamber, rack, shelf, space between two vertical supports (column), and can. It is unnecessary for all containers of a given entry to occupy contiguous positions in the storage chamber and no spaces are reserved for additions or changes. The only requirement is that all containers of a given accession be listed consecutively and the total amount of seed over all containers recorded.

As accessions are multiplied or rejuvenated, notes are taken on kernel and ear traits and agronomic characteristics. These involve days to pollination, ear height, kernel color, endosperm texture, per cent plants with two or more stalks, per cent plants with more than one grain-bearing ear per stalk, ear length, and thickness and number of ears harvested. For the past five years, Ing. Efraim Hernández X. of the National School of Agriculture has been examining the pollinated ears of the propagated accessions and fitting them into one or more of the described races of maize. These data, along with the information provided by the collector, by bank users, and by the evaluation activities presented in the next to the last section of this paper, represent the bulk of the documentation available for the accessions in the bank.

The large number of accessions in the bank and the bulk documentation make electronic computers mandatory in bank management. Computerization is also necessary to participate in the planned international network of information centers that will link individual scientists and institutions through national centers to an international center (6).

Computer programs for inventory listings, inventory updating, preparation of shipping lists, and combinations of information from different sources are now available and being used at CIMMYT. However, the adoption of a documentation system such as Taxic is being seriously considered to handle present and future needs.

4.3.2 ADDITIONS PLANNED

The maize collections made in 1951-1954 under the auspices of the U. S. National Academy of Sciences-National Research Council did not cover the whole area where maize is grown in the Americas, nor did they include any region outside this Hemisphere. Collections were generally restricted to the more easily accessible areas. A total of 2,380 accessions from Eastern South America were deposited in the Brazilian Bank at the expiration of the project. However, it is not generally recognized that 96% of these were collected in the four southernmost States of Brazil or that 63% originated in the States of Rio Grande do Sul and Sao Paulo.

There is no question that gaps exist in the collections -- gaps that seem to widen when accessions lost by all major maize Banks in the American Hemisphere are considered. To fill such gaps the Maize Germplasm Resources Committee has recommended collecting expeditions to India's Northeastern Frontier and the Upper Amazon Basin. These expeditions are planned for 1974 and 1975, with financial help provided by The Rockefeller Foundation.

4.3.3 PRINCIPAL WORLD COLLECTIONS

A preliminary survey of maize germplasm banks was prepared by the Crop Ecology and Genetic Resources Unit of the Food and Agriculture Organization of the United Nations and published in 1972 (16). The survey includes 145 institutions in 44 countries all over the world, having a total of 185,687 samples of maize and 100 teocintle collections under storage. There are a number of evident omissions in this list, plus some apparent duplications, and it is more than likely that the bulk of samples reported are breeding materials rather than germplasm sources.

Only 18 institutions maintain collections of 2,000 or more accessions and 14 of these have special seed storage facilities. Of the latter, eight are in the American Hemisphere, four in Asia, and two in Europe. All but one of these collections are in official or international organizations and no information is given on how many are actively engaged in germplasm distribution.

4.3.4 RELATIONS WITH OTHER MAIZE BANKS

CIMMYT maintains close working relationships with all maize germplasm banks in the American Hemisphere. In September 1973, CIMMYT convened a meeting of maize germplasm workers to study and adopt documentation systems compatible among the different banks represented and systems used by other international and national institutions. Fourteen participants representing Argentina, Colombia, Mexico, Perú, and the United States attended.

In addition to regular seed exchanges, CIMMYT has an agreement with the maize program of the Universidad Nacional Agraria in Lima, Perú for the propagation of maize collections from the highlands of Bolivia, Chile, Ecuador, and Perú. Part of the seed from these propagations will be brought to CIMMYT's headquarters; the rest will go to the germplasm bank of the Universidad Nacional Agraria.

A total of 1,785 maize collections from Colombia (received by CIMMYT from the U. S. National Seed Storage Laboratory at Fort Collins, Colorado in 1967) were transferred to the Maize Germplasm Bank of the Instituto Colombiano Agropecuario to replenish its seed stocks in late 1973.

Similarly, collections from CIMMYT's bank are being provided to the Gene Bank for Economic Crops in Southeast Asia (University of the Philippines, College of Agriculture) for evaluation and eventual use in that area of the world.

Arrangements were completed in 1973 through the Maize Germplasm Resources Committee to place duplicate samples of all maize accessions in the Latin American banks in long-term storage at the U.S. National Seed Storage Laboratory for insurance purposes.

4.4 CIMMYT'S MAIZE PROGRAM USE OF GERmplasm COLLECTION

4.4.1 ACCESSIONS AND EVALUATION

The effective utilization of the germplasm collections in the bank depends on an adequate body of information and the adoption of a system for its rapid and accurate retrieval.

Accessions in the bank are being documented as they are propagated and rejuvenated. In addition, a program for their systematic evaluation in replicated field tests at several locations in Mexico was initiated in 1973. A total of 1,904 accessions of tropical origin (from elevations of 1,000 m. or less) together with 16 checks are being grown

at Poza Rica in the winter and summer of 1974 and at Rfo Bravo, in summer, 1974. Replicates of these tests were sent to Argentina, Nigeria, Thailand, and Zaire to obtain information on the reaction of the entries to downy mildew, Sesamta calamistis, and streak virus. One replicate of these tests is being used by Plant Protection personnel of our maize program to evaluate insect reactions under conditions of natural infestation. The remaining two replicates will be used to measure agronomic and yield performance and disease reaction will be determined in all three replicates.

Similar tests involving 972 entries and 13 checks from high elevations have already been planted at El Batán and Toluca. Table 4-4 summarizes the relevant data for this work.

No results from these tests are as yet available; however, data obtained in 1972 illustrate the great genetic potential available in the germplasm bank. Comparisons were made of 499 accessions from low elevations using the checks Tuxpeño Planta Baja, Composite 301, and Chalqueño A in two randomized complete blocks grown at Tlaltizapán.

Table 4-5 summarizes the range in grain yield, days to silking, grain moisture at harvest, and percent root lodging of the 28 highest yielding entries, plus the best check in the test which was Tuxpeño Planta Baja. Although the experimental entries in this test had not undergone any selection, a good number of them yielded as well or better and were of similar maturity to a check that has undergone several cycles of selection.

Superior genotypes from the evaluations just described will be turned over to the back-up unit of the breeding program for utilization in maize improvement. The information obtained will be incorporated in the data file to provide better services for bank users in the future. These materials could also be incorporated in the International Maize Adaptation Nurseries (IMAN) for testing on a wider scale.

4.4.2 CIMMYT'S PROJECTED ACTIVITIES: 1974-1980

CIMMYT will continue its progress with the maize germplasm bank: the rejuvenation and documentation of the available accessions; the computerization of bank operations, including preparation of inventory listings, inventory updating, etc.; and the evaluation of accessions for their potential value in the institution's maize breeding program. By 1980, CIMMYT expects to have:

- (1) seed less than 10 years old for all accessions presently available in the bank
- (2) established a documentation system compatible with those used by other institutions
- (3) tested in replicated field tests all accessions adapted to growing conditions in Mexico
- (4) published an open-ended catalog with the documentation available about the accessions in the Bank
- (5) placed in long-term storage duplicate samples of all accessions in the bank
- (6) completed the collections in India's North Eastern Frontier and the Upper Amazon Basin recommended by the Maize Germplasm Resources Committee
- (7) increased the number of collections of Zea mexicana of species of the genus Tripsacum and also to have added other members of the Maydeae Tribe

Activities relating to the eighth function of the maize germplasm bank, i. e. the incorporation into maize of useful traits available in related genera, are covered separately in section 5A of this Symposium.

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Table 4-1.

Accessions available in CIMMYT's maize Germplasm Bank arranged by
broad geographic origin and population type

<u>O r i g i n</u>	<u>N u m b e r o f</u>			<u>S u m</u>
	Collections	Groups	Composites	
U. S. A.	9		3	12
Mexico	2327	390	53	2770
Central America and West Indies	1813	194	10	2017
South America	5386	86	28	5500
Africa	46			46
Asia	34			34
Europe	9			9
S u m	9624	670	94	10388

Table 4-2.

Shipments made and number of maize populations distributed
by CIMMYT's Germplasm Bank during the period 1967-1973.

Year	Number of		
	Shipments	Populations	Countries
1967 *	69	1840	27
1968	69	953	35
1969	102	2825	32
1970	88	3337	34
1971	50	1279	13
1972	50	2390	20
1973	44	2159	19
S u m	472	14783	

* May 1st. - December 31st.

Table 4-3.

Number of maize populations planted in México for multiplication during the period 1969-1973

<u>O r i g i n</u>	<u>Number of populations planted in</u>					<u>S u m</u>
	1969	1970	1971	1972	1973	
Asia	9	1	19			29
Africa	6		7	31		44
Caribbean Islands	138	4	137			279
Central America	775	51	42	49	187	1104
Europe			5			5
Mexico	395	1108	474	231	385	2593
South America	2767		596	435	371	4169
S u m	4090	1164	1280	746	943	8223

Table 4-4.

Summary of replicated field test involving lowland-tropical and highland maize populations from the germplasm bank that will be grown in Mexico in 1974

Information	Lowland	Highland	Sum
Experimental Entries	1,904	972	2,876
Checks	18	13	31
Tests	8	4	12
Locations	3	2	5
Total number of replicates	72	24	96
Experimental plots	18,432	6,144	24,576
Area, hectares	9.8	3.3	13.1

Table 4-5.

Range of grain yield, days to silking, moisture percent at harvest, ear height, and percent root lodging of the 28 highest yielding entries and the best check in replicated field test involving 496 accessions of the germplasm bank and three checks grown at Tlaltizapán, Morelos in 1972.

Character	Range of 28 Highest Yielding Entries	Check
Grain yield (kg/ha.)	8,479 - 6,087	5,989
Days to silking	64 - 77	74
Moisture % at harvest	14.34 - 22.38	19.74
Ear height (m.)	1.38 - 1.96	1.31
Percent root lodging	31 - 87	37

5.0A

MAIZE-TRIPSACUM CROSSING AT CIMMYT

by
Mario Gutiérrez G.

5.1A INTRODUCTION

CIMMYT's maize program is greatly concerned with the preservation and exploitation of the existing genetic variability; not only in the genus *Zea*, but also in the related genus *Tripsacum* that constitutes a vast reservoir of genes of potential value in maize improvement. As part of its germplasm collection, CIMMYT maintains a garden, including all known species of this genus.

Discussion in this section provides background information about *Tripsacum*, crossing techniques, and maize-*Tripsacum* crosses including cytology of the hybrids, genetic transfer from *Tripsacum* to maize and routes to follow to accomplish such transfer. Some preliminary results of CIMMYT's recently initiated work in maize-*Tripsacum* crossing are presented, along with projected plans for future work.

Hopefully, this discussion will provide a point of departure for Dr. Bates' presentation in "Wide Crosses" to follow (5.0B).

Zea mays L. is a highly variable species, and it is safe to assume that breeding needs in this crop for the immediate future can be met with the variation presently available. However, for the continued agronomic and nutritional improvement of the crop, it is advisable to pay attention now to the possible transfer of genes from other species and genera. All usable genes should be brought into play in meeting the food demands of an ever-increasing population.

Crossing in nature, either at the interspecific, intergeneric level, or both has played a role in the origin of field crops such

as wheat, oats, cotton, tobacco, and sugar cane. Wide crosses have been used successfully in the improvement of ornamentals, horticultural crops, to transfer disease resistance to wheat, and in the development of Triticale: there is no a priori reason to anticipate that wide crosses could not be used in the improvement of corn, although it is realized that this is not an easy task.

Methods to cross *Tripsacum* and maize as well as evidence that gene transfer between these two genera can be accomplished have been available for some time. Information has also accumulated on the genus *Tripsacum*, including taxonomy (13), cytology (6,2,3) breeding behavior of maize-*Tripsacum* F₁'s and backcross derivatives (3,4), as well as routes to follow for genetic transfer from *Tripsacum* to maize (9).

5.2A AMERICAN MAYDEAE

Two genera of American origin are recognized in the Maydeae Tribe: *Zea* and *Tripsacum*. The first comprises three species: corn, *Z. mays* L., and the annual and perennial forms of teocintle, *Z. mays* ssp. *mexicana* (Schrad.) Iltis and *Z. perennis* (Hitch.) Kuntze. Annual Teocintle is distributed in Mexico, Guatemala, and Honduras. Maize and annual teocintle have 10 pairs of chromosomes, hybridize freely under natural conditions to produce fertile F₁'s, showing recombination rates similar to those observed in pure maize. Perennial teocintle has 2n = 40 and approximately the same frequency of 7-9 quadrivalents at meiosis as autotetraploid maize (12) and shows complete chromosome homology with the latter (15). All known collections of this species originated in a single colony found near Ciudad Guzmán, Jalisco in Mexico.

Nine species of *Tripsacum*, all perennials with a dense compact rhizome system, are recognized: *T. australe* Cutler & Ander., *T. dactyloides* (L.) L., *T. floridanum* Porter ex Vasey, *T. lanceolatum* Rupr. ex Fourn., *T. latifolium* Hitch., *T. laxum* Nash, *T. maizar* Hern. & Rand., *T. pilosum* Scribn. & Merr., and *T. zopilotense* Hern. & Rand. (Three additional species (*T. andersoni*, *T. bravum* and *T. spathiflorum*) have been recently proposed by J. R. Gray (Jack R. Harlan, personal communication). Seven of these are indigenous to Mexico and Guatemala (13); one (*T. floridanum*) is native to Florida and the Gulf Coast of Texas, and another (*T. australe*) is native to South America. The genus extends from the north central and northeastern United States southward into Mexico, Central America, the West Indies and South America to Bolivia and Paraguay (13). The center of variation for

Tripsacum is the western escarpment of Central Mexico (17). The basic gametic chromosome number in the genus is 18 and forms with $2n = 36, 54, 64,$ and 72 have been reported. Somatic chromosome counts of $36, 45, 54, 72, 90,$ and 108 were recorded by Farquharson (5,6) from different plants of predominantly tetraploid populations of U.S. T. dactyloides, and evidence presented that this unusual series resulted from polyembryony, facultative apomixis, and the occurrence of twin seedlings.

Forms with 18 pairs of chromosomes behave like normal diploids and are commonly referred to as such in the literature. From the morphological similarities between the genera Manisuris and Tripsacum and the fact that reduced chromosome number in the former is 9, Randolph (12) proposed that Tripsacum forms with $n = 18$ probably should be considered as natural tetraploids and both genera placed in the same tribe, as suggested by Weatherwax (16). Consequently, forms with 54 and 72 somatic chromosomes would be hexaploids and octoploids, respectively. De Wet et al. have used this nomenclature in some of their published work (3, 4) but since no Tripsacum with 9 pairs of chromosomes has been found so far, and considering the diploid cytological behavior of forms with 18 pairs of chromosomes, they will be referred to as diploids in this discussion. Forms with 54 and 72 somatic chromosomes will be considered as triploids and tetraploids, respectively.

5.3A CROSSING TECHNIQUES

Mangelsdorf and Reeves (11) showed that diploid T. dactyloides and maize could be hybridized using maize as the pistillate parent by shortening the silks and applying abundant amounts of Tripsacum pollen. This technique was successfully modified by Randolph (12) by slitting longitudinally the husks of the ear shoots in two or three places from the tip downwards and opening the resulting segments sufficiently to sift a mixture of Tripsacum and maize pollen onto the maize silks near their attachment to the ovary. Glassine bags were wrapped around the husks and kept in position with rubber bands after pollination. The maize pollen applied carried endosperm and aleurone marker genes and it was used to produce a few normal maize seeds and stimulate cob development.

The reciprocal cross was difficult to produce but Farquharson (7) was able to obtain hybrid plants that reached maturity when diploid and triploid T. dactyloides were pollinated with a corn stock from Puno, Perú. It is now known that the major incompatibility mechanism between Z. mays and Tripsacum is

gametophytic and that reciprocal crosses can be obtained, provided the proper genotypes are used.

Artificial culture of the F_1 embryos has been used by some researchers to obtain F_1 plants, but others claim to have had satisfactory results without embryo culture.

F_1 plants are perennial and resemble the *Tripsacum* parent.

5.4A CYTOLOGY OF MAIZE, TRIPSACUM, AND THEIR F_1

A good knowledge of the cytology of species of the two genera, their F_1 's, and backcross derivatives is indispensable to assess the possibilities of genetic transfer and to determine the most indicated route to follow for this purpose.

Maize is a regular diploid with 20 somatic chromosomes and shows normal behavior during sporogenesis.

Most of the *Tripsacum* chromosomes are shorter than maize's, having arm ratios of about 1:3 or 1:4, in comparison to 1:1 or 1:2 for maize and mostly terminal knobs on the long arm while those of corn are mostly intercalary and when terminal are on the short arm. The nucleolus organizer in *Tripsacum* is near the centromere and occurs in two different chromosomes in various species of the genus, but in maize there is only a single terminal organizer on the short arm of chromosome 6.

Galinat and co-workers (8) have identified the T. dactyloides chromosomes carrying dominant alleles to maize recessives and found that while a few of the maize and *Tripsacum* homeologs have retained a similar assemblage of common loci, at least in one chromosome arm, other homeologs have become highly differentiated.

De Wet et al. (3) have reported on the cytology of diploid, triploid, and tetraploid T. dactyloides and their F_1 with diploid maize involving combinations of 10 maize chromosomes and 18, 36, 54, and 72 T. dactyloides chromosomes. The last two combinations were obtained through the fertilization of unreduced eggs produced by triploid and tetraploid T. dactyloides. The following section is a brief summary of their cytological findings.

Diploid T. dactyloides ($2n = 36$) shows bivalent formation at prophase I and regularly produces cytologically reduced gametes.

Triploid forms ($2n = 54$) have irregular meiosis showing uni- and multivalents at prophase I and loss of chromosomes in the daughter nuclei at telophase I; they are partially sterile, and only unreduced eggs are functional. In contrast, Anand and Leng (1) have reported observing the formation of 27 bivalents in microsporocytes of a 54-chromosome clone of T. dactyloides from near Santa Claus, Indiana obtained from Farquharson.

Tetraploids ($2n = 72$) behave like segmental allotetraploids with essentially normal bivalent formation in some collections and multivalent formation in others. The latter fall apart in late prophase, and at metaphase the chromosomes are mostly present as bivalent in the equatorial plate. Balanced reduced gametes are formed and tetraploids are often fully sexual. Partially apomictic tetraploids frequently produce polyhaploids with diploid cytological behavior and normal gamete formation.

F₁ hybrids between maize and diploid T. dactyloides show little or no chromosome pairing, but one or two loose ZZ or ZT associations are occasionally observed. These hybrids are androsterile but partially gynofertile from rare unreduced megaspores.

Hybrids with 46 chromosomes are characterized at meiosis mostly by 11 univalents, 16 bivalents, and one trivalent, but as many as four trivalents or 22 bivalents were observed in some cells by de Wet and coworkers (3). Chromosome behavior of these hybrids is reported to be determined by the cytological behavior of the tetraploid parent. The 36 *Tripsacum* chromosomes in the hybrid mostly synapse into bivalents, and the 10 maize chromosomes frequently pair among themselves when the *Tripsacum* parent has a regular meiosis. Hybrids whose *Tripsacum* parent behaved like an autopoloid show tri- and tetravalents involving chromosomes from both parents, and as many as four maize chromosomes sometimes compete successfully in synapsis with *Tripsacum* chromosomes. These hybrids are also androsterile but partially gynofertile through the functioning of unreduced megaspores.

Hybrids with 64 chromosomes (54 T + 10 Z) are reported to be completely sterile, showing extremely irregular pairing and being difficult to analyze.

In 82 chromosome hybrids (72 T + 10 Z), all 10 maize chromosomes often synapse into bivalents with *Tripsacum* chromosomes. The maize chromosomes also pair autosyndetically or form multivalent associations with *Tripsacum* pairs that persist into metaphase. Occasionally, all chromosomes are present as bivalents; such hybrids are reported to produce .1% functional pollen and to be about 1% gynofertile.

GENETIC TRANSFER FROM TRIPSACUM TO MAIZE

Maguire (10) obtained a segmental interchange involving the distal half of the short arm of chromosome 2 of maize and a corresponding segment from a T. dactyloides chromosome bearing a conspicuous terminal knob derived from a chromosome half as long as maize chromosome 2, and having an arm ratio of 1:3.3. Plants normal for chromosome 2, heterozygous and homozygous for the segmental interchange were compared for a number of traits, and it was shown that a Tripsacum chromosome segment could be substituted for a maize chromosome segment equal to about 3% of the total length of the maize genome.

Reeves and Bockholt (14) compared the performance of the original and three recovered lines obtained by four backcrosses to maize of an F_1 between maize and diploid T. dactyloides. The recovered lines were found to differ significantly from the original in nine or ten of the traits measured, including grain yield; with rare exceptions, the modifications were in the direction of Tripsacum and interpreted to be the result of genetic transfer from Tripsacum to maize.

Harlan and de Wet (9) have recovered maize lines through backcrossing T. dactyloides-maize crosses to maize which showed great variability and some primitive characters that did not occur in the lines used as the recurrent parent, although the same can be found in maize. Among such traits were ears on which the pedicillate spikelets are male and the sessile spikelets female, ears with male tips, plants with branching systems in the leaf axils like teocintle, up to six ears at a single node, high ears, etc. These authors point out that possibilities exist for restructuring the maize plant and some of the types isolated may have value as an entirely new kind of maize plant.

Reeves and Bockholt (14) thought that the principal reason for the skepticism of the possible genetic transfer from Tripsacum to maize was due to the high genetic diversity of the maize parent used in most crosses.

Drawing on the cytological behavior of the F_1 hybrids between maize and various ploidy levels of T. dactyloides, Harlan and de Wet (9) have discussed three pathways for the genetic transfer from Tripsacum to Z. mays. The first of these, called the 28 → 38 → 20 pathway, involves both diploid Tripsacum and maize. F_1 's are androsterile but produce functional unreduced megaspores with 28 chromosomes which upon backcrossing to maize give BC_1 's with 38 chromosomes, and with repeated backcrossing to maize the

Tripsacum chromosomes are eliminated and maize is recovered. This pathway has been found on the whole to be conducive to very little genetic transfer, and it is not considered to be very promising.

The 46 → 56 → 38 → 20 pathway involves tetraploid Tripsacum and diploid maize. F₁'s have 46 chromosomes (36 T + 10 Z), are androsterile, but produce unreduced eggs which upon fertilization by maize give rise to 56 chromosome plants in which all chromosomes have a partner and pairing is reported to be generally regular. BC₂ plants have mostly 38 chromosomes and from here on this and the previous pathway are similar. A slower rate of elimination of the Tripsacum chromosomes is reported in the 46 → 56 → 38 → 20 than in the 28 → 38 → 20 pathway, and the most frequent karyotype of the backcrossed progenies of the 38 chromosome plants is 20 maize plus 3 Tripsacum chromosomes, and plants carrying from 4-7 Tripsacum chromosomes are common. The possibilities of genetic transfer by the second route are considered to be higher.

Irregular pathways use stabilized 46 chromosome lines (36 T + 10 Z) in which the 10 maize chromosomes in each succeeding backcross to maize are contributed by the pollen parent; nevertheless, the Tripsacum chromosomes become increasingly contaminated with maize material as evidenced by a higher number of multivalent formation involving chromosomes of both genera. Combinations involving a complete genome from each one of the two species are viable and a vast array of chromosome combinations are possible.

Although the first two pathways presented above are designated as regular, it is evident from the published data on the cytology of backcross derivatives of maize-Tripsacum hybrids that such regularity does not exist, and it would seem that these pathways are mere idealizations of the real situation.

Other pathways, besides those mentioned above, are available; they involve autopolyploid maize and the various ploidy levels in Tripsacum plus the alternative of recovering either diploid or autopolyploid maize.

A less desirable route for the genetic transfer from Tripsacum to maize is the development of addition lines combining the full maize genome plus one or more Tripsacum pairs. Such lines tend to be cytologically unstable and the addition of whole chromosomes has the shortcoming of adding not only desirable genes but also deleterious ones. Galinat (8) claims to have developed a true breeding stock with 20 Z + 2 T chromosomes involving a homozygous Tripsacum pair.

5.6A CHARACTERS OF SPECIES OF THE GENUS TRIPSACUM OF POTENTIAL VALUE

Species of the genus *Tripsacum* show adaptation to a wide range of environmental conditions and constitute a vast reservoir of genes of potential value in corn improvement. Among these, it is possible to list the following, although it is anticipated that not everybody will agree on their desirability or interest:

1. Exceptional tolerance to differences in day-length and extremes of temperature found among species with widespread distribution in both temperate and tropical areas.
2. Wide range in adaptation to various kinds of soils differing in composition, pH values, fertility levels and moisture-holding capacity, such as limestone out-crops, lava flows, sterile hill-sides, and rocky ledges, as well as agricultural lands well adapted to corn culture.
3. Cold tolerance in the adult plant and in the seedling stage is available in species adapted to high altitudes in the tropics and to winter climates of the Temperate Zone.
4. A more adequate, essentially disease-free root system effectively supporting the plant in both light and heavy soils and under conditions of minimal to excessive rainfall, available among various Mexican species.
5. Resistance to most corn diseases may be assumed from the fact that such diseases are rarely observed in Mexican *Tripsacum* populations, even where they are located near corn fields.
6. Rapid post-fertilization seed maturity (about 3 weeks) is characteristic of all species.
7. Exceptional hybrid vigor potential as seen among various *Tripsacum* species hybrids.

5.7A TRIPSACUM COLLECTION AT CIMMYT

With the invaluable help and guidance of Dr. L.F. Randolph, *Tripsacum* species and clones representing some of the variation in the genus were collected in the States of Colima, Chiapas, Guanajuato, Guerrero, Jalisco, Mexico, Michoacán, Morelos, Nayarit, Oaxaca, Puebla and Veracruz, in Mexico, and British Honduras during the summer months of 1971, 1972, and 1973. Additions were obtained from The

Fairchild Tropical Garden through the kind courtesy of Drs. Hugh Popenoe and L. F. Randolph. Dr. Jack R. Harlan has kindly contributed several maize-Tripsacum F₁'s involving T. dactyloides, as well as Mexican species of the genus.

All accessions are established in a clonal garden arranged by species at the Tlaltizapán Field Station. The collection includes all known species in the genus represented by two or more clones, as summarized in Table 5-1A.

5.8A PRODUCTION OF TRIPSACUM-MAIZE F₁'S

Since crossability is a function of the genotypes involved, an attempt was made during the summer of 1973 to determine which of the genotypes in the Tripsacum garden at Tlaltizapán cross more readily with maize. For this purpose, an A B P1 stock with Antigua Group 2 background and known to carry the Ga₁^S allele was planted between the Tripsacum rows to be used as a pollinator. All old Tripsacum inflorescences were eliminated when the pollinator reached anthesis, and as new inflorescences developed, they were emasculated by clipping the terminal staminate portion, pollinated with maize pollen as the silks appeared, and enclosed in a glassine bag. All clones blooming were pollinated and about 10,000 pollinations made over a six-week period. It has not been possible to process as yet all the pollinations made, but a preliminary summary is presented in Table 5-2A. No F₁'s were obtained when maize was crossed with T. latifolium, T. maizar, and T. zopilotense. Caryopses were obtained in combinations involving T. dactyloides, T. dactyloides ssp. hispidum, and T. pilosum. Frequency of putative F₁ caryopses ranged from 0-4.96%.

5.9A ACTIVITIES PROJECTED FOR 1974-80

Before stating what activities and accomplishments are expected in this line of work during the period 1974-80, it is appropriate to quote the words of caution used by Harlan and de Wet (9) to refer to the possibilities offered by crosses of maize with species of Tripsacum other than T. dactyloides: "The possibilities are enormous but totally unexplored at this time. We predict some exciting results in the future, but, after some 10 years cumulative experience at Illinois, we will not predict that the results will come quickly."

By 1980, we hope that the following activities can be accomplished:

1. To have enlarged the present *Tripsacum* collection.
2. To know the karyotype of all entries in the collection.
3. To have produced a sizable number of maize-*Tripsacum* F₁'s.
4. To have obtained some recovered maize contaminated with *Tripsacum*.
5. To have determined which genotypes in the collection cross more readily with maize and which of them give a higher rate of genetic transfer to maize.
6. To have assessed satisfactorily the possibilities of the program and to have gained enough decision elements to either enlarge or discontinue it.

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5-2A	Preliminary summary of crossability of Antigua Group 2 stock with five species of <i>Tripsacum</i> . Tlaltizapán, Morelos. 1973.

Table 5-1A.

Number of hybrids and clones for different species of
Tripsacum available at the Tlaltizapán garden, 1974

Species or hybrids	Number of clones
<u>T. australe</u>	6
<u>T. dactyloides</u>	39
<u>T. dactyloides</u> ssp. <u>hispidum</u>	8
<u>T. floridanum</u>	2
<u>T. lanceolatum</u>	10
<u>T. latifolium</u>	9
<u>T. laxum</u>	4
<u>T. maizar</u>	9
<u>T. pilosum</u>	10
<u>T. zopilotense</u>	6
Tripsacum-maize F ₁ 's	28
Interspecific Tripsacum hybrids	6

Table 5-2A.

Preliminary summary of crossability of Antigua Group 2 stock
with five species of Tripsacum. Tlaltizapán, Morelos. 1973

Species	Clones	Number of Pollinations	Fruits	Caryopses	Range in % Crossability
<u>T. dactyloides</u>	18	887	7002	140	0-4.96
<u>T. dactyloides</u> ssp. <u>hispidum</u>	3	87	637	2	0-2.08
<u>T. latifolium</u>	1	19	540	0	0
<u>T. maizar</u>	2	73	3669	0	0
<u>T. pilosum</u>	6	311	8883	40	0-1.97
<u>T. zopilotense</u>	3	73	377	0	0

ANNEX 5-A

CIMMYT'S POLICY ON RADICAL RESEARCH

CIMMYT staff prepared a policy statement on "radical research and the role of CIMMYT," which was approved by the CIMMYT Board of Trustees on April 2, 1974. The following is a summary of the policy statement.

1. Nearly all maize and wheat breeding in the world today is of the "conventional type"--that is, two plants from within the same species are crossed sexually (pollen from one plant is applied to the emasculated flower of the other), giving variable progeny, and the breeder then selects among the progeny for desirable characteristics. Conventional breeding has been going on for more than a century. Such breeding gives variability for plant architecture, disease resistance, yield, nutritional quality, and other economic characteristics which can help the human food supply. Progress is still possible.

2. CIMMYT staff believe that the results of continued conventional breeding will permit the world's producers of maize and wheat to stay ahead of population growth for the next 20 to 30 years. During that period, population will double and so will the production of maize and wheat. But CIMMYT staff have no confidence that conventional breeding efforts will enable the world to feed itself with today's crops after the next doubling of world population (say, beyond 2000 A. D. and beyond a population of 7.0 billions).

3. To produce a further quantum leap in production of maize and wheat beyond 2000 A. D. will require some form of "radical research"... that is, something outside the limitations of conventional breeding. Two possibilities are for the plant breeder to introduce new variability into the existing crop species, or create completely new crop species. Both can be achieved by crosses between plants from different cereal crop genera (for example, between wheat and barley), or between more widely differing cereals (wheat and maize), or between plants of different botanical families (for example, between a cereal like wheat and a legume like soybean). All these examples are called "Wide Crosses."

4. Success in wide crosses is expected to be slow, proceeding from plants which are near relatives to plants which are more distantly related. As a guess, we can say 25 years will be needed, minimum, to develop new wide cross, to make hundreds or thousands of primary hybrids within that new cross, and then to transform those primary hybrids into a stable, usable commercial crop that is superior in yield, or nutrition, or environmental adaptation, compared to present crops. A period of a quarter century suggests that research started in the mid-1970's would not benefit the world's population before 2000 A.D., when the breeders may be approaching the end of variability in the genetic makeup of today's crops.

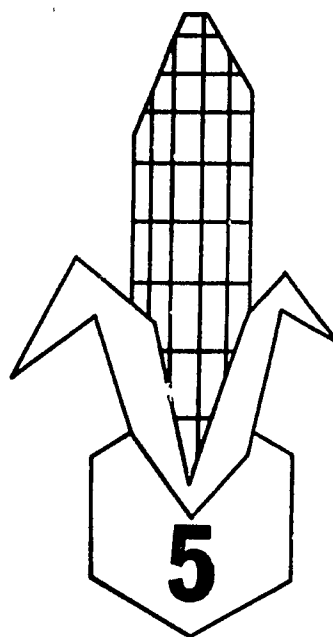
5. Fortunately, new developments in plant breeding of recent years, and even during 1973, suggest that there are now better prospects for success in wide crosses. New developments have included:

- (a) Progress with triticale (a cross between wheat and rye) has shown that a wide cross that was little more than a curiosity can be turned into a commercial crop within a period of one or two decades.
- (b) Chemicals are now undergoing trial which may neutralize the rejection factor, or incompatibility, whereby pollen from one species of plant has previously refused to germinate when placed upon the female organ of a plant from another species.
- (c) A new staining technique now makes possible the more rapid identification, under the microscope, of the numbers of chromosomes in a wide cross hybrid, and tells us which parent contributed each chromosome. This identification can greatly speed up the breeder's work.

6. During 1973, CIMMYT had been associated with these developments; opening the CIMMYT greenhouses, experimental plots, and laboratories to visiting scientists who are exploring new techniques, and CIMMYT scientists have shared in the exploration. We do not think, however, that this work should divert CIMMYT from its more immediate tasks of raising the world's food production by conventional breeding, year after year, at a rate at least as fast as population growth.

7. Our staff discussed CIMMYT's role in radical research for the next two years (1974-1976) and recommended to the Trustees the following steps:

- (a) That CIMMYT should maintain an experimental program for wide crosses of maize and wheat at Headquarters in Mexico, built around a common service laboratory which will specialize in embryo culture and cytogenetics; this laboratory to be manned by a top-level visiting scientist from a collaborating institution. The maize and wheat programs at CIMMYT should each employ one full-time post-doctoral fellow working on wide crosses. These fellows might be posted to CIMMYT by a university.
- (b) That CIMMYT should encourage collaboration between itself and a few outside research centers which have proved themselves to be centers of excellence in this work. Such collaboration is already developing between CIMMYT and Kansas State University (in the U. S. A.) and with the Plant Breeding Institute, Cambridge, England.
- (c) That CIMMYT should leave to outside institutions, as far as possible: the development of methodology on wide crosses; the demonstration that specific crosses are feasible; and the multiplication of primary hybrids for any feasible crosses. CIMMYT should normally become a major participant when an experimental hybrid is ready for transformation into a commercial crop. However, during the next two years (1974-1976), CIMMYT itself should undertake some of the above activities to stimulate interest and activity in collaborating institutions.
- (d) For the time being, CIMMYT's work on radical research can be financed primarily by restricted or special grants, which are not expected to exceed \$100,000 per year for the two years 1974-1976.
- (e) CIMMYT's Board of Trustees will be asked to review and approve a role for CIMMYT in this work at the next meeting of the Trustees in April 1974.



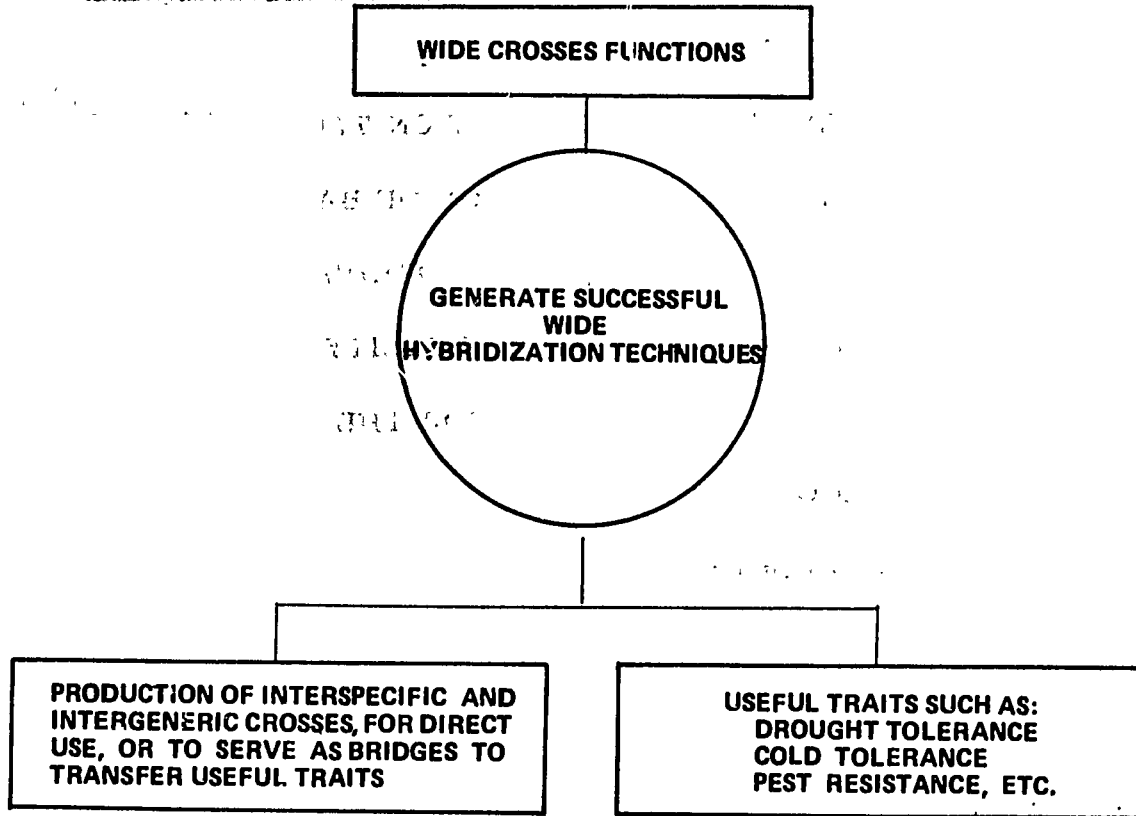
WIDE CROSSES

by
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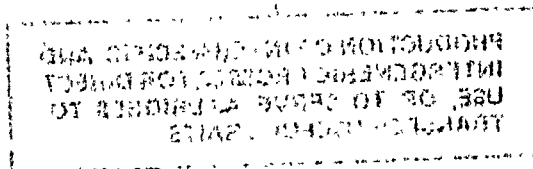
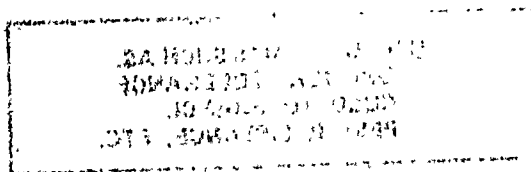
**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



FARM PRODUCTION

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5.0 B

WIDE CROSSES

by

Lynn Bates

5.1 B INTRODUCTION

Dr. Gutiérrez has introduced the subject of wide hybridization and has outlined CIMMYT's work with Zea mays x Tripsacum hybrids and the Tripsacum garden. In this presentation, focus is shifted from genetics to biochemical genetics, with some speculation and predictions for both the near and distant future. Some current wide hybridization techniques are discussed first, followed by a projection to 1980 and beyond.

5.2 B PRESENT WIDE HYBRIDIZATION TECHNIQUES

There are two basic approaches to wide hybridization: (1) modified sexual fertilization and (2) somatic cell fusion. Each route has its devoted advocates, and each is confronted by at least two formidable problems.

Modified Sexual Fertilization: The primary barrier for these techniques is gametic incompatibility; more precisely, the cross-incompatibility facet of pre-fertilization events. Cross-incompatibility (used in its broadest sense as in interspecific and intergeneric hybridization prevention mechanism) is undoubtedly a primordial barrier system to promote specialization and speciation. Little is known about this barrier, but a general class of stereospecific inhibition reactions (SIR) is believed to exist, analogous to immunochemical systems in animals (Bates and Deyoe, 1).

Another crossability barrier is hybrid necrosis, a post-fertilization phenomenon. Hybrid necrosis is a breakdown of differentiation that can be caused by innumerable conditions, ranging from failure of a single, non-functioning allele critically needed for seedling development to the more extreme conditions of failure of the total paternal

genome to be recognized or activated in the zygote. However, results of the breakdown are the same--death from an unknown cause.

Both the above types of barriers have been tackled with a modicum of success via phytohormones, embryo culture, mutagens, or other methods to upset or modify sexual fertilization.

Somatic Cell Fusion: Advocates of this approach circumvent gametic incompatibility and minimize hybrid necrosis by asexually combining two functional meristematic cells. The cell walls are dissolved enzymatically and the naked protoplasts forced together by slow-speed centrifugation. The hybrid cells are encouraged to resynthesize cell walls and to form calli on a special medium. Calli are stimulated to produce plantlets by additional transfers to hormone-laced media.

Unfortunately, the nuclei remain separate when the cell contents fuse; thus, the resultant dikaryon or double nucleated cell has two control centers for growth and differentiation. True hybrid cells have been obtained only in cross-compatible interspecific crosses. The net result is "no gain." Somatic cell fusion simply trades the difficulties of modified fertilization techniques for the equally puzzling problems of nuclei fusion, stimulation of hybrid callus differentiation, and stabilization of the callus cultures on the growth medium until plantlets form.

5.2.1B CHEMICAL CONTROL OF BARRIERS

Since the trade-offs seem equally exasperating for both above approaches, our Kansas State University-CIMMYT project has explored another route: the complete chemical control of barriers to crossability. The objective is to chemically "set-up" a maternal plant to recognize and utilize unrelated or distantly related paternal genomes. Fertilization is accomplished via chemical and/or mechanical pre-treatment, followed by in vivo or in vitro pollination. It is assumed that maintenance of as much natural information as possible in the cultivar can minimize the shock of alien germplasm in building new species.

Chemical control of SIR barriers provides the latitude to withdraw chemical agents at will and allow resynthesis of hybrid barriers. Thus, bioengineered species developed in the future will be protected from continual hybridization and contamination from their progenitors by resynthesis of the very barriers that were broken down to use the progenitors.

Tests have begun on the SIR hypothesis and on the feasibility of synthesizing new cereal species via simple biochemicals and com-

monly used interspecific hybridization techniques in small grains. Maize, sorghum, Tripsacum, and teosintle have also been studied.

5.3B POSSIBILITIES OF MAIZE X SORGHUM CROSSES

Maize x sorghum crosses have long interested plant breeders. The crossing of two such similar species appears deceptively easy, and the cross has probably been attempted many times during the past dozen decades or so. However, few individuals have admitted, much less reported, their attempts or results. Garrish did find sufficient literature to review by 1967, but the findings reported were negative (Garrish, 2).

In various studies using both detasseled maize and male-sterile sorghum as the maternal parents, some ovular stimulation has been obtained; but most breeders believe that the seed set was due to illegitimate fertilization, parthenogenesis, or a breakdown of male sterility. Breeders have detected some effects from the crosses on subsequent progeny in one or two cases, but no determinations were made as to whether introgression or hybridization had actually occurred.

Maize and sorghum crosses finally achieved legitimate stature with the initiation of a formal project at Iowa State University, directed by Dr. J. J. Mock. In three years, 1,920 maize x sorghum and 1,499 male sterile sorghum x maize pollinations were completed, representing in excess of a million potential fertilizations. Numerous genotypes were used, totalling 389 different parental combinations. All resulting progeny were found to be haploid, polyhaploid, or from illegitimate fertilizations, and the conclusion was that "a relatively complete incompatibility barrier exists between Zea and Sorghum" (Mock and Loescher, 3).

5.3.1B KANSAS STATE UNIVERSITY-CIMMYT STUDIES

Preliminary maize x sorghum crossing experiments were begun during the winter-spring 1972-1973 season in an informal, cooperative venture by Kansas State University and CIMMYT. At CIMMYT's Tlaltizapán research farm, maternal plants from 22 different maize genotypes were treated daily with 5 ml of e-amino caproic acid (EACA) at a concentration of 1 mg/ml. The solution was applied to the leaf axils for two weeks before pollination. Approximately 600 pollinations were made with pollen from 38 different sorghum genotypes, using conventional bag techniques. Embryo sacs were examined at 21 days post-pollination and were found to have abnormal green chlorophyll development. Chloroplasts may have developed following differ-

tiation of the unfertilized eggs. Other seeds were harvested at maturity; however, these were presumed contaminants due to seed set frequency comparisons with controls. No somatic chromosome counts were made. Conclusions from the study were that: field treatment with chemicals could be done, but the EACA level was probably too low and pollinations probably should be more carefully controlled (possibly only in vitro pollinations would suffice).

Findings from the above study and a new chemical treatment technique were incorporated in experiments performed at El Batán in summer 1973. Several concentrations of three chemicals--EACA, acriflavin, and salicylic acid--were applied to the tops of plants that had been cut off below the tassel. Large test tubes containing the solutions were sealed on the cut stalks, with a rubber dam, allowing continuous contact of the chemicals with the plants' vascular system. After 17 days of treatment, ear shoots were removed. The shoots were then sterilized in 70% ethanol and 3% calcium hypochlorite in a laminar flow chamber and individual florets were excised, pollinated, and placed in culture medium. Pollinations were made via injection of pollen into the stylar canal or into the micropylar area, and by dusting pollen on shortened silks. Sections of treated ear shoots with shortened silks also were dusted with pollen (under sterile conditions). Untreated pollen from sorghum and Tripsacum was used in all cases.

Microorganism contamination from unsterilized pollen was a constant problem. Microbe growth in single floret cultures was controlled by resterilization and transfer to fresh medium, a process that is impractical for ear shoot sections. Several florets with uncontrollable mold growth were sacrificed after two weeks. Untreated maize x sorghum control crosses had watery, but empty, embryo sacs, whereas the treated material had tissue growth resembling embryos. It could not be determined if a true embryo was developing, but there was evidence that at least a portion of the crossability barriers had been broken down. Other florets apparently developed into full seeds at a very slow rate, but eventually were lost to microorganism growth. Again, no positive determination could be made that true embryos had developed.

5.3.2B CONSIDERATIONS FOR THE FUTURE

The previous results are encouraging and suggest that a maize x sorghum hybrid should be achieved within the next two to five years. Although techniques are crude as yet, it now appears feasible in the near future to move germplasm freely among maize, sorghum, teocintle, Tripsacum, Coix, sugar cane, or any other similar species.

The potential has never been better for new sources of insect or disease resistance and of environmental tolerance. Drought tolerance and root worm resistance transfers to maize can now be considered. Perhaps the maize ear shoot(s) should be moved to the top of the plant for easier harvesting; or maybe the sorghum head should be enclosed in a bird-proof husk with low-tannin grain. Multiple energy sinks could become a reality; for example, the utility of maize or sorghum forage would be increased many-fold if sugar cane sweetness could be incorporated to complement the grain harvest. Additionally, if the growing season were long enough, five or six ear shoots might be encouraged to fill completely with seed. Another possibility would be a perennial plant type. The benefits resulting from these kinds of potential modifications are enormous, both nutritionally and economically, for maize, sorghum, or in the form of new species.

5.4B OUTLOOK FOR 1974-1980

The ever-widening gap between food production and population needs, plus the present world-wide energy shortage, have limited our alternatives so sharply that simply increasing yields of present cultivars no longer seems an acceptable goal (that is, unless abject world-wide starvation leaves no other choice). Instead, the emphasis of plant breeding should be shifted toward increasing nutritional quality per unit of land cultivated. Since protein is the nutrient most limiting in the present world food supply, the essential questions at this point are (1) whether the aim should be to increase the yield or of high quality protein per unit land already under cultivation, or (2) whether the high quality protein yield increases should be extended to presently uncultivated land. The mandate for protein, however, seems clear; few, if any, alternatives exist.

Wide hybridization can be useful for any, or all, alternatives-- with time the limiting factor. At present, there seems no conceivable way a new hybrid could have any impact on production within the 1974-1980 period discussed at this Symposium. Maize is an efficient and widely adaptable plant, and alleles for improved protein quality are known--yet, the opaque-2 gene discoveries of ten years ago have hardly begun to influence world nutrition. It seems inconceivable that the characteristics most desired from intergeneric maize hybrids--complexly interrelated factors of cold and drought tolerance and disease and insect resistance--could be stabilized and fully tested in time to make an impact in the next seven years, even if the hybrids were available today. Thus, wide hybridization offers no simple panacea for maize improvement.

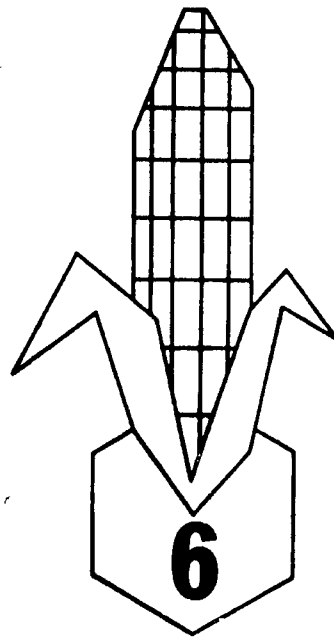
Perhaps the only foreseeable immediate impact from wide hybridization would be that gained by the KSU-CIMMYT chemical approach, provided that unmasking of non-functional genes actually occurs and results in new phenotypic expressions of agronomic value. There have been suggestions of, but no proof of, gene unmasking in polyploids resulting in new recombinations, and there is less reason to believe it would occur in diploid maize. However, unmasking of many loci by stripping off histones or other proteinaceous material from the chromosomes seems conceivable and is included under the "speculative license" for this Symposium topic. This approach would require several years of locating and testing newly recombined genotypes, and the modified cultivars would have only a minimal impact by 1980. Taking into account the above considerations, it seems probable that wide hybrids will have little impact on agriculture for 15 to 20 years, except for a stimulative effect on agronomic research.

During this lag phase, efficient maize genotypes must be developed via introgression, along with new widely adapted intergeneric hybrids. Future cultivars should be designed initially for present crop lands, but with an intergenerically broadened germplasm base. After the wide hybrid manipulative techniques are perfected, hybrids can be designed specifically for developing marginal land cultivation. Based on past patterns of adoption, a new hybrid species for marginal lands would require 20 to 30 years to produce a significant production impact--even if it were a phenomenal success.

CIMMYT's role in wide hybridization over the next seven years can, perhaps, be best served as a leader and catalyst. Few international organizations are endowed with such extensive staff expertise in so many different disciplines. This talent should be invested in some basic research, as well as the applied production studies, to fill the time gaps between the advent of new ideas and their acceptance by governments or other funding agencies for more intensive basic research. CIMMYT's present policy limiting basic research to 5% of its effort seems adequate if such responsibilities are focused in key individuals or areas. In its catalytic role, CIMMYT could coordinate research and serve as an occasional wide hybrids forum for the world, in efforts such as this Symposium today. Linkage lines to centers of excellence for wide hybridization, such as that being built at Kansas State University, would be developed via liaison scientists to maintain and ensure the immediate translation of basic research into applied reality.

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ADAPTATION IN MAIZE

by
Peter Goldsworthy, CIMMYT

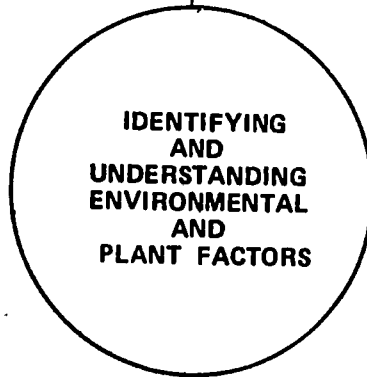
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**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**

**FUNCTIONS FOR DEVELOPING
ADAPTATION AND YIELD STABILITY**



PLANT FACTORS PROVIDED BY:

- GERM PLASM BANK ACCESSIONS**
- BACK-UP POOLS**
- ADVANCED POPULATIONS**
- EXPERIMENTAL VARIETIES**
- ELITE EXPERIMENTAL VARIETIES**

**ENVIRONMENTAL FACTORS
PROVIDED BY:**

**MULTIPLICATION
TESTING**



FARM PRODUCTION

ADAPTATION IN MAIZE

by

Peter Goldsworthy**6.1 INTRODUCTION**

Maize has spread from its geographical origin in Central America to many countries around the world. This global spread, along with the numerous locally adapted taxa and varieties that have evolved or been developed in the process, is strong evidence of the genetic variability that exists in the species for adaptation to a wide range of environments. It would, however, be prohibitively expensive to attempt the scientific improvement of local materials for each of these environments. Fortunately there is little evidence to suggest that this is necessary or desirable. There is fairly general consensus among breeders that it is both feasible and an efficient use of resources to develop varieties that are adapted to a wide range of environments.

At the international program level, this is believed to be the only practical approach; and the development and improvement of widely adapted varieties is a central part of the philosophy and objectives of international institutes such as CIMMYT. The organization of trials that has been described for selecting progeny and testing experimental varieties across a number of environments is a central concept. These trials provide a means of using available genetic variation for the deliberate and systematic development of populations and varieties that are more productive and useful in a wider range of environments than those varieties developed in local or regional programs.

Selection and breeding for disease resistance is an important objective of this series of trials. This aspect is covered in the next paper by Ortega (7.0). The present paper attempts to summarize some of the methods available that may be helpful to the CIMMYT maize program in its effort to develop maize varieties that will perform well in seasonally variable climates and over a range of environments. Final discussion centers on the application of these methods to the series of progeny and variety trials described earlier.

6.2 DISTRIBUTION OF CROP AND CLIMATE

The map (Fig. 6-1) shows the geographical distribution of maize production. M indicates the quantity produced, rather than the area cultivated. It can be seen that maize is grown extensively as a crop from about $40^{\circ}N$ to $40^{\circ}S$ of the Equator. In recent years it has spread to even higher latitudes, into Canada and Northern Europe (15).

The second map (Fig. 6-2) shows the major climatic regions of the tropics and sub-tropics which cover most of the area between these latitudes. The accompanying climatic diagrams (Fig. 6-3) illustrate the characteristics that distinguish these major climatic areas. Some of the most important features can be summarized as follows:

1. Tropical

Tropical wet: continuously hot; heavy precipitation all seasons.

Tropical savanna: hot summer, warm winter; moderate to heavy precipitation confined to the summer season.

2. Sub-Tropical

Sub-Tropical moist: warm summer, cool winter; moderate precipitation all seasons but with a summer maximum.

Sub-Tropical dry: hot summers, mild winters; moderate to light precipitation confined to winter season.

3. Other Climates

Highland: generally cooler than lowlands in the same latitude.

Desert: continuously hot; negligible precipitation. (The irrigated land of the Nile Valley is the only area where maize is grown in the climate.)

The map which shows the geographical distribution of maize production and the climatic zones (Fig. 6-2) indicates how production is distributed by climatic zones. The main points that emerge are:

Half the area grown and over 65% of the grain produced comes from outside the tropics and sub-tropics, principally from the U.S.A. and Eastern Europe.

The area grown in the tropics is almost twice as large as in the sub-tropics, but the total production from the two regions is similar because the yields in the tropics are low.

Most of the tropical production comes from the savanna with seasonal rainfall.

Highland areas of production are confined to Central America, the Andes, and East Africa.

Table 6-1 gives a summary of the distribution of production in the different climatic zones.

Most of the maize production within the tropics is in developing countries where it is used directly as human food. Much of CIMMYT's activity is concerned with these areas where, traditionally, yields are low and the need for food is great. This is reflected in the distribution of the maize trials, most of which are located in countries in Central and South America, West and East Africa, and in Asia and Southeast Asia. Although most of these locations are within the tropics and sub-tropics they represent a wide diversity of environments.

6.3 ADAPTATION OF CROP TO CLIMATE

The principal factors which determine the length of time available for growing a crop are temperature and rainfall. Low temperatures in the spring and autumn determined the growing season for maize in temperate, highland, and sub-tropical climates. Temperature is not usually limiting in tropical climates. In tropical savanna climates, however, rainfall is the principal factor that determines when the growing season begins and ends. It is also the determining factor in some dry, sub-tropical climates.

Clearly, adapted varieties must have the ability to complete the processes of germination, vegetative growth, flower production, and grain filling in the growing season that is available. Since there are large varietal differences in time to maturity, this is one of the primary factors governing the choice of material for a given environment.

Fig. 6-4 shows some results from studies being conducted at CIMMYT's stations at different altitudes in Mexico, which can help to illustrate varietal differences in maturity and how these are influenced by the environment. The results are from contrasting varieties; a Tuxpeño short-plant selection which produces 24 leaves, and China I which only produces about 14 leaves. The time to anthesis is directly related to the number of leaves produced. The evidence available

(Francis, 9; CIMMYT, 5) suggests that within tropical latitudes, and probably within latitudes 30°N and 30°S , the number of leaves depends on the genetic material and is little affected by changes in daylength. At latitudes greater than 30° there is a response to the increase in daylength in a summer growing season and more leaves develop. Thus, when Tuxpeño was grown at Purdue University (43°N latitude), the number of leaves produced increased to 34.

The time to anthesis is, however, directly affected by the environment in another way. Fig. 6-4 shows how the rate of appearance and expansion of leaves is slower at low temperatures. Thus, for a given number of leaves, it takes longer to reach anthesis at El Batán (2250 m elevation) than at Poza Rica (60 m elevation); the difference becomes larger as the number of leaves increases.

Information of this kind has been collected for a number of materials from CIMMYT and elsewhere during the past two years, and is now being collected for all the materials in the advanced unit of the breeding program. The intention is to develop a basis for selecting materials likely to be suited to a given area in tropical latitudes, using these data combined with information on the length of the season for growing a crop and the average temperatures prevailing during that season. Such predictive analysis (based on centralized testing, rather than on empirical regional evaluation or the logistics of breeding programs) would have a valuable, practical application in the CIMMYT program.

The differences between climatic regions indicated above and the seasonal variations that occur within them, are largely predictable. Allard and Bradshaw (1) distinguish these variations in environment from those that are unpredictable, for example, unpredictable fluctuations in weather (such as the amount and distribution of rainfall) as opposed to differences in climate. They stress that because year-to-year fluctuations are unpredictable, the implications for the breeder of variety x year interactions are very different from those of variety x location interactions. Finlay & Wilkinson (8) in their studies of barley also observed that seasonal variability was the principal factor in the environment.

The relative importance of the variety x year, variety x location, and variety x year x location interactions varies substantially: both among major geographic regions and among crop species or populations within a species. Estimates of these sources of variance may be made, and they serve as a guide in the design of test procedures. In many cases, however, the V x Y x L interaction has been substantial and this finding indicates that effective and meaningful evaluation must involve tests at a number of locations and over a series of years. This is more important than striving for precision at any one location.

The breeder's objective is to develop varieties with a consistently good performance across environments; he is attempting to minimize the unfavorable effects of environments on yield. Allard and Bradshaw (1) describe two forms of genetic buffering mechanism - - individual buffering and population buffering - - which minimize these effects and contribute to increased phenotypic stability of yield.

However, in a large breeding program, the variations from site to site and season to season are such that the conventional analysis of variance, into variety x locations, variety x season, and variety x location x season does not provide the breeder with an adequate means of recognizing the characteristics of most interest. That is, they do not provide information in a form suitable for use in selection for adaptation reactions. This is not so much a function of variation among years and locations, as of the number of genotypes that are usually involved and of the inadequacies of the form of analysis of variance itself. Thus, several methods have been developed in the past ten years to characterize genotype x environment interaction in terms of parameters that are useful to the breeder in manipulating adaptation reactions in selection. Some of these methods are described next.

6.4 GENOTYPE x ENVIRONMENT INTERACTIONS

6.4.1 CLASSIFICATION OF GENOTYPE - ENVIRONMENT INTERACTION

A two-way table is the basic data set for an analysis of adaptation, or stability of yield, of a group of varieties over environments (Table 6-2). To illustrate the possible types of interactions that may occur, Allard and Bradshaw (1) used an example in which they assumed there were two genotypes, A and B, and two environments, X and Y, which gave yield differences such that the four genotype-environment combinations can be placed in rank order one to four. Six of the possible 24 interaction types are reproduced in Fig. 6-5. The points to note about these interaction types are: whether genotype A does better than B in each environment (Fig. 6-5, type 1); whether A is superior to B in one environment and inferior in the other (as in type 4); and whether the change in environment affects the genotypes in opposite directions (as in type 3). In practice, the situation is immensely more complicated. With $m = 10$ genotypes and $n = 10$ environments, Allard and Bradshaw give the possible types of interaction as $(m \ n) \cdot n!$ or approximately 10^{145} .

The illustration is used here to emphasize that the genotype x environment interactions in large breeding programs are immensely

complex; thus programs relying solely on the conventional analysis of variance with the variety x locations, variety x season, and VxLxY interactions as measures of adaptability are making quite inefficient use of the data available. Such analyses provide an indication of the overall importance of genotype x environment interactions, but they give no information on the phenotypic stability or adaptation responses of individual entries.

6.4.2 MEASURES OF YIELD STABILITY

Approaches to partitioning the genotype-environment interaction have been made on the basis of the contribution of particular environments to the total G x E interaction (Horner & Frey, 12) and on the bases of the contribution of particular genotypes to the total G x E interaction (Plaisted & Peterson, 19; Baker 2).

The regression analysis described by Finlay and Wilkinson (8) provides a more useful technique for partitioning genotype x environmental interaction into meaningful parameters that describe crop yield stability. The form of the model is given in Table 6-3. The analysis employs a regression, on a logarithmic scale, of variety mean yield on an environmental index. The environmental index was obtained as the logarithm of the mean yield of all varieties grown at the site, and it provides a simple and useful integration of the overall biological effects of the favorable and unfavorable factors of each environment. The adaptation of a variety is defined in terms of its mean yield and a regression coefficient (β). Figure 6-6 shows the population mean and the regression lines of four varieties given by Finlay and Wilkinson to illustrate types of varietal response to environment.

The population mean by definition has a slope, $\beta = 1.0$. Finlay and Wilkinson summarized the types of response as follows:

$\beta = 1.0$ indicates average stability (e.g., Atlas). When associated with low mean yields, the variety is poorly adapted to all environments (e.g., BR 1239).

$\beta > 1.0$ describes varieties that are sensitive to environmental change (have below average stability) and are specifically adapted to high yielding environments (e.g., Provost).

$\beta < 1.0$ indicates relative insensitivity to environmental change (above average stability) and such varieties are specifically adapted to low yielding environments.

The model described by Eberhart and Russell (7) is essentially

similar except that it uses actual yield rather than logarithms. The form of the model is shown in Table 6-4. It provides a means of partitioning the genotype x environment interaction into two parts: the variation due to the response of variety to varying environmental index (SS due to regression) and the unexplained deviations from regression. The analysis of variance is shown in Table 6 5 With this model, as with the Finlay and Wilkinson (8) model, various definitions of a desirable adaptation on stability response can be made, and their relevance depends on the specific nature of the breeding program and the environmental regimes involved. For maize in Midwest USA environments, Eberhart & Russell (7) defined stability as $\beta=1.0$ and $\sum \delta^2_{ij} = 0.0$. Thus, a desirable cultivar would be one with a high mean yield, a regression coefficient of unity, and deviations from regression as small as possible. Rather different definitions of stability and desirability would be relevant in different environmental circumstances and at different levels of plant improvement. Jowett (3) compared the two models in a study on sorghum and noted a number of significant differences between them.

6.4.3 LIMITATIONS OF REGRESSION ANALYSIS

Finlay and Wilkinson (8) observe that lack of a quantitative integrating measure of complex environments, more than any other single factor, has held up the study and exploitation of adaptation in plant breeding programs. Although the use of - - an average performance of a group of varieties has proved a useful method of -- evaluating and grading sites, Eberhart and Russell (7) and Finlay and Wilkinson (8) note the limitations of an environmental index which is not independent of the experimental varieties. The most serious objection to an index of this kind is that the yields of any one variety are, unavoidably, partially correlated with the environmental index against which they are being tested. In addition, the distribution of varieties about the mean yield will depend on the sample of varieties, seasons and sites used for the estimation. Thus, it is very important that estimates of stability parameters are based on results from an adequate number of sites representing the full range of possible environmental conditions, and on an adequate sample of varieties. Freeman & Perkins (10) made several suggestions to avoid this statistical dependency, but they appear to have little practical application for analysis.

6.4.4 BIOMETRICAL- GENETICAL MODELS

An example of a rather different approach, based on models which specify the contribution of genetic, environmental, and genotype

x environmental interactions, is provided by the work of Perkins and Jinks (17, 18). They used the model shown in Table 6-6 to describe the performance of multiple inbred lines. The corresponding data specifications for ℓ varieties in n environments is shown in Table 6-7. The regression analysis is applied to the G x E interaction effects, so that the G x E interaction variance is partitioned into a regression component and deviations from regression. This gives coefficients β which center around zero, since environmental effects have been removed (see Fig. 6-7).

An illustration of the form of the analysis of variance for the regression of the G x E interaction of a single entry over environments and the analysis of variance for a joint regression for a group of varieties over environments is shown in Table 6-8.

In the joint analysis Table 6-8 (2) both parts of the genotype-environment interaction (the heterogeneity between regression MS and the remainder MS) may be significant when compared with the pooled error σ_e^2 .

Perkins & Jinks (17) give the following summary for the interpretation of various situations from these analyses:

1. If either the heterogeneity between regression or the remainder MS is significant, genotype x environment interactions are present.
2. If the heterogeneity MS is significant, it indicates that some of the β 's are significantly positive and others significantly negative, since $\sum \beta_i = 0$.
If this component alone is significant, then genotype x environment interactions can be predicted from the linear regression of the environmental values.
3. If the remainder MS alone is significant, there is either no relationship, or no simple relationship between the genotype environment interactions and the environmental values, so that no predictions can be made.
4. If both components are significant, the practical value of predictions will depend on the relative magnitude of the two components. Even if the heterogeneity of regression MS is not significantly larger than the remainder MS, there is the possibility that the regression of $(d_i + g_i y)$ on ϵ_j for some varieties individually may be significant. For these lines reliable predictions can still be made.

An examination of each of the varieties in turn, for the presence of genotype - environment interactions and for a linear relationship between the latter and the additive environmental values (environmental index) will show that they fall into one of the following categories (see Perkins & Jinks (18)):

1. Varieties which exhibit no genotype-environment interactions, i. e., the response of the variety to environmental variation does not differ from the average for all lines ($\beta = 0.0$).
2. The variety exhibits genotype - environment interactions, in which case it falls into one of the following classes:
 - (a) The linear regression between this interaction and the additive environmental effects accounts for most or all of the interaction.
 - (b) The remainder MS accounts for most of the interaction.
 - (c) Both components are significant.

Perkins and Jinks (17) used the mean performance and regression coefficient to describe the sensitivity of a line to changing environments. With this model, a regression line of $\beta = 0.0$ with zero deviations from regression would be classified as having average stability, and would represent zero genotype x environment interaction. A genotype which is particularly sensitive to environmental change will have a β value $>$ zero. A genotype which is insensitive to environmental change will have a β value which is significantly negative (i. e., $<$ zero).

6.4.5 A COMPARISON OF MODELS

Removing the environmental effects as in the Perkins & Jinks model overcomes some of the objections that apply to the analyses which involve regression of mean yield and an environmental index (Finlay & Wilkinson, 8; Eberhart & Russell 7).

A brief consideration of the differences between the two forms of model will help to explain why. Fig. 6-8 illustrates the relationship between the coefficients in the two types of model.

From Fig. 6-8 (1) it can be seen that the regression coefficients of Finlay and Wilkinson and of Eberhart and Russell center around 1.0 and are equal to $\beta+1$ since they involve the regression of

y_i on ϵ_i and $\frac{1}{n} \sum y_{ij} = \bar{y}_{ij} = \sum \epsilon_j$.

By including the additive genetic contribution d_i of the i^{th} variety to give

$$y_{ij} = \mu + d_i + \epsilon_j,$$

the line is displaced vertically from the mean of all varieties, but its slope is not altered (Fig. 6-8 (2)).

Extension of the model to include the genotype-environment interaction term g_{ij} to give $y_{ij} = \mu + d_i + \epsilon_j + g_{ij}$

causes the line to rotate about the variety mean, but it rotates about $\beta = 1.0$ (Fig. 6-8 (3)). Finally, in the Perkins & Jinks (17) model, the additive environmental effects are removed. The genotype-environment interaction, is plotted against the environmental index so that we are testing the hypothesis that a part of the genotype-environment interaction sum of squares is a linear function of the additive environmental values (environmental index). The coefficients so obtained are centered about zero.

Table 6-9 illustrates the difference in the results obtained from an analysis using the Perkins & Jinks model and an analysis using a regression of mean yield on the environmental index (data from 4th ISWYN, Byth (4)). The regression of mean yield differs from the analysis of the G x E interaction effects in the following ways:

- (a) For each variety the regression coefficient for mean yield is equal to regression coefficient for G x E interaction + 1.0.
- (b) The regression mean square is much larger.
- (c) The mean square for deviations from regression is identical.
- (d) Since the regression mean square is larger and the mean square for deviations from regression is the same, the values of r and R^2 are also larger.

Thus, regression analysis of mean yield indicates that regression accounts for 80 to 90% of the variation over environments, whereas regression analysis of GxE effects reveals that regression only accounts for between 0 and 30% of the variation over environments.

Both models are valid, the difference in the result being a facsimile of the differences between the models. However, it does reveal the influence of the correlation between mean yield and environmental index on the tests of significance of regression. The models

therefore demand different interpretation. Regressions involving mean yield express deviations from linearity in terms of overall yield response, and provide valid comparisons among varieties on this basis. In contrast, regressions involving the G x E interaction effects express deviations from linearity in terms of the G x E interactions variance. That is, they indicate the magnitude of linear and non-linear environmental responses of a genotype. These differences between the models suggest that regression of yield may provide a useful indication of stability of response, but it is relatively uninformative on the specifics of environmental response. Regression of the G x E interaction effect provides equivalent information on the slope of the regression response, and it can provide much more information on the adaptation reactions (G x E interaction effects) of genotype.

Both models described suffer from two main deficiencies: they assume a form of response against which actual responses are compared; secondly the deviations from the assumed response are pooled, so that the analyses give no information on specific forms of response that would be of help in trying to identify the environmental factors causing the response and the bases for differences in reaction. Consider, for example, the situation shown in Fig. 6-9. The two varieties have exactly opposite responses to each environment, yet from a linear regression analysis, mean yield, β and the deviations from regression are the same. Perkins and Jinks (18) examined the non-linear portion of the G x E interaction and found that it could be reduced by separating genotypes into groups on the basis of significant positive and negative correlations for the deviations from the linear regression, such that all the positive correlations occur between members of the same group and all the negative correlations between members of different groups. This effectively separates the two varieties in Fig. 6-9 and the groups to which they belong can then be examined separately.

The regression coefficient β is a useful parameter of yield stability if the deviations from regression are small; that is, if the assumed response form approaches validity for all the varieties tested. The meaning and value of β is reduced as the deviation mean square increases in relative magnitude, regardless of the significance of β . Where large amounts of data are involved, as in CIMMYT's proposed maize progeny tests, it is probable that many of the responses will be non-linear and the deviations from regression will be large. In these circumstances other forms of analysis now being developed may prove more useful.

6.4.6 GROUPING ANALYSIS METHODS

A new approach to the analysis of genotype-environment

interaction, being developed at the University of Queensland may provide a more informative basis of examination for the plant breeder than the methods now generally available (Byth, 4). Some aspects of the procedures and results will be described briefly here, and additional information on parts of the analysis and an application were presented by Mungomery, Shorter, and Byth (16).

The analysis involves the application of numeric classificatory (or cluster or pattern) analyses to the classification and interpretation of environmental responses. In brief, the procedures aim to reduce the immense complexity involved in the comparison of dynamic responses of varieties, by grouping those varieties which respond in a similar manner across environments. A limited number of relatively homogeneous groups of varieties can be derived in this way, and comparisons of the responses of these groups may then be made comparatively simply.

Some of the main features can be summarized as follows:

- (1) No assumed distributions are involved, and the actual differences among responses of cultivars are studied.
- (2) Groups of lines, which respond in a similar way across environment, are formed.
- (3) The dynamic responses of these relatively homogeneous groups across environments can be compared, using simple graphical techniques. This information can be used directly in selection and breeding, and provides a basis for the physiological analysis of the response of populations to environments.
- (4) The usefulness of particular environments as test sites for the selection of specific response differences can be documented, and this may allow definition of more efficient testing procedures in breeding.
- (5) Classification of environments can be done in order to identify groups of environments within which varietal response is similar. In association with (3) above, this allows the possibility of objective analysis of the environmental factors underlying response.

This form of analysis has already been applied to data from ISWYN 4. Linear regression analysis showed 91% of the G x E interaction variance to be non-linearly related to the environmental index. Analysis of individual cultivars showed a maximum of 33% linearity.

Thus, linear regression analysis of adaptation responses resulted in the pooling of most of the information on response as non-specific and relatively uninformative deviations from linearity. In contrast, classificatory analysis allowed the identification of groups which accounted for 94% of the G x E variance. Discussions with CIMMYT wheat breeding staff confirmed that their experience and knowledge of these cultivars from ISWYN 4 validated much of the information provided by this analysis of published data. They indicated that the analysis also supplied additional or more precise information on response of which they were unaware. The power of the procedure is shown by its accurate reflection of the known detailed responses of cultivars, using only the published information of ISWYN 4. This finding suggests that the method may be very useful in the breeding and selection of populations of breeding lines.

Some potential applications of parts of these procedures in breeding, selection, and physiological analysis were discussed by Mungomery, Shorter, and Byth (16).

6.5 APPLICATION OF ADAPTATION ANALYSIS IN THE CIMMYT MAIZE PROGRAM

The maize testing program that CIMMYT is now sending to the field consists of two main parts: progeny tests and experimental variety trials. Discussion here focuses on how some of the presently available methods of analysis can be applied to the results from this series of trials and thus help the breeder develop varieties with a consistently good performance.

6.5.1 PROGENY TESTS

CIMMYT now has identified 28 advanced populations that will be tested in an international series of progeny trials in 1974. The trials will be 16x16 simple lattice designs with two replications at each site. There will be 250 progeny families in each trial with 6 check varieties. The seed available from the 1973/74 winter season nursery is sufficient to provide for up to 6 trials of this kind for each population in addition to reserve seed and seed needed to establish the next nursery (winter 1974/75). By March/April 1974, 157 of these trials will have been sent to 23 countries and will be grown at 32 different locations.

From the results of these trials, about 50% of the progenies will be selected for the next generation. In addition, up to ten progenies will be selected at each site and ten progenies will be selected on the basis of results across sites, for the formation of experimental varieties.

Clearly the task of selection from such large numbers of progenies is formidable and, if it is to be effective, a well-organized procedure of selection is needed. To be of any value, the results of the progeny trials have to be available before crosses are made in the following nursery. The very limited time available, as shown in Fig. 6-10, makes the development of an efficient and rapid system of selection even more imperative. Winter nurseries will be shown in Mexico in November so that pollinations will have to be made in mid-January. CIMMYT intends to plant all 250 progenies in the nurseries in November to extend the period available for the return, checking, and analysis of data. The decision on which of these progenies to use as parent materials will be made before mid-January (when pollinations have to be made), and will be based on the results of the progeny tests. The present discussion is concerned primarily with how the data has to be assembled, analyzed, and presented to ensure that the breeder has the information he needs to make informed decisions.

6.5.2 METHODS OF SELECTION

Consider for example, the selection of progenies for the formation of experimental varieties. In the early stages of the testing program which CIMMYT is establishing this year, the breeder wishes to select up to ten of the "best" progenies at each site and the ten "best" progenies over all sites. This need has been accepted, since initially it is probable that only a few of the progenies selected will be common to two or more sites. However, if selection for wider adaptation and stability of yield is effective, the expectation is that, over time progressively more of the selected progenies will be found common to several sites. Indeed, this will be one of the first indicators of whether the strategy is successful or needs to be modified.

To proceed with our example, assume that, in the first instance, selection is based on yield. Table 6-10 shows the results of such a selection based on the analysis of individual experiments at each of four sites and of a combined analysis for the four sites. It is interesting to note that two of the selections over sites (progeny No. 135 and 178) were not among the best ten at any individual site. Apart from this, however, the incomplete table is uninformative and tells the breeder nothing about the difference in performance between his selected progenies and the rest of the progenies at any one site; nor does it tell him anything about the performance of the selection from one site at other sites.

If we complete the table, by adding the yields that are missing, some of these points become more apparent (Table 6-11). For example, four of the progenies selected at two low yielding sites (progeny Nos. 77

and 244 at Poza Rica; progeny Nos. 40 and 46 at Obregón) have average yields well below the rest of the selected population. If we now look at some of these yields graphically (Fig. 6-11), it can be seen that the mean yield of the selection is higher than the mean yield of the whole population; mainly as a result of the performance of a few progenies (Nos. 108, 135, 165, and 178). The response of the group to favorable environments is probably similar to that of the overall population. However, it also can be seen that, in addition to their low mean yield, the progenies selected at the low yielding site are less responsive to favorable environments. This raises the question as to whether their selection is justified by their better -than- average performance at one site, and whether they would have been selected if information on their performance at other sites had been available to the breeder in a readily assimilable form. This decision will of course also be influenced by the error variance of the observations at the site where the selection is made. The least significant differences shown on the graph suggest that, in the example being considered, a decision on whether the difference is real or apparent is in some cases marginal; in view of their performance across sites, the selections may be questionable.

This example is given only because it seems to illustrate the difficulties that face the breeder, and emphasizes the urgent need to develop a system that will provide him with the information required in a more complete and readily assimilated form.

Similar problems are faced by all breeders testing across environments, but they are particularly formidable for the CIMMYT maize program because of its sheer size and complexity. The problem is further compounded by the fact that so many different aspects of performance have to be taken into account in selection. This is necessary because the analytical methods used do not describe clearly the specific adaptation reactions shown by lines across environments; so a very complex combination of criteria have to be used. Part of the problem is that breeders and others have not been able to define the precise forms of adaptation response desirable or necessary for particular situations.

6.5.3 A SELECTION PROCEDURE

To overcome at least some of these problems, the CIMMYT maize program needs to develop selection procedure that will make better use of the information that is available.

However potentially useful they may be, the grouping analyses that have been described are not a present developed to the point where they are available to CIMMYT. Within the limitations of the other methods, the biometrical-genetical model of Perkins and Jinks (17) appears to offer some advantages. Therefore, for the purpose of illustrating how a selection procedure might be developed, the assumption is made that CIMMYT will probably use this model. The selection of progenies for experimental varieties is used as an example of how the analysis would be applied. The illustration is not intended to be definitive but shows the steps which are likely to be involved (see Appendix).

Stage 1: involves the analysis of the individual trials and the formation of tables of means. The results from individual trials are output to a file tape which will serve as the input to subsequent stages of the analysis, for all 28 populations.

Stage 2: Is the analysis of complete sets of trials (usually six). It includes the formation of data into a two way classification by entries and by environments in preparation for the analysis of adaptation and stability of yield.

The output of this stage includes a tabulation summarizing the performance of each entry over environments, and a combined analysis of variance of the genotype-environment interaction for the 250 entries.

The analyses would be made on yield, but a similar analysis and summary could be made for any other chosen variable.

Stage 3: Includes several aids to selection of progeny on the basis of the analysis completed in Stage 2. No attempt is made to illustrate a self-contained selection procedure though it is possible that a more self-contained system than the one illustrated could be developed as information becomes available. The first aid consists of a division of the progenies into categories according to the type of interactions they exhibit. The results of this division may suggest another separation of the progenies into homogenous groups on the basis of correlations between the deviations from regression for pairs of progenies.

Finally, selections based simply on mean performance over sites and performance at each site are tabulated so that the means of each group of selections can be compared with the population mean.

6.5.4 EXPERIMENTAL VARIETY TRIALS

There are already many examples of adaptation and yield stability analyses applied to maize variety trials (Bolton & Scaife (3), Eberhart Penny and Harrison (6), Harrison (11), and Little (14)).

The experimental varieties derived from the CIMMYT progeny testing program will probably be tested in 6x6 sample lattice trials. The trials will be stratified according to varieties and climates, but within anyone group of trials it is expected that the number of test sites will be large. To determine the extent and the limits of adaptation of varieties a similar analysis to the one described will have to be developed for these series of trials also.

The evidence suggests that by a methodical analysis of information from these two series of trials (the progeny trials and the experimental variety trials) CIMMYT can develop varieties which have above average mean performance across a range of environments. To this end it is important that the various populations undergoing improvement are assessed at the outset for their mean performance and sensitivity to environmental variations. It is also important that this sensitivity be measured over those environments where the materials are ultimately to be grown.

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TABLE 6-1.

**ESTIMATED PRODUCTION AND AREA OF MAIZE
BY CLIMATE REGIONS**

REGIONS	PRODUCTION 000's m.t.	AREA 000's ha	YIELD kg/ha
Tropical Rainforest	8,441	8,037	1050
Tropical Savanna	47,842	40,851	1171
Sub-tropical	44,254	23,715	1866
Temperate	169,115	44,752	3779
	<hr/>	<hr/>	<hr/>
Total	261,175	28,846	

TABLE 6-2.
DATA SET FOR ANALYSIS OF
ADAPTATION AND YIELD STABILITY

Environments. $j = 1, n$

Variety $i=1, \ell$	E_1	E_2	E_3 - - - - -	E_n	
V_1	Y_{11}	Y_{12}	Y_{13} - - - - -	Y_{1n}	$\sum_j Y_{1j}/n = \mu_1$
V_2	Y_{21}	Y_{22}	Y_{23} - - - - -	Y_{2n}	$\sum_j Y_{2j}/n = \mu_2$
V_3					.
.					.
.					.
V_ℓ	$Y_{\ell 1}$	$Y_{\ell 2}$		$Y_{\ell n}$	$\sum_j Y_{\ell j}/n = \mu_\ell$
	$\sum_i Y_{i1}/\ell$		- - - - -	$\sum_i Y_{in}/\ell$	$\sum_{ij} Y_{ij}/\ell n$

The environmental index I_j at the j^{th} environment is given by:

$$I_j = \left(\sum_i Y_{ij}/\ell - \left(\sum_{ij} Y_{ij}/\ell n \right) \right), \sum_j I_j = 0.$$

TABLE 6-3.

YIELD STABILITY MODEL

Finlay, Wilkinson (1963)

$$\log_{10} Y_{ij} = \mu + d_i + \beta_i I_j + \delta_{ij}$$

where:

Y_{ij} = the yield of the i^{th} variety in the j^{th} environment

μ = is the mean yield of all varieties at all sites

d_i = yield deviation of i^{th} variety

β_i = the regression coefficient for the i^{th} variety on I_j

I_j = the environmental index at the j^{th} environment

δ_{ij} = the deviation from regression of the i^{th} variety at the j^{th} environment.

TABLE 6-4.

YIELD STABILITY MODEL

Eberhart & Russell (1966)

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

where:

Y_{ij} = the yield of the i^{th} variety in the j^{th} environment

μ_i = the mean of the i^{th} variety over all environments

β_i = the regression coefficient that measures the response of the i^{th} variety to varying environments

δ_{ij} = the deviation from regression of the i^{th} variety at the j^{th} environment

I_j = the environmental index at the j^{th} environment, defined in terms of the deviation from the mean of all environments.

TABLE 6-5.

ANALYSIS OF VARIANCE OF ESTIMATES OF STABILITY PARAMETERS
(From: Eberhart & Russell (1966))

<u>SOURCE</u>			
Total		vn-1	$\sum_{ij} \sum Y_{ij}^2 - CF.$
Varieties		v-1	$\frac{1}{n} \sum_i Y_i^2 - CF.$
Within varieties		v(n-1)	$\sum_{ij} \sum Y_{ij}^2 - \sum_i Y_i^2/n$
Regressions		v	
Regression Var	1	1	$(\sum_j Y_{1j} I_j)^2 / \sum_j I_j^2$
Var	2	1	$(\sum_j Y_{2j} I_j)^2 / \sum_j I_j^2$
	⋮		
Var	v	1	$(\sum_j Y_{vj} I_j)^2 / \sum_j I_j^2$
Deviations		v(n-2)	
Var	1	n-2	$\sum_{ij} \delta_{ij}^2 - (\sum_j Y_{1j}^2 - (Y_1^2)/n) - (\sum_j Y_{1j} I_j)^2 / \sum_j I_j^2$
Var	2	n-2	$(\sum_j Y_{2j}^2 - Y_2^2/n) - (\sum_j Y_{2j} I_j)^2 / \sum_j I_j^2$
	⋮		
Var	v	n-2	

TABLE 6-6.

BIOMETRICAL-GENETICAL MODEL (Perkins & Jinks (1968))

The performance Y_{ij} of the i^{th} line in the j^{th} environment can be written as:

$$Y_{ij} = \mu + d_i + \epsilon_j + g_{ij} + e_{ij}$$

where:

μ = grand mean over all entries and environments

d_i = additive genetic contribution to the i^{th} variety

ϵ_j = additive environmental contribution of the j^{th} environment

g_{ij} = genotype - environmental interaction of the i^{th} line in the j^{th} environment

e_{ij} = experimental error of estimate

d_i, ϵ_j and g_{ij} are considered as fixed effects so that

$$\sum_i d_i = 0, \quad \sum_j \epsilon_j = 0 \quad \text{and} \quad \sum_{ij} g_{ij} = 0.$$

TABLE 6-7.

SPECIFICATION FOR l ENTRIES IN n ENVIRONMENTS FOR
BIOMETRICAL-GENETICAL MODEL (Perkins & Jinks (1968))

Entries ($i=1, l$)	Environments ($j=1, n$)			Sum	Mean
	1	2	n		
1	$\mu + d_1 + \epsilon_{11} + g_{11}$	$\mu + d_1 + \epsilon_{12} + g_{12}$	$\mu + d_1 + \epsilon_{1n} + g_{1n}$	$Y_{1.}$	$Y_{1.}/n = \mu + d_1$
2	$\mu + d_2 + \epsilon_{21} + g_{21}$	$\mu + d_2 + \epsilon_{22} + g_{22}$	$\mu + d_2 + \epsilon_{2n} + g_{2n}$	$Y_{2.}$	$Y_{2.}/n = \mu + d_2$
\vdots					
\vdots					
\vdots					
l	$\mu + d_l + \epsilon_{l1} + g_{l1}$	$\mu + d_l + \epsilon_{l2} + g_{l2}$	$\mu + d_l + \epsilon_{ln} + g_{ln}$	$Y_{l.}$	$Y_{l.}/n = \mu + d_l$
Sum	$Y_{.1}$	$Y_{.2}$	$Y_{.n}$	$Y_{..}$	
Mean	$Y_{.1}/l = \mu + \epsilon_1$	$Y_{.2}/l = \mu + \epsilon_2$	$Y_{.n}/l = \mu + \epsilon_n$		$Y_{..}/ln = \mu$

$$\epsilon_j \text{ estimated from } \mu + \epsilon_j = Y_{.j}/l$$

$$d_i \text{ estimated from } \mu + d_i = Y_{i.}/n$$

$$\mu = Y_{..}/ln$$

hence g_{ij} estimated as $g_{ij} = Y_{ij} - \mu - d_i - \epsilon_j$

TABLE 6-8.

BIOMETRICAL-GENETICAL MODEL (Perkins & Jinks (1968)).

1. Regression Analysis for the i^{th} Variety:

	Environments			
	1	2	3	
$(d_i + g_{ij})$	.	.	.	$= d_i$
ϵ_j	.	.	.	
Source	d.f.			M.S.
Regression	1			$\beta_i^2 \sum (\epsilon_j)^2$
Remainder	(n-2)			$\sum_j \delta^2_{ij} / (n-2)$

2. Joint Regression Analysis for l Varieties:

Source	d.f.	M.S.
Varieties	($l-1$)	$n \sum_i (d_i)^2 / (l-1)$
Environments	($n-1$)	$l \sum_j (\epsilon_j)^2 / (n-1)$
Lines x Envir.	($l-1$) ($n-1$)	
Heterogeneity between regression	($l-1$)	$\sum_i (\beta_i)^2 \sum_j (\epsilon_j)^2 / (l-1)$
Remainder	($l-1$) ($n-2$)	$\sum_{ij} \delta^2_{ij} / (l-1) (n-1)$
Pooled error	σ_e^2	

Table 619

Estimates of stability parameters from the regression of mean yield (Y_{ij}) and of the genotype-environment interaction ($g_i E_j$) on the environmental index
(data from 4th ISWN. Byth (4))

Groups of Varieties	Mean Yield Kg/ha	No. in groups	EFFECT INVOLVED IN REGRESSION											
			Groups mean Yield Y_{ij}						G x E Interaction effect $g_i E_j$					
			Total S.S. x10 ⁻⁶	Reg. Coeff. β	Reg. M.S. x10 ⁻⁶	Dev. M.S. x10 ⁻⁶	r	R ² %	Total S.S. x10 ⁻⁶	Reg. Coeff. β	Reg. M.S. x10 ⁻⁶	Dev. M.S. x10 ⁻⁶	r	R ² %
I	2.630	5	98.7	0.912	82.0	.274	.91	83	17.47	-.038	0.77	.274	-.21	4.3
II	2.512	4	74.5	0.841	69.7	.078	.97	94	7.26	-.159	2.50	.078	-.59	34.4
III	2.732	5	119.1	1.048	108.3	.177	.95	91	11.02	.048	0.23	.177	.14	2.0
IV	2.398	4	112.8	0.989	96.5	.268	.92	86	16.36	-.011	0.01	.268	-.03	0.1
V	1.960	3	67.9	0.617	37.5	.497	.74	55	44.84	-.383	14.49	.497	-.57	32.3
VI	3.338	9	142.0	1.171	135.2	.111	.98	95	9.67	.171	2.88	.111	.54	29.8
VII	3.518	3	189.8	1.304	167.7	.362	.94	88	30.98	.304	9.09	.362	.54	29.2
VIII	3.077	5	107.0	0.968	92.5	.237	.93	86	14.51	-.032	0.10	.237	-.08	0.7
IX	3.074	6	96.9	0.938	86.8	.164	.95	90	10.41	-.062	0.38	.164	-.19	3.6
X	3.098	5	125.8	1.022	103.1	.373	.80	82	22.78	.022	0.05	.373	-.05	0.2

TABLE 3-10. PROGENIES SELECTED AT EACH OF FOUR SITES AND ON MEAN YIELD OVER SITES AS BASIS FOR FORMATION OF EXPERIMENTAL VARIETY

(EXP No. 25 YELLOW GRAIN BASE POPULATION 1973)

PROGENY No.	GRAIN YIELDS Kg/ha				MEAN OF 4 SITES
	TLALTIZAPAN	PANAMA	POZA RICA	OBREGON	
9	10,854	-	-	-	-
40	-	-	-	4,273	-
46	-	-	-	4,420	-
77	-	-	4,999	-	-
90	11,017	-	-	-	-
103	-	6,276	-	4,480	-
108	11,594	6,292	5,053	-	6,756
118	-	-	5,173	-	-
119	-	-	-	4,471	-
129	-	-	-	4,624	-
134	11,631	-	-	-	6,225
135	-	-	-	-	6,035*
150	-	-	5,256	-	-
162	11,303	-	-	-	6,254
163	-	6,124	-	4,713	6,248
165	10,862	6,197	-	4,402	6,515
168	-	6,932	5,184	-	-
170	-	6,299	-	4,912	5,657
172	-	6,251	5,299	-	-
173	11,252	-	-	-	-
175	10,982	-	-	-	-
178	-	-	-	-	6,612*
188	-	6,256	-	-	-
193	-	-	-	4,621	-
196	-	-	-	4,472	-
205	-	6,351	5,139	-	6,072
208	11,005	-	-	-	-
217	-	6,243	5,638	-	6,337
230	-	-	4,975	-	-
242	10,773	-	-	-	-
244	-	-	5,138	-	-

Site means

*low av. yield selected on mean over 4 sites

TABLE 6-11. PROGENIES SELECTED AT EACH OF FOUR SITES AND ON MEAN YIELD OVER SITES
AS BASIS FOR FORMATION OF EXPERIMENTAL VARIETY
(EXP No. 25 YELLOW GRAIN BASE
POPULATION 1973)

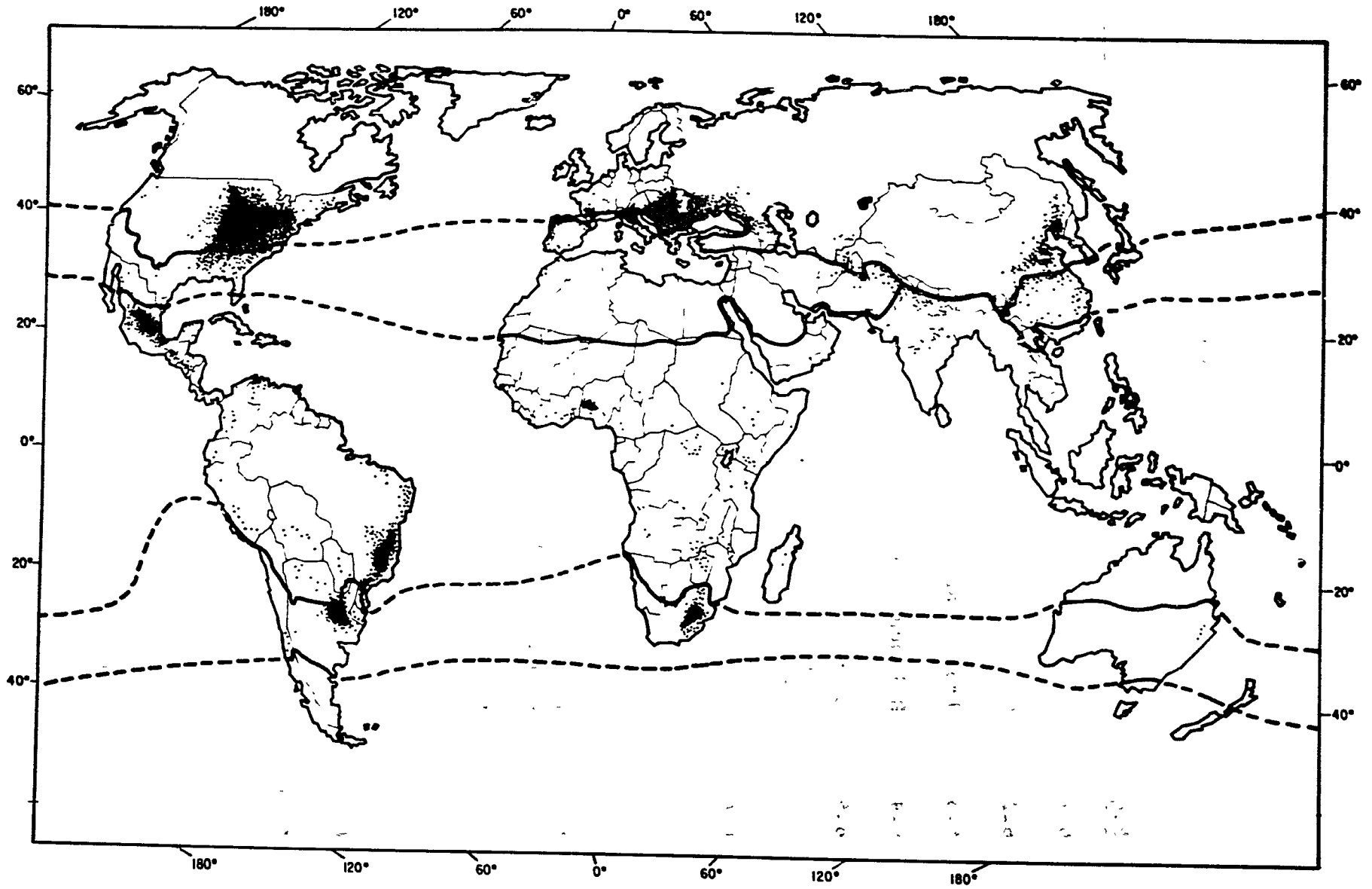
PROGENY No.	GRAIN YIELDS Kg/ha				MEAN OF 4 SITES
	TLALTIZAPAN	PANAMA	POZA RICA	OBREGON	
9	10,854	4,381	4,795	3,765	5,948
40	8,392	5,075	3,156	4,273	5,224 ←
46	7,400	4,273	4,356	4,420	5,112 ←
77	6,657	4,406	4,999	2,578	4,658 ←
90	11,017	5,226	4,373	3,501	6,029
103	9,102	6,276	3,340	4,480	5,800
108	11,594	6,292	5,053	4,084	8,756
118	9,929	4,347	5,173	3,408	5,714
119	9,351	5,148	4,267	4,471	5,809
129	8,835	5,292	4,561	4,624	5,828
134	11,631	5,869	4,230	3,171	6,225
135	10,153	4,202	4,776	5,008	6,035 *
150	7,527	5,657	5,256	3,174	5,404
162	11,303	5,155	4,551	4,008	6,254
163	9,737	6,124	4,419	4,713	6,248
165	10,862	6,197	4,599	4,402	6,515
168	7,452	6,932	5,184	2,657	5,556
170	9,590	6,299	4,826	4,912	5,657
172	9,756	6,251	5,299	2,904	6,053
173	11,252	4,423	3,917	3,689	5,820
175	10,982	5,664	3,371	3,308	5,831
178	10,326	6,226	4,155	3,942	6,162 *
188	9,564	6,256	3,196	3,690	5,677
193	8,974	5,375	3,710	4,621	5,670
196	8,259	5,379	4,120	4,472	5,558
205	9,087	6,351	5,139	3,709	6,072
208	11,005	5,671	4,131	2,711	5,880
217	9,524	6,243	5,638	3,942	6,337
230	8,716	4,612	4,975	3,025	5,332
242	10,773	4,993	3,872	2,562	5,550
244	7,566	4,849	5,138	2,913	5,117 ←
Site means	9,586	5,466	4,373	3,779	5,825

* low. av. yield selected on
mean over 4 sites ←

LIST OF FIGURES

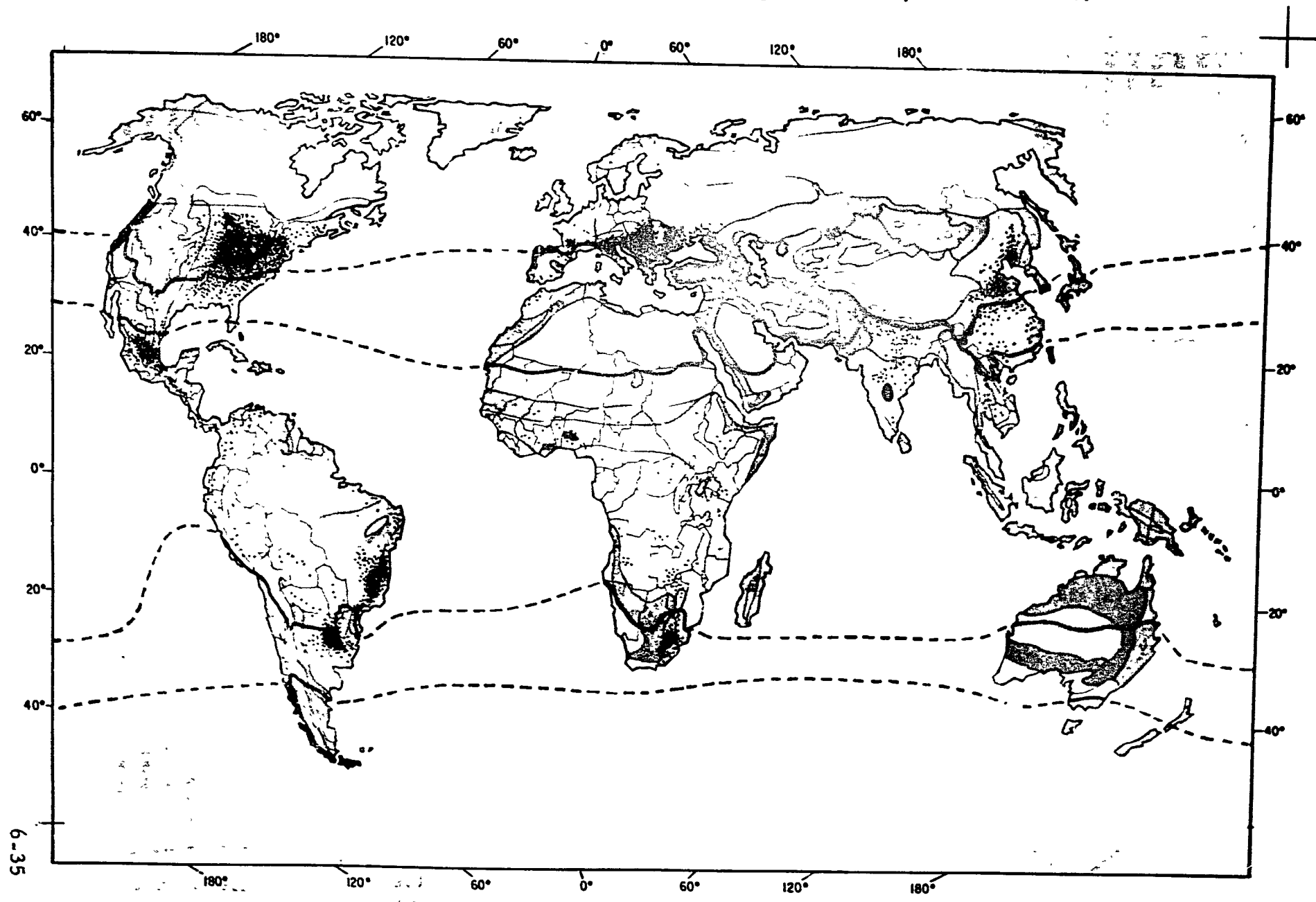
<u>Figure</u>	<u>Title</u>
6-1	Geographical distribution of maize production
6-2	Distribution of maize production by climate zones
6-3	Tropical and sub-tropical climates
6-4	Relation of number of leaves and days to anthesis
6-5	Graphical representation of some genotype-environment interactions (Allary & Bradshaw (1964))
6-6	Regression lines, showing the relationship of individual yields and four varieties and population mean of 277 varieties of barley grown at different sites and seasons. C, Clinton; M, Minlaton; W, Waite Institute. (From Finlay & Wilkinson (1966))
6-7	Regression of genotype-environment interaction and environmental index (Perkins & Jinks (1968))
6-8	Relation between regression coefficients
6-9	Varieties with opposing responses as deviations from regression
6-10	Timetable for data analysis and interpretation
6-11	Performance of some selected progeny at four test sites (From Exp. No. 25 "Yellow-grain" base population, 1973)

Fig. 6-1. Geographical distribution of maize production.



6
E
3
4
0

Fig. 6-2. Distribution of maize production by climate zones.



6-35

Fig. 6-3. TROPICAL AND SUB-TROPICAL CLIMATES

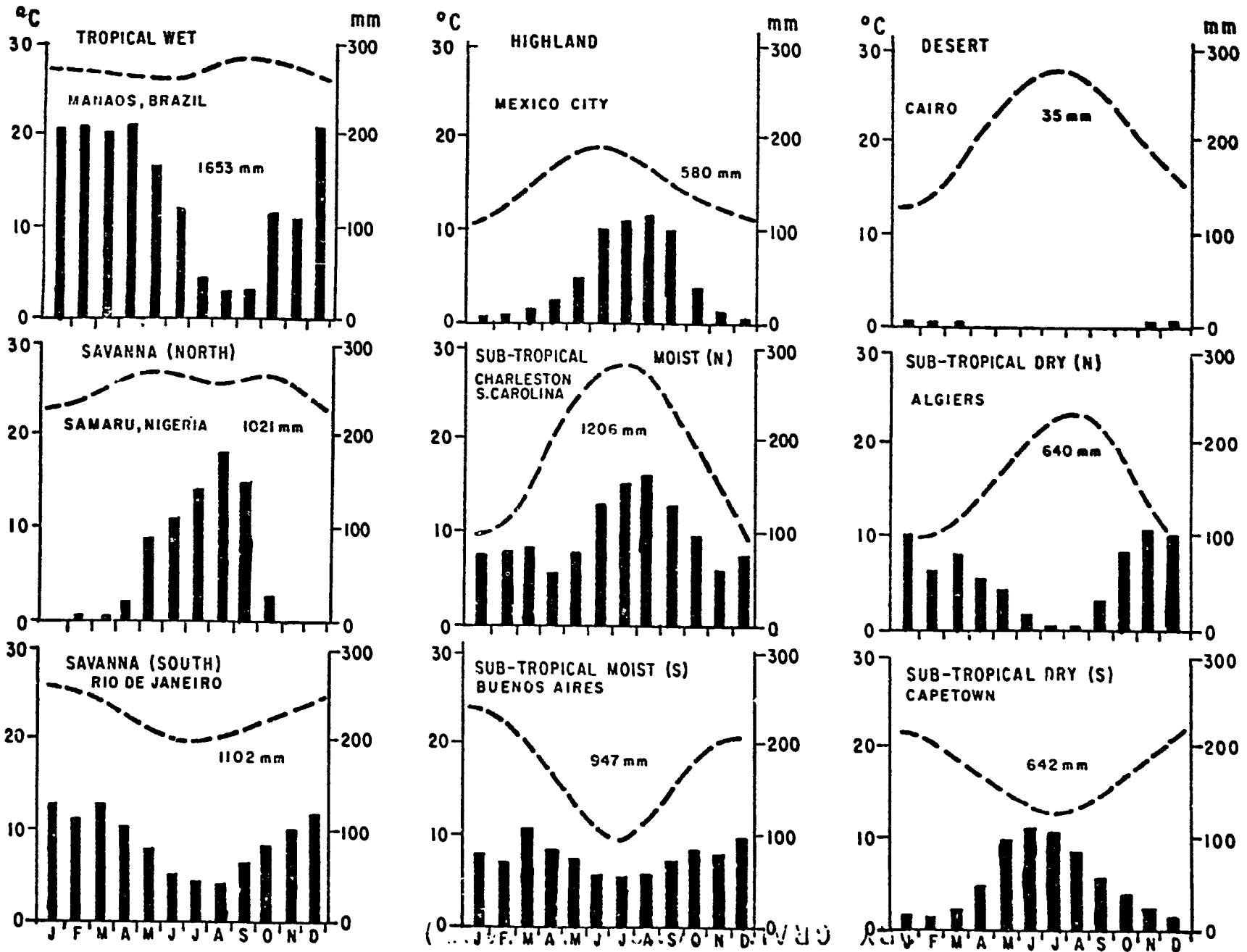
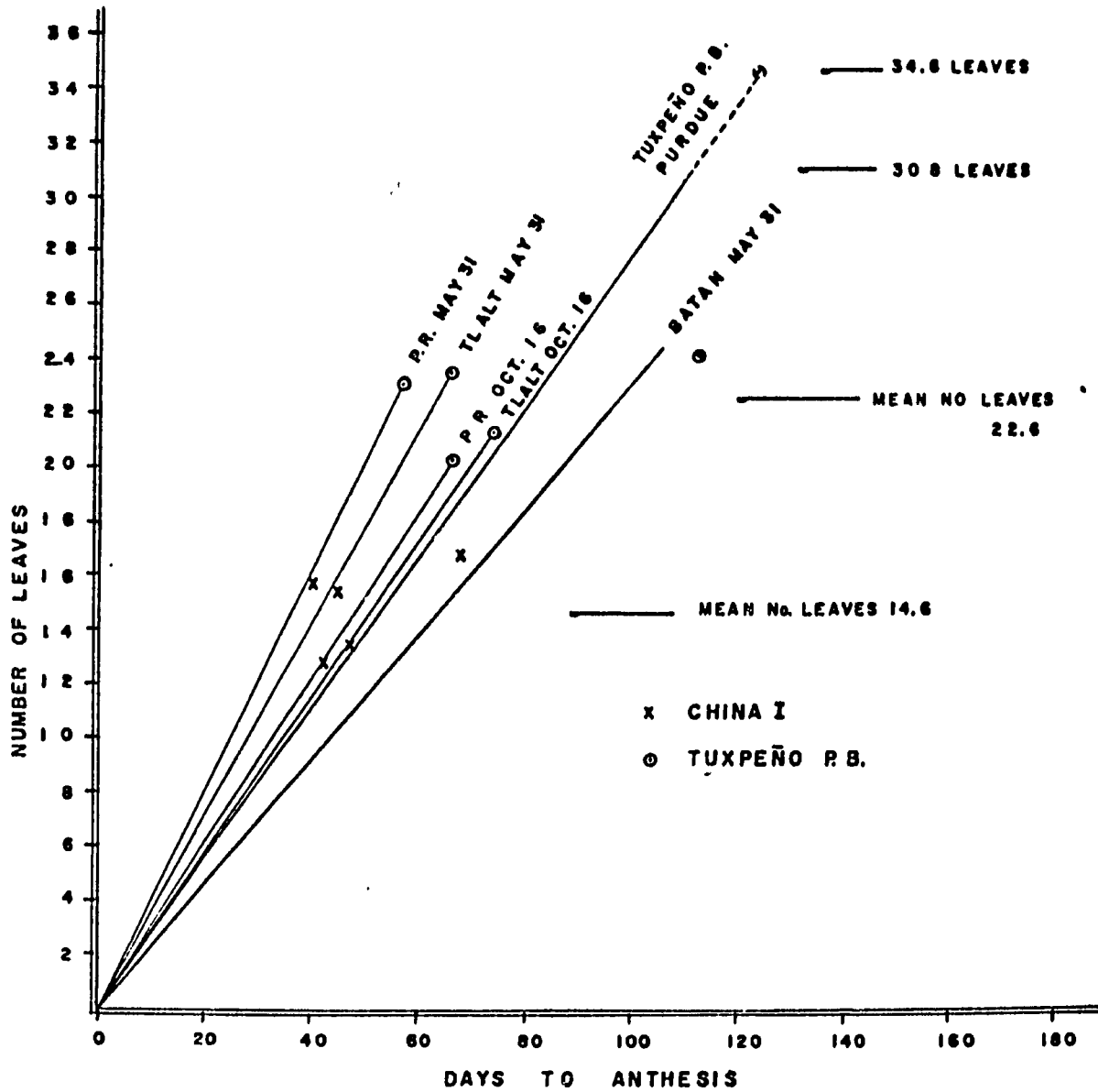


Fig. 6-4.

RELATION OF NUMBER OF LEAVES AND DAYS TO ANTHESIS

WINTER AND SUMMER CROPS AT THREE SITES IN MEXICO



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Fig. 6-5 GRAPHICAL REPRESENTATION OF SOME GENOTYPE-ENVIRONMENT INTERACTIONS. (Allard & Bradshaw (1964))

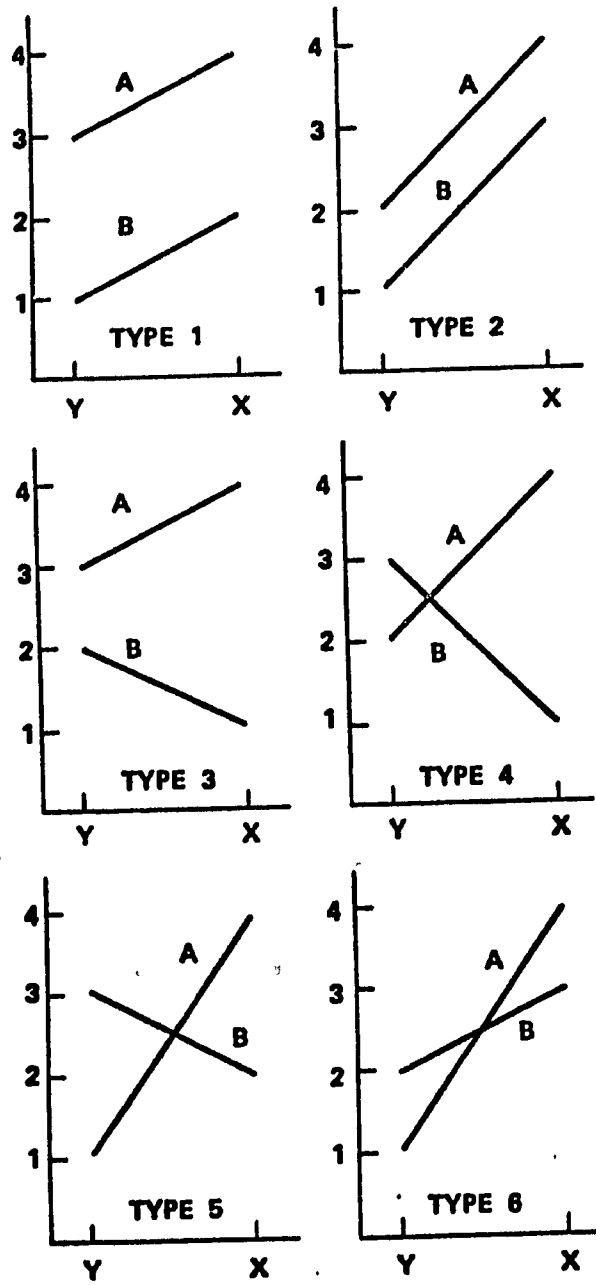


Fig. 6-6. Regression lines, showing the relationship of individual yields and four varieties and population mean of 277 varieties of barley grown at different sites and seasons. C, Clinton; M, Minlaton; W, Waite Institute. 58, 59, 60 represent 1958, 1959, 1960.

(From Finlay & Wilkinson (1966))

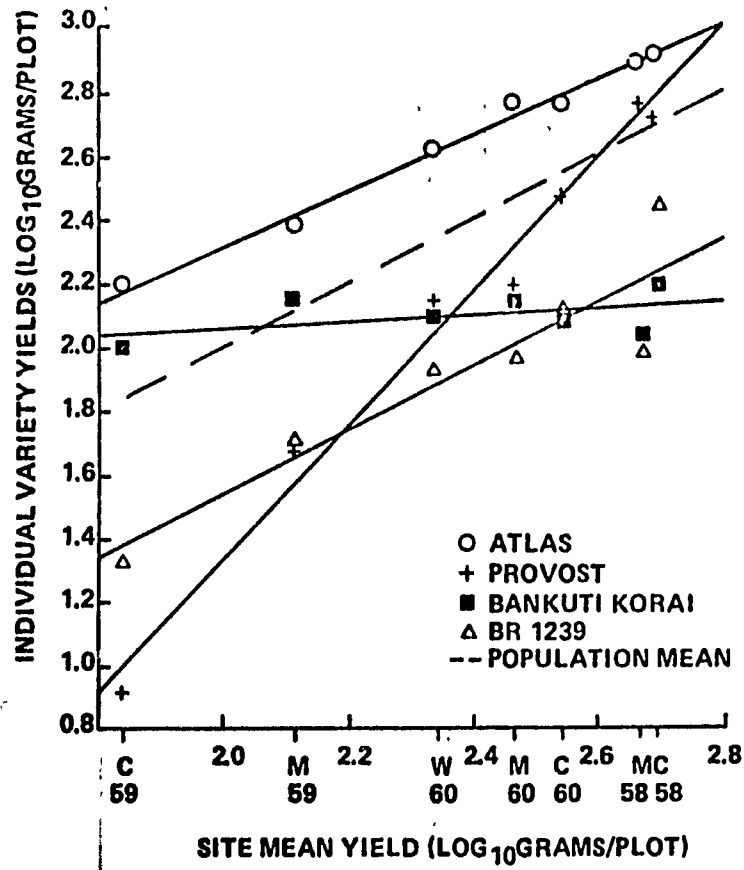


Fig. 6-7. REGRESSION OF GENOTYPE-ENVIRONMENT INTERACTION AND ENVIRONMENTAL INDEX (Perkins & Jinks (1968))

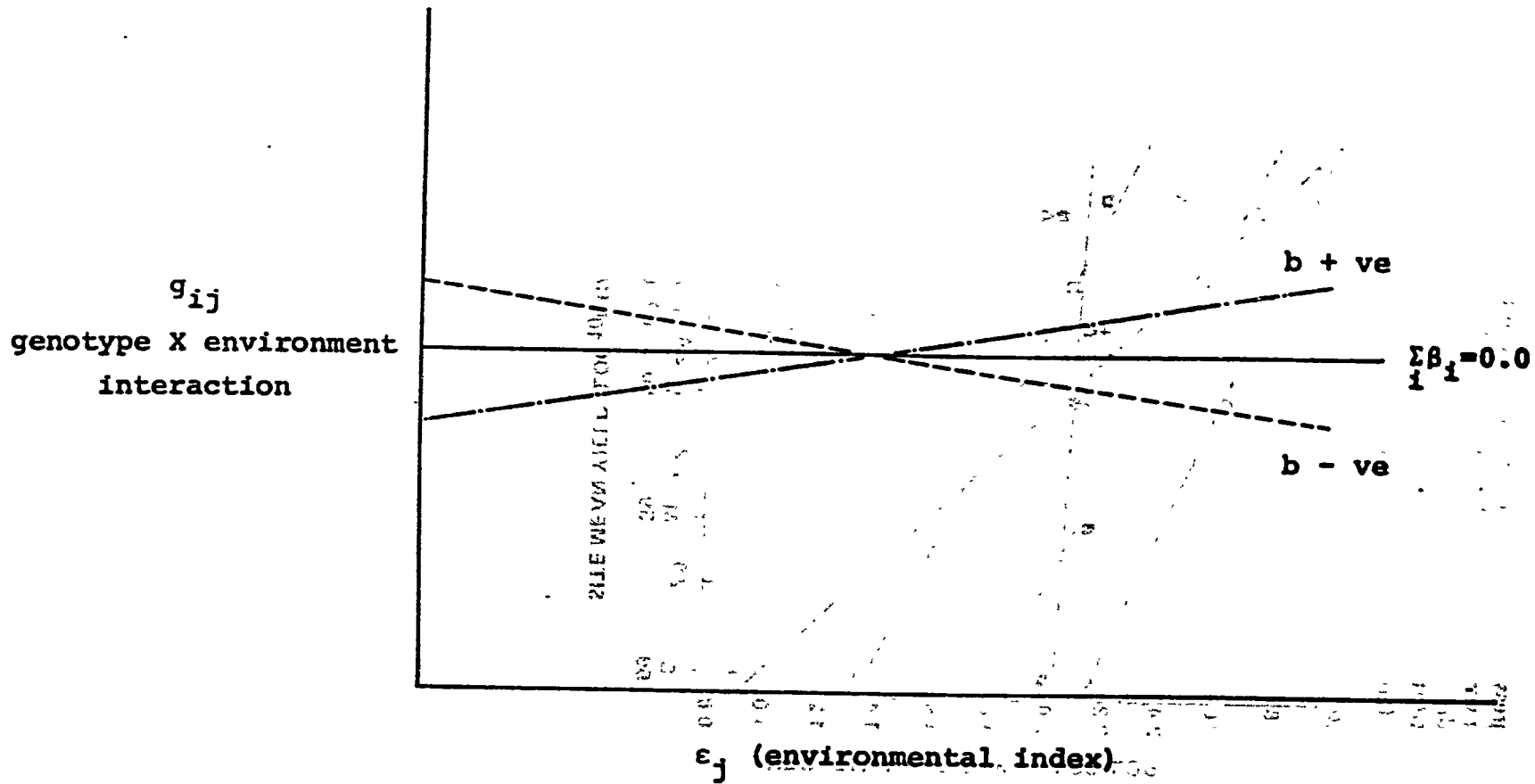


Fig. 6-8. RELATION BETWEEN REGRESSION COEFFICIENTS

(1) REGRESSION OF MEAN YIELD ON ENVIRONMENTAL INDEX

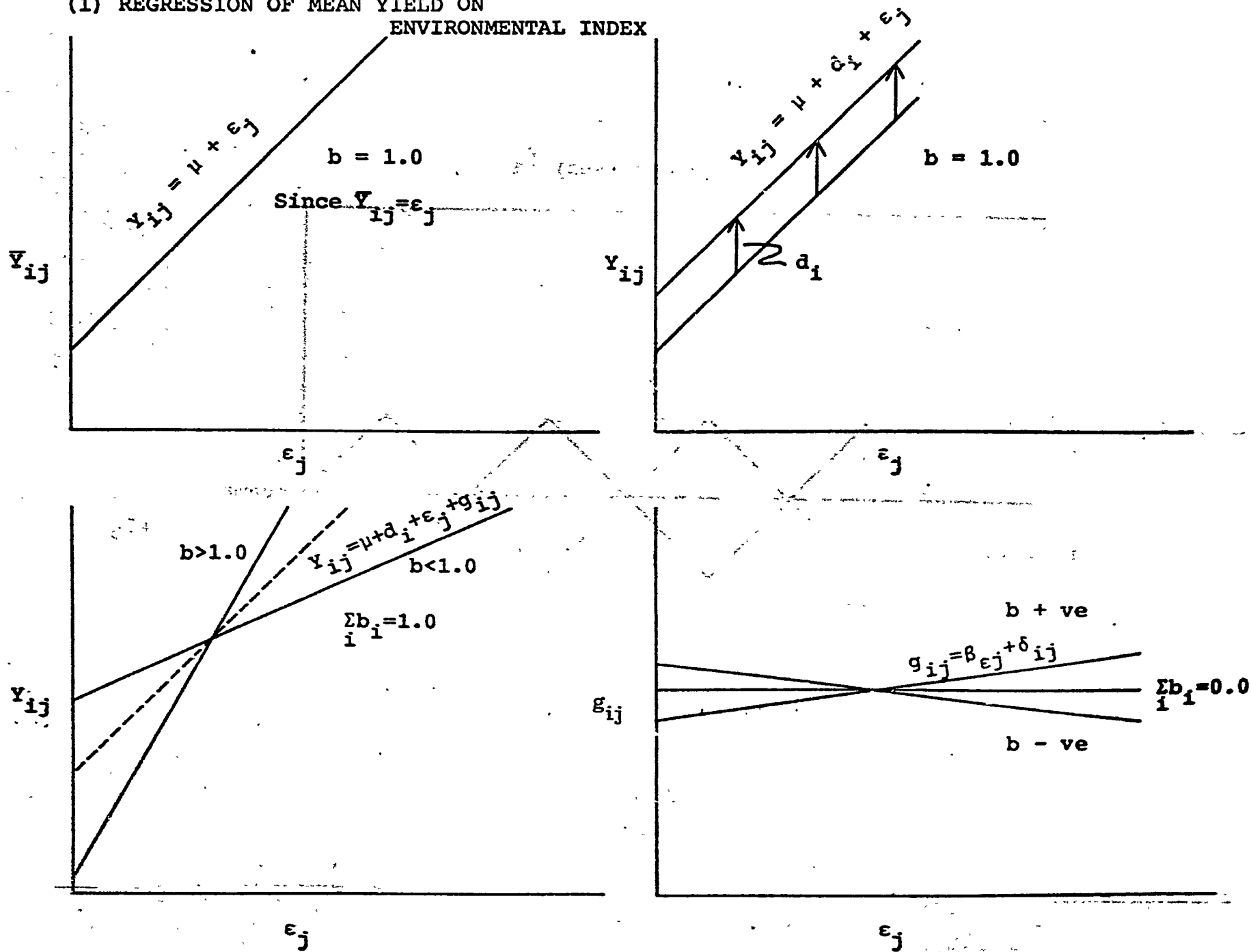


Fig. 6-9. VARIETIES WITH OPPOSING RESPONSES AS DEVIATIONS FROM REGRESSION

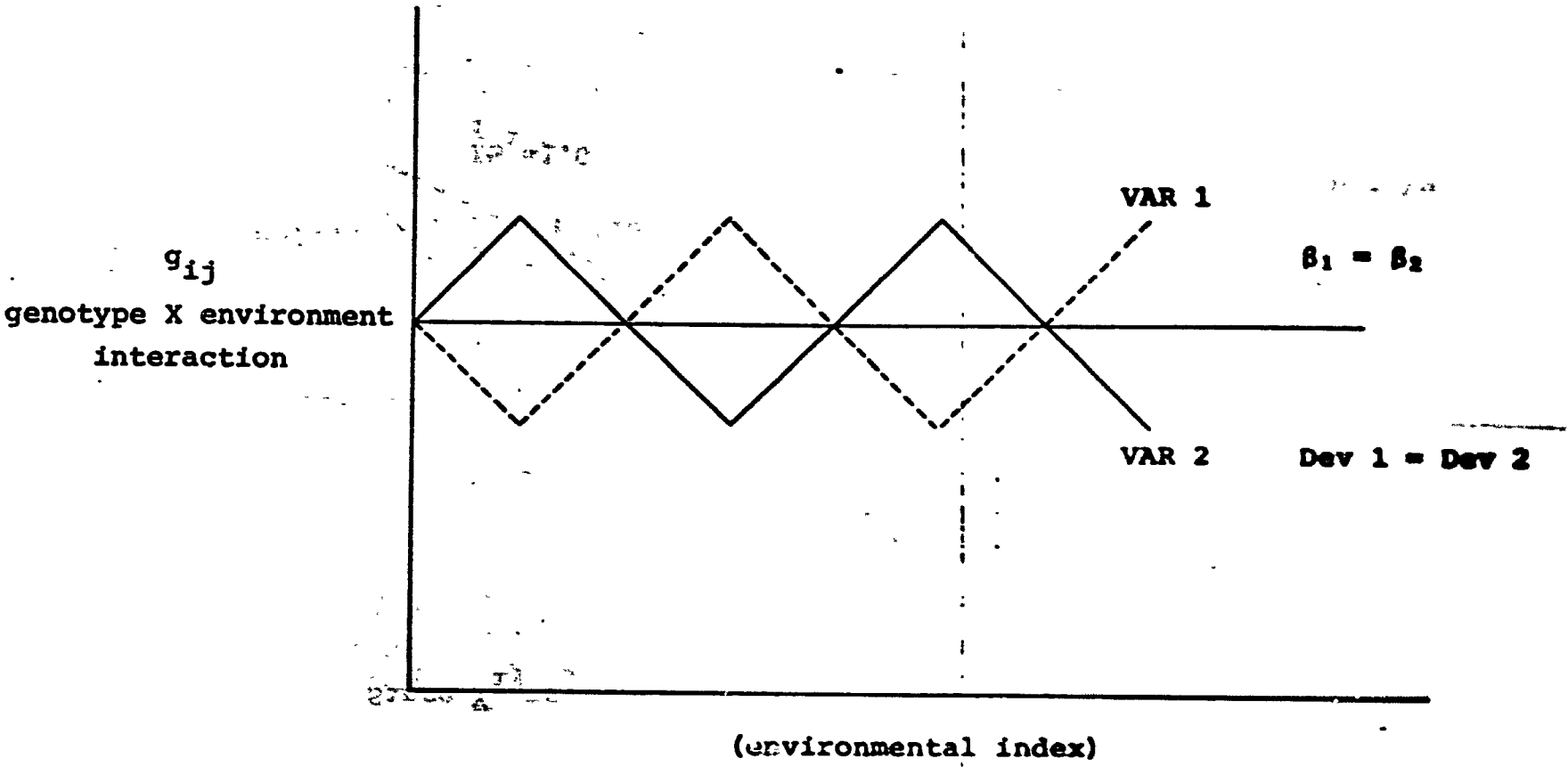


Fig. 6-10. TIMETABLE FOR DATA ANALYSIS AND INTERPRETATION

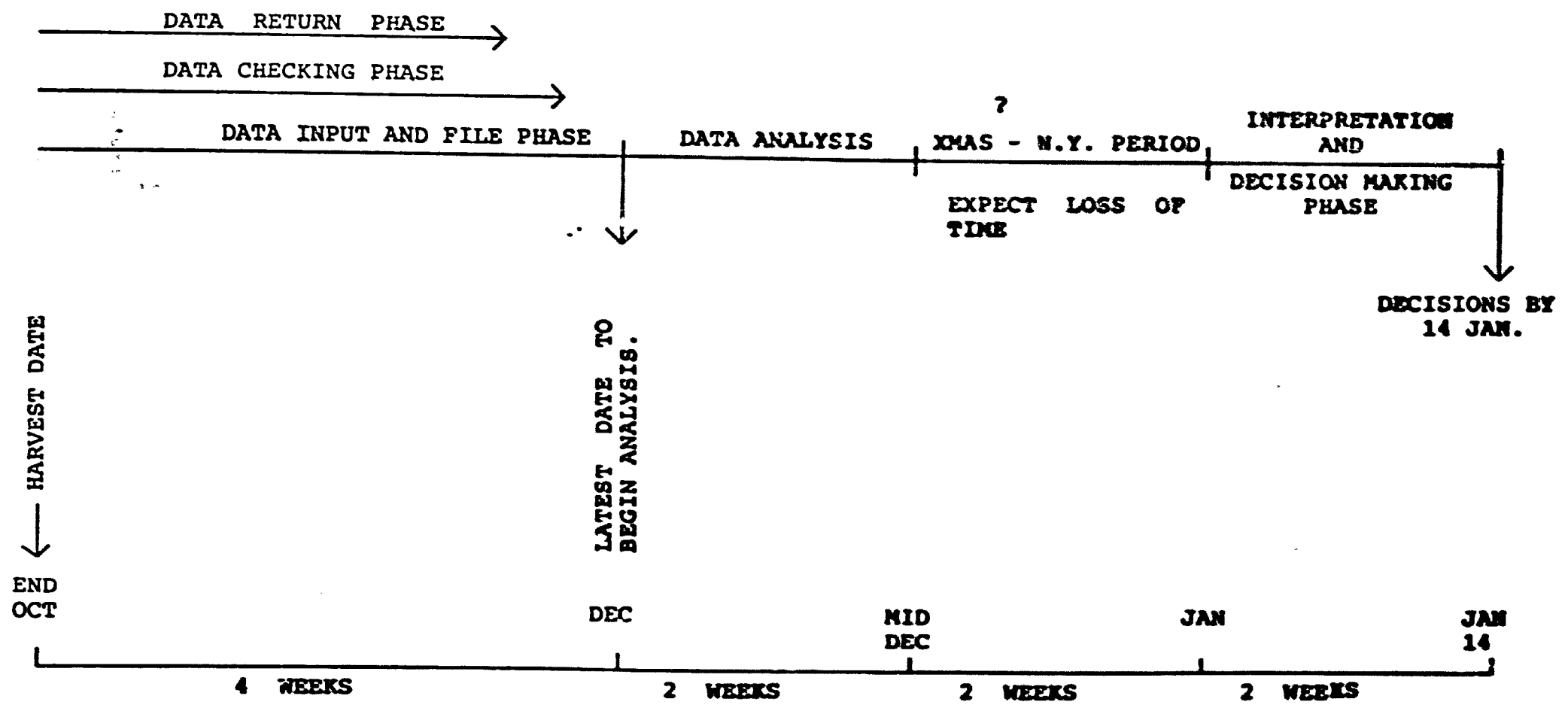
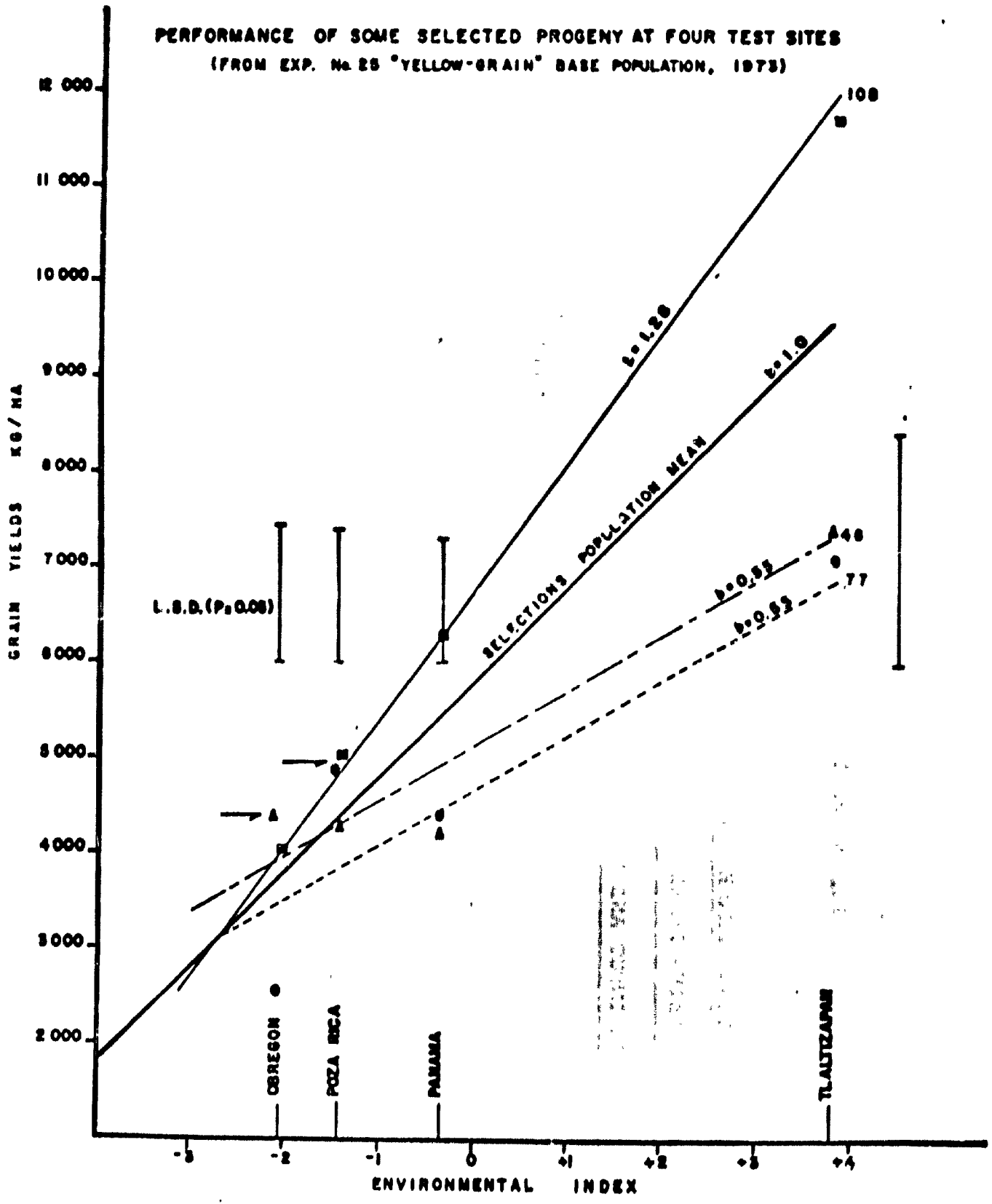


Fig. 6-11.



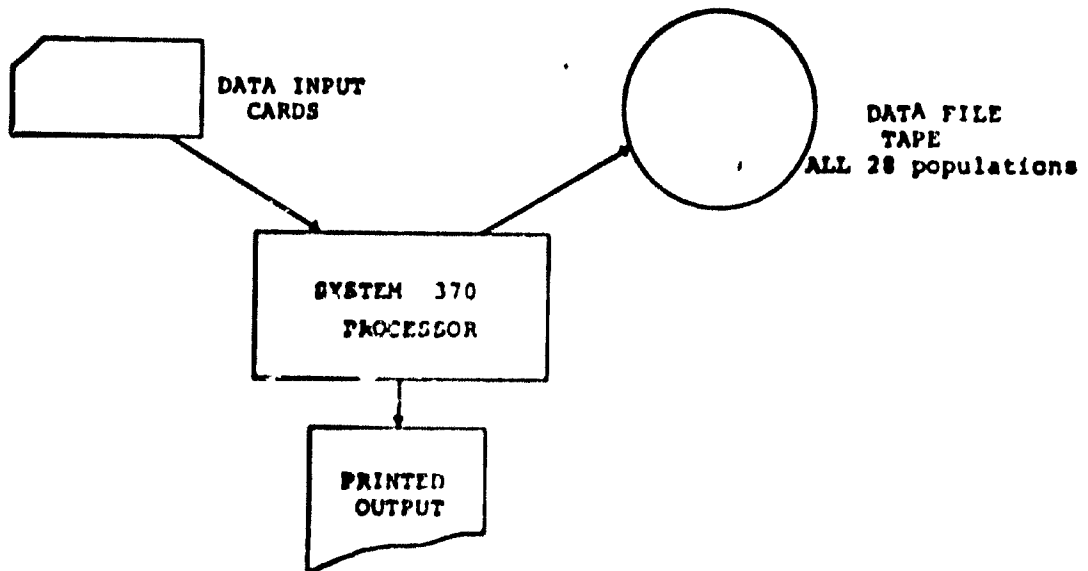
ANNEX 6.0

**ANALYSIS AND SELECTION PROCEDURE
FOR PROGENY TRIALS**

<u>Stage</u>	<u>Topic</u>
1	Analysis of each experiment.
2	Analysis of complete set of six trials.
3	Selection of progenies.

**ANALYSIS AND SELECTION PROCEDURE
FOR PROGENY TRIALS**

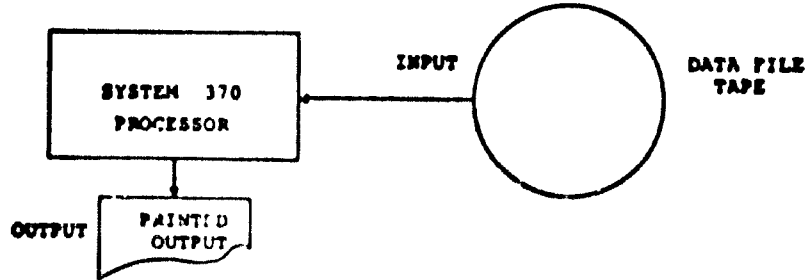
STAGE 1. Analysis of each experiment



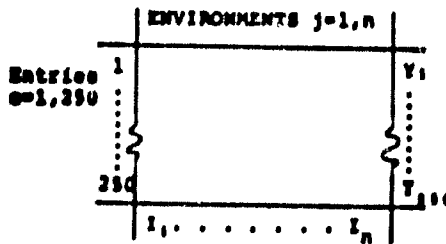
- STEP 1. WRITE DATA TO FILE TAPE**
2. A.O.V.: yields
 3. SORT yield into descending order.
 4. TABULATE MEANS FOR EACH PROGENY
yield days to flower; height; disease data.
- STEP 5. PRINT MEANS FOR POPULATION (250 progenies)**
yield days to flower; height; disease data.
6. PRINT MEANS FOR TEST ENTRIES
yield days to flower; height; disease data.
 7. PRINT L.S.Ds
 8. CALCULATE YIELD FREQUENCY DISTRIBUTION CURVE FOR
250 ENTRIES.

**ANALYSIS AND SELECTION PROCEDURE
FOR PROGENY TRIALS**

STAGE 2. Analysis of complete set of six trials



**STEP 1. MAKE UP 2-WAY TABLE OF YIELDS
FOR ADAPTATION - STABILITY
ANALYSIS (means - not AOV)**



**STEP 2. RUN ADAPTATION-STABILITY ANALYSIS ALL ENTRIES
AND TABULATE (Perkins & Jinks ())**

ADDITIVE GENETIC-ENVIRONMENTAL INTERACTION COMPONENTS FOR 250 ENTRIES

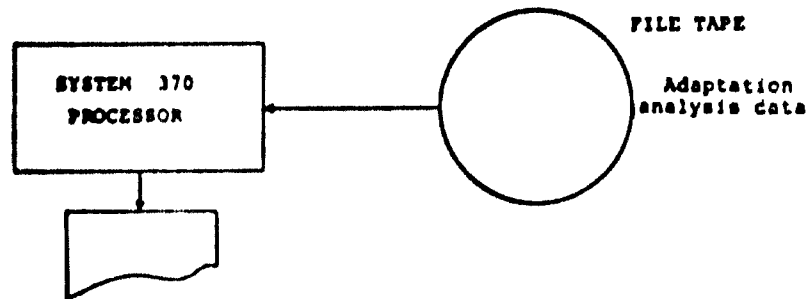
ENTRY No.	ENVIRONMENTS						d_1	s_1	REG. S.S.	DEV. S.S.	GxE S.S.	p	DEV. REG. M.S.	q
	1	2	3	4	5	6								
1	$(d_1 + g_{11})$	.	.	.	.	$(d_1 + g_{16})$	d_1	s_1						
2	$(d_2 + g_{21})$	.	.	.	.	$(d_2 + g_{26})$	d_2	s_2						
.						
.						
250	.	.	.	.	.	.	d_{250}	s_{250}						
e_j	e_1	e_2	e_3	e_4	e_5	e_6	e_j	s_j						

STEP 3. PRINT JOINT REGRESSION ANALYSIS FOR 250 ENTRIES
(as shown in Fig.)

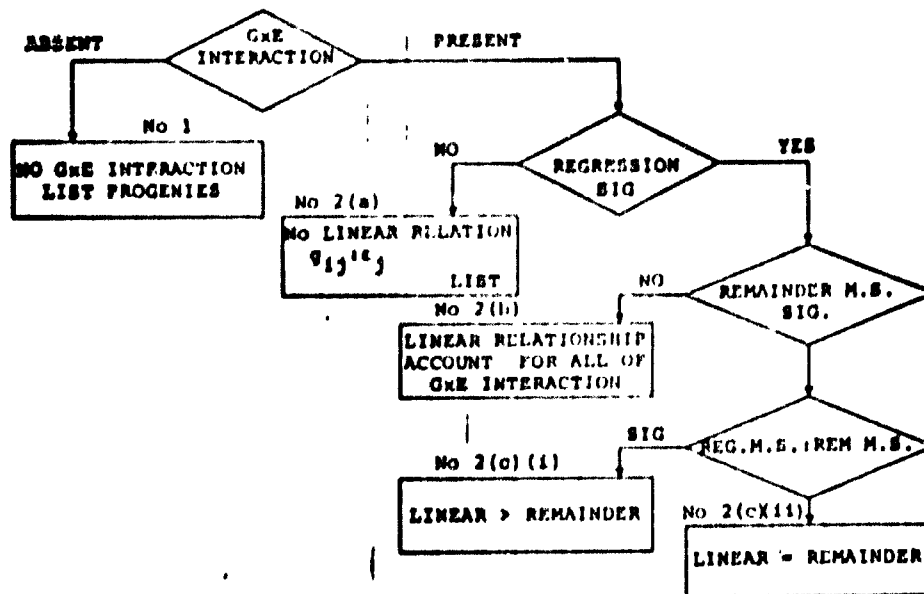
**STEP 4. REPEAT STEPS 1 TO 3 FOR OTHER VARIABLES TO BE
CONSIDERED E_{q1} DAYS TO FLOWER
HEIGHT**

**ANALYSIS AND SELECTION PROCEDURE
FOR PROGENY TRIALS**

STAGE 1. Selection of progenies



STEP 1. (a) GROUP PROGENIES INTO FIVE GROUPS ACCORDING TO GxE EFFECTS
(see Perkins & Jinks ())



(b) LIST PROGENIES IN EACH CATEGORY

**(c) IF PROPORTION OF PROGENIES IN 2(a) or 2(c)(1) IS LARGE THEN
CONSIDER GROUPING PROGENIES ACCORDING TO STEP 2.**

Stage 3, Cont.

STEP 2. (a) TEST CORRELATION OF DEVIATIONS FROM REGRESSION FOR PAIRS OF ENTRIES (Perkins & Jinks ())

**GROUP: SIGNIFICANT POSITIVE CORRELATIONS
SEPARATE: SIGNIFICANT NEGATIVE CORRELATIONS**

(b) TEST: ANALYSIS OF VARIANCE BETWEEN AND WITHIN GROUPS

EXAMINE CHARACTER OF GROUPS, PROCEED WITH ANALYSIS BY GROUPS IF INDICATED.

OR,

STEP 3. (a) SELECT BEST 10 PROGENIES ON YIELD OVER SITES

(b) SELECT BEST 10 PROGENIES ON YIELD AT EACH SITE

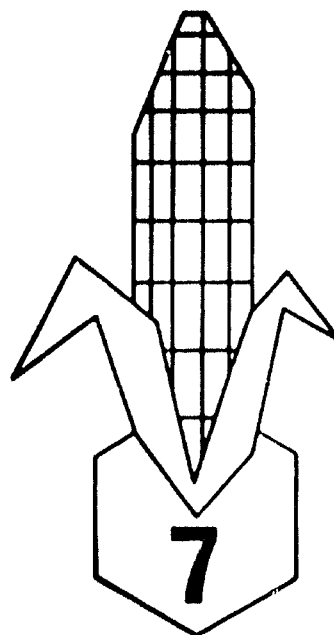
STEP 4. (a) TABULATE YIELD DATA FOR SELECTED PROGENIES (Same form as in Stage 2)

ADDITIVE GENETIC-ENVIRONMENTAL INTERACTION FOR SELECTED PROGENIES

ENTRY No.	ENVIRONMENTS						d_1	s_1	MEANS OF SELECTED PROGENIES
	1	2	3	4	5	6			
<u>ALL SITES</u>	1	...	10					$\bar{y}_{\text{over sites}} =$	
<u>SITE No. 1</u>	1	...	10					$\bar{y}_{\text{site No 1}} =$	
<u>SITE No. 6</u>	1	...	10					$\bar{y}_{\text{site No 6}} =$	
								all selections whole population	

(b) TABULATE DATA FOR OTHER VARIABLES FOR SELECTED FAMILIES (eg. DAYS TO FLOWER, HEIGHT)

5. EXAMINE DATA AND MAKE FINAL SELECTIONS



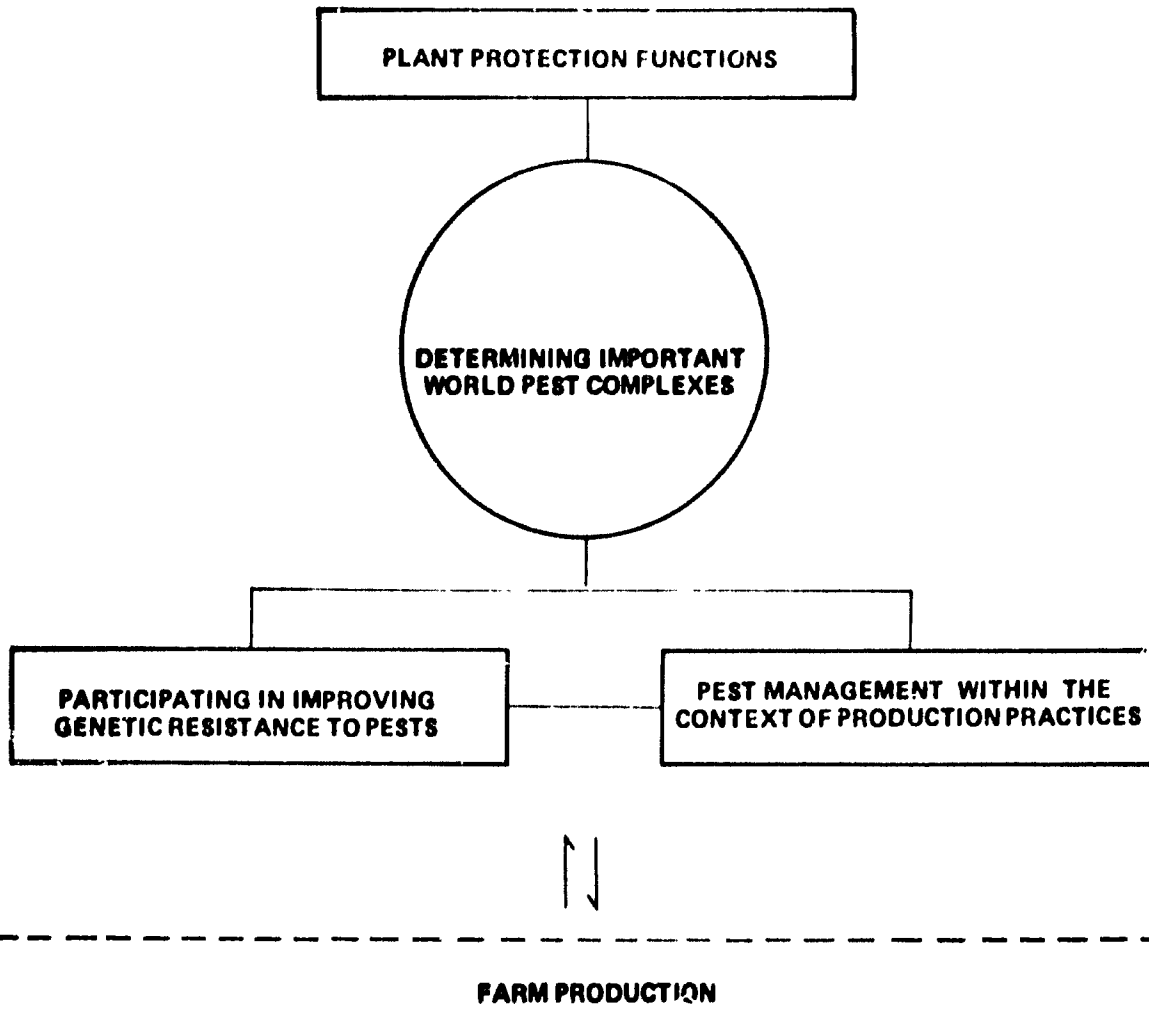
MAIZE INSECTS AND DISEASES

by
Alejandro Ortega, CIMMYT

Lead Discussant:
Dr. William R. Young
The Rockefeller Foundation
Bangkok, Thailand

7.0

**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



CONTENTS: 7.0 MAIZE INSECTS AND DISEASES

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INTERNATIONAL CENTER FOR MAIZE AND WHEAT IMPROVEMENT
CARRINGTON CAMPUS, MANAGUA, NICARAGUA

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7.0

MAIZE DISEASES AND INSECTS

by
Alejandro Ortega

7.1 INTRODUCTION

CIMMYT's plant protection concept involves a complete integration of plant pathology and entomology. We feel that this linkage is necessary to cope more efficiently with the kinship that exists among pathogens and insect pests.

Particularly in the maize plant, there are several outstanding examples that support this need. We are concerned with maize streak in Africa which is disseminated by leafhoppers; corn stunt which is also spread by leafhoppers in Mexico, Central America and South America; and the cosmopolitan sugarcane mosaic which is propagated by aphids. In the first two examples, the evolutionary processes have not as yet crossed the bridge from obligated parasitism to symbiosis. The etiological agents capable of multiplication within both hosts-the maize plant and the insect- still can affect seriously their 'normal' development, becoming of economic importance as far as the maize crop is concerned.

There are less well defined, but still close associations in other maize-pathogen-insect relationships. Maize ear and stalk rots caused by Fusarium can become more prevalent when earworm and stalk borer larvae are abundant.

In studying the above kinds of host plant and pest interrelations, our plant protection approach working jointly with breeding and agronomy staff, attempts to produce appropriate pest management practices to reduce pest damage.

This presentation discusses (a) the major objective of plant protection, providing a background of activities, (b) the relative importance of major diseases and insects, and (c) current plans and projections for the 70's.

7.2 MAJOR FUNCTIONS AND OBJECTIVES

The core functions (Fig.7-1) of Plant Protection contribute:

First, to the improvement of (a) genetic resistance to major insects and diseases and (b) interrelated activities associated with techniques for mass production of inoculum and insect eggs, for artificial inoculation and infestation, and for assessing damage.

Second, to pest management within the context of production practices, with (a) development of ecologically selective chemical pest control (b) genetic resistance in combination with chemical control and (c) interaction among agronomic practices and pest incidence.

In addition, the plant protection group is deeply involved in training activities, which are discussed in Section 11 of the Symposium.

7.2.1 EVALUATION AND SELECTION

7.2.1.1 Genetic Resistance

The search for genetic resistance was initiated with the aim of developing specific sources. For this purpose the reaction of several hundred bank accessions was evaluated independently. That is, each was examined for a single specific character. We soon found that some materials resistant to one of the pests might be rather susceptible to other pest problems. Because of this, our program has now shifted to encompass as many of the pest problems as possible.

The program also has contributed to the development of broad-based composites such as the Caribbean and the so-called World Composite, which can generate germplasm complexes to provide resistant sources among other attributes.

Four populations have been generated (Table 7-1) by the above activities. Two of these populations, Cogollero and IDRN, have been promoted to the advanced unit and will enter the international progeny testing phase of the improvement program. In addition, they have also become components of several lowland tropical back-up pools.

In Mexico the levels of resistance to foliar diseases, except to tar spot (Phyllachora maidis), are adequate. Also these two

populations and Planta Baja x Cogollero have good resistance to stalk and ear rots. The Cogollero population was derived from the Caribbean Composite. Some of the Caribbean land varieties have consistently shown less damage by ear rots, budworm, stem borer, and corn stunt when compared to germplasm sources from other areas.

The IDRN population was developed by recombining 36 maize collections previously identified as having been less damaged by the three borer species occurring in Mexico. Some collections, like those from Antigua, in addition have shown to be somewhat tolerant to budworm. Other materials, like Zapalote Chico, are resistant to earworm. In addition, those materials carrying resistance to ear and stalk rots, leaf blights and corn stunt were incorporated. The 36 entries represented equal proportions of early, intermediate and late maturing types of tropical, sub-tropical and temperate origin.

Another dimension was added to the IDRN population when in 1972, over a thousand F₁ varietal crosses were evaluated by Dr. V. Gracen from Cornell University at their Aurora Experimental Station. Out of these F₁'s, 190 crosses showed resistance comparable to that of highly resistant European corn borer inbred lines from the United States corn belt. During the off-season 1972-1973, the materials were evaluated and selected for corn stunt, budworm, ear and stalk rots at Tlaltizapán in Mexico. In the summer of 1973, at Cornell the resistant selections were crossed to European corn borer-resistant sources. Presently, 287 highly resistant crosses are being evaluated at Tlaltizapán under sugar cane borer artificial infestation. This pool has shown remarkably wide adaptation, since it has been grown successfully at both 42° and 18° North Latitude, and will be the material in which attempts will be made to incorporate resistance to African and Asian borer species, along with other traits.

Working closely with Dr. Vasal in the maize quality protein program, we have determined that in the converted opaque-2 materials Fusarium ear rotting is significantly higher in tropical, subtropical, and highland environments, as compared to their 'normal' counterparts (Fig. 7-2). It seems that incidence of this ear rotting is also associated to a higher earworm susceptibility (Fig. 7-3). Reaction to other foliar diseases and insect pests seems to be similar to that observed in 'normal' counterparts.

Stored-grain insect studies have shown that in similar genetic backgrounds the 'normal' and modified (flinty) opaque-2 versions are comparatively less damaged than the soft endosperm opaque-2 counterparts (Table 7-2). With regard to stored-grain fungi, no differences in reaction were detected among 'normal' and opaque-2 versions.

7.2.1.2. Development of Techniques

Techniques for mass production of inoculum for ear rots and stalk rots and inoculation techniques have evolved to the point that every progeny can be inoculated with several major pathogens. Spore dilution tests are permitting us to identify the spore concentration most suitable to assist in discriminating between susceptible and resistant maize families.

For example, previous evaluations showed that injection of heavy spore suspensions or toothpick inoculation with *Diplodia* ear rots were too severe, spraying silks with a spore suspension was not reliable either. The technique which has proved the most efficient so far is the injection of a diluted spore suspension about ten days after silking (Table 7-3). In addition, this latter technique has given enough sensitivity to the test to be useful in discriminating among diverse germplasm sources (Table 7-4).

Field inoculation techniques have been improved by reducing considerably the amount of time required to inoculate large numbers of progenies. Techniques have also been streamlined for inoculating with rusts, blights, and corn stunt utilizing the insect vectors.

Study has been made of the relative efficiency of injury rating techniques for both diseases and insects. For the most part, foliar diseases and stalk or ear rot reactions are being visually estimated in a rating scale of 1 = no incidence to 5 = very high incidence. The same visual rating scale of 1 to 5 has proved to be equally useful in determining damage by the budworm when compared to actual leaf area removed (Table 7-5). For foliar borer damage the rating scale used is from 1 to 9, and stem boring damage is estimated by determining the number of damaged internodes instead of using the more time-consuming technique of stalk splitting, since both are highly correlated (Table 7-6).

The production of borer earworm and budworm eggs for artificial infestation is increasing rapidly. Adequate quantities will be available in coming cycles to determine the reaction of maize families, from the back-up pools and advanced populations. The diet can be used successfully to grow five different species: *Diatraea saccharalis*, *Zea diatraea lineolata*, *Z. grandiosella*, *Spodoptera frugiperda*, and *Heliothis zea* (Table 7-7 gives the diet ingredients and procedure to prepare it). Techniques for artificial infestation are similar to those developed for the European corn borer in the corn belt of the USA.

7.2.2. PEST MANAGEMENT

7.2.2.1 Chemical Control

In the chemical control studies, a large number of insecticides have been tested. The aim has been to develop selective chemical control measures that complement the levels of resistance obtained in improved maize cultivars. Although maize production in the tropical belt has thus far made very little use of pesticides, we strongly feel that a judicious utilization of the new chemicals particularly the systemic ones, can be adopted by the farmers.

Timing, interval, and number of insecticide treatments have been worked out. Relative performance of liquid and granular formulations has been studied. Soil, seed dressings, and plant treatments have been evaluated. Based on this information, it has been determined that:

- (a) Pesticide granular formulations are the most effective and provide a higher degree of selectivity as compared to sprays.
- (b) It has been determined that economic insect control can be secured with two granular whorl applications with the most effective materials.
- (c) Trials to estimate timing of whorl granular applications with effective materials indicate that the first application is to be made two to three weeks after plant emergence and the second five to six weeks after plant emergence.
- (d) Seed dressings or soil hill and soil band treatments with systemic insecticides have been another effective and selective procedure to control most insect pests for the first three weeks after plant emergence. Corn stunt incidence is also reduced considerably by these materials. These treatments in combination with one or two whorl applications of systemic or non-systemic materials seem to provide the most effective control that substantially reduces damage and contributes economically to increase production (Fig 7-4).
- (e) Grain protectant trials have indicated that pesticides of low mammalian toxicity can provide effective control of the cosmopolitan granary weevil over a year in temperate, subtropical, and tropical environments when used at the rate of 7.5 to 15 ppm (Table 7-8).
- (f) Several fungicides have been selected to assist in determining yield potential of otherwise susceptible

cultivars. This protection in the tested materials has almost doubled the grain production.

7.2.2.2. Interaction Among Agronomic Practices

It should be recognized that increased production will demand among other inputs, higher fertility levels and higher plant densities of short plants. There is very little information concerning the interaction of such practices and pest incidence in the tropical belt. The general trend suggests that intensive management favors higher levels of pathogens and insects in temperate environments (1, 2, 5, 7, 9, 10, 13).

Preliminary research initiated at CIMMYT on normal and opaque populations indicates that budworm populations and stalk rots were not influenced by nitrogen levels. Ear rots in opaque-2 varieties would seem to increase slightly at high nitrogen levels. Also in these trials, it was found that ear rot incidence increased as plant density was increased. Earworm damage increased only slightly (Tables 7-9 and 7-10).

Although, the actual percentage of damaged plants due to budworm, earworm, and stalk rots is lower under higher plant densities; the total number of damaged plants per hectare increases with increased plant population. However, some varieties reacted differently to this general tendency (Table 7-11). Now, I would like to briefly discuss which are the major pest complexes of widespread economic importance in maize production.

7.3 MAJOR MAIZE PEST PROBLEMS

A useful and informative review of the geographical distribution and relative importance of major diseases of maize in temperate and tropical environments, was recently presented by Renfro and Ullstrup (8). (Table 7-12).

CIMMYT's maize program also produced some information on both diseases and insects in 1971, which was based on a written survey and personal experience of the maize staff (6). (Table 7-13).

Both studies reveal that the most widespread and economically important diseases in the world are the northern and southern leaf blights, common and southern rusts, the downy mildew complex, maize streak, sugar cane mosaic, maize dwarf mosaic, corn stunt, stalk and ear rots. Other problems such as seedling blights, kernel rots, and nematodes, are usually of minor importance.

Among the foliar diseases, the downy mildews can be regarded as one of the most important maize disease complexes in the world. In addition to its major importance in Southeast Asia, the endemic presence of sorghum downy mildew (Sclerospora sorghi) on sorghum and maize in several countries of East and West Africa and its dispersal in several countries in the American Continent (Argentina, Honduras, Mexico and the United States) poses a serious threat to maize production (4). The sorghum downy mildew seems to have spread and is becoming more prevalent in those areas where narrow genetic diversity of widely cultivated maize varieties is a common denominator. Also, the spread of the downy mildew seems to be associated with the considerable expansion of the area devoted to sorghum, at least in the northeastern part of Mexico, Southern United States of America and in some of the maize growing areas of Argentina.

In addition to the downy mildew complex, other major diseases which require attention are the maize streak virus disseminated by the leafhopper vector Cicadulina spp. in East and West Africa; the corn stunt, disseminated by Dalbulus spp. leafhoppers in Mexico and Central America; and the cosmopolitan sugar cane mosaic virus complex spread by several aphid species, mainly Rhopalosiphum maidis.

With regard to insects, stem borers represented by different genera in tropical America, Africa and Asia, the Spodoptera budworms, the Heliothis earworms and the stored-grain insects can be regarded as the most important. In addition to their direct damage, the borers and earworms favor the invasion of ear and stalk rotting organisms.

We recognize that there are other pest problems which may be more important than those mentioned above in some localized areas. For the most part, they will have to be tackled by the national or regional programs. Whenever possible, CIMMYT may assist in such problems.

Pathogens causing disease and insect pests are more prevalent and more severe at altitudes below 1,200 to 1,500 m. elevation in the tropical belt. Under these conditions temperature and moisture and the prevalence of insect vectors influence the severity of the pest complexes in time and space and seem to be the major agents regulating their geographical distribution.

Quarantine regulations at the international level, have in some instances retarded the dispersal of economically important pests, but they are, as implemented now, serious obstacles to a systematic movement and evaluation of new germplasm and new sources of resistance that should be available for all programs.

If superior genetic diversity is to be recognized, it will be through the exposure of the maize germplasm in contrasting environments in close association with national programs and regional networks. Adequate support and an efficient systematic testing can produce a continuous flow of genetically broad-based, superior progenies, with balanced genetic resistance. Such a process allows simultaneous monitoring of genetic shifts in the pest complexes. Therefore, it is important that governments review their policies concerning maize seed movements and not simply wait passively behind a weak fence of regulations for protection. There should be a positive attitude change, accompanied by all necessary precautions in seed disinfection and treatment with suitable pesticides before shipment to the testing site.

Again, only an aggressive worldwide germplasm testing program can yield superior, widely adapted materials with adequate levels of field resistance to pests. When coupled with efficient production practices and freely accepted by farmers, these materials could demonstrate their remarkable potential.

7.4 CIMMYT'S STRATEGY FOR THE 1970'S

Drs. Sprague and Johnson have illustrated and discussed the structure and interrelated functions in CIMMYT's maize program. Our overall effort has evolved toward a more dynamic and systematic approach to population improvement. A continuous flow of information and materials is sought, from row materials to superior progenies, experimental varieties and elite experimental varieties, with each step closely coordinated with national programs and regional networks.

7.4.1 STRATEGY FOR HOST PLANT RESISTANCE

Considerable attention continues to be given to genetic resistance of maize cultivars to pest complexes, particularly in the temperate regions of the world. However, highly efficient cultivars grown in these areas have a restricted genetic base. Thus, serious setbacks are sometimes caused by relatively sudden pest susceptibility. Because of the nature and genetic plasticity of pests, breeders and plant protectionists are engaged in a constant struggle to reduce losses caused by pest complexes.

CIMMYT feels that the pest nursery is one of its most powerful tools to alter the susceptibility of the maize plant to pest complexes. These nurseries involve exactly the same germplasm bank accessions, or families being progeny tested for yield and other agronomic traits. The best performing entries are selected after evaluating their response under adequate levels of artificially supplemented

pathogens or insects. After careful judgement of the problem, priorities can be assigned.

Although land varieties are individually susceptible to pests, particularly when transferred to a new environments, the genetic diversity represented by the hundreds of narrowly adapted varieties has prevented large-scale pest losses, particularly in the centers of distribution in tropical America.

Using the large genetic diversity available in the germplasm banks, CIMMYT intends to systematically evaluate reaction to pests in different parts of the world. Reference was made earlier (p. 7.2) to such an activity whereby more than a thousand entries were evaluated and some materials selected, based on their tolerance to corn stunt, borers, ear rots, and budworms.

7.4.2 GERmplasm BANK PEST NURSERIES

The response of each lowland tropical and subtropical, highland, and temperate accession from the bank will be evaluated for resistance to the attack of pests under natural incidence on their respective environments.

Briefly, this procedure consists of growing a five-meter row per accession, with about 33 plants, half of which are protected by hill systemic insecticide soil treatment at planting time and whorl granular applications later on. The unprotected half is used to estimate the response to insect pests and the protected half to evaluate disease reaction.

Selected bank accessions which are to enter the back-up pools will be determined by the information produced by the pest nursery, coupled with pest incidence data recorded in the yield trials, and information received from trials established by cooperating programs in key sites in different parts of the world.

7.4.3 BACK-UP POOLS PEST NURSERIES

As indicated by Dr. Johnson, the back-up pools are developed by recombining desirable materials for several cycles. A core of the pool is identified and then worked with as a family structure. New families are assimilated into the core from 'donors' after their performance has been raised to the desired standard. New donors will be added constantly as new sources of variability to correct deficiencies. The back-up pools pest nurseries will be established along with progeny testing trials, with both using families from the core of a given pool.

Two nurseries are now planned: one for insect pests and the other one for diseases. Uniform levels of inoculum or insect eggs will be deposited at appropriate plant development stages. The disease nursery and half of the insect nursery will be protected with insecticides as indicated for the germplasm bank nursery. In each nursery, each progeny will be represented by about 33 plants in a 5-m row. These nurseries will be established in one or two locations. Back-up pool development and/or improvement will occur mainly in Mexico. The progeny tests established in several sites will add information concerning pest reaction. Thus, every cycle of recombination superior families selected on the basis of its pest resistance, yield, plant high and wide adaptability may be fed to the appropriate advanced populations, and will remain as components of the donating pool.

7.4.4. ADVANCED POPULATIONS PEST NURSERIES

The pest nurseries -- one for insects and one for diseases for the advanced populations -- will be established at only one location in Mexico. Essentially, the same general procedure will be followed as indicated for the back-up pools pest nurseries. At this stage in the improvement process, we enter the international progeny testing phase of the program, applying maximum selection pressure for pest resistance in these steps for further refinement. The data from the international progeny testing trials will be essential in revealing where our weaknesses lie and what action is needed for correction.

Our approach has a built-in mechanism - with multi-location testing of bank materials through all stages to the elite experimental varieties - for selecting for horizontal or generalized resistance. These tests should contribute to wide adaptation and yield stability, and allow for monitoring shifts in pest pathogenicity.

Although research evidence is scanty, some findings suggest that resistance is controlled by several factors and is additive in nature particularly in the case of downy mildew and European corn borer (4, 11, 12). Therefore, breeding approaches that exploit the additive genetic variance such as full sibs or half sibs should allow pyramiding of genes for resistance. However, there is a need for additional efforts to understand inheritance of resistance to pests. Such studies might be developed as research problems for M.Sc. or Ph.D. candidates.

Within the interrelated activities associated with raising the level of resistance in our pools and populations, there is a need for

mass production of inoculum and insect eggs for artificial infestation and inoculation. Procedures should be streamlined, particularly in mass insect rearing to produce the quantities of insect material to infest 4, 000 to 6, 000 families or 40, 000 to 60, 000 plants at appropriate stages of plant development.

There also is a need for maintenance of high genetic variability in the insect colonies and pathogen cultures, which can be done by regularly introducing new material from the wild population.

As experience dictates, we shall also be improving our procedures for infesting, inoculating and assessing the reaction of the materials under improvement.

For example the approach for selection against stalk rot resistance should be reviewed critically. All too often, severely rotten stalks bear well-developed ears. Are these very efficient genotypes? Just what factors are involved?

It is well known that there is a high negative correlation between total sugar content in the stalk and rot susceptibility. And it has been observed, for example, that an otherwise susceptible plant from which the developing ear is removed becomes resistant to stalk rot. For selection purposes, perhaps we need to combine the toothpick method with actual sugar content determinations. We shall work closely with the physiology group to gain better understanding of how to proceed. Dr. Goldsworthy will discuss efficiency of tropical maize in a later presentation(9.0). Possible study questions are: Is the insidious nature of stalk rot organisms in any way preventing a higher grain-to-stover relationship? Stalk borers also tend to complicate the issues, not only in reducing the 'plumbing system', but as well as agents that favor pathogen invasion.

As resistant materials are developed, joint efforts with other institutions will allow a more comprehensive analysis of resistance factors. For example, such a study is being conducted in collaboration with Dr. Gracen (Cornell University). It has been established that the DIMBOA content (the chemical substance responsible for resistance) in first generation European corn borer-resistant lines is about ten times greater than that found in susceptible lines. On the other hand, his determinations show that the DIMBOA content in the IDRN-resistant families is low. This has suggested that there are other mechanisms that are involved in providing resistance to borers. Furthermore, DIMBOA seems to play a significant role in resistance to Helminthosporium turcicum and also has been associated with resistance to the stalk rot caused by Diplodia zea (3). Again, the low levels of DIMBOA in IDRN, suggest other sources of resistance to these pathogens.

Also, as materials are generated by the wide cross project, studies will be conducted to assess their value as pest resistant sources, along with other traits.

Other institutions such as the Southern Grain Insect Research Laboratory (USDA, ARS, ERD) are better equipped with staff and facilities for basic work in the field of insect physiology. Their valuable studies on insect hormones, pheromones, attractants, arrestants, repellents are leads that may prove useful in the future in insect pest management. We need to establish closer links with this and other centers of excellence, and our sister institutions.

Ideally, there should be service-oriented pest mass production facilities in key sites in different parts of world to cope with present and future problems that do not occur in México. Thus, the inoculum and insect materials produced would be used to expose the progenies undergoing improvement from national and international programs. The overall aim is to raise the level of generalized resistance to pests.

Finally, in addition to the pest nurseries, a high plant density nursery managed by the agronomists includes the same sets of families from each pool and population. This occurs in both the back-up unit and advanced unit, providing an opportunity to monitor pest reaction when the crop is grown at very high plant densities.

7.4.5 DEVELOPMENT OF DISEASE AND INSECT RESISTANT POOLS

Four major pest problems require intensive and systematic work to complement the efforts of national programs, regional networks, and sister institutions. They are: maize streak virus, corn stunt and its associated insect vectors, the downy mildew complex, and the borer complex.

The first objective will be to develop populations for countries that have planting seasons differing widely from those in Mexico; a second objective is to build resistance to those pests that are limiting production. In addition (because we now cannot determine with any degree of certainty when these pest problems will invade new areas), we shall attempt to use these pools as donors to our back-up pools and appropriate advanced populations.

During the summer of 1974, four pools with grain textures and colors fitted to needs of large specific areas will be crossed to resistant sources available in the program. When new sources are identified, they will be fed into the system. We hope to work out arrangements through which about 500 to 1,000 F₁ families generated

from each pool will be simultaneously tested in Southeast Asia, Central America and Africa, in at least two key sites within every region. At these sites, crosses among F_1 plants from resistant families if any, will be generated and their seed returned to CIMMYT. These families will be then back-crossed to their respective pools and may contribute to the pollen source. These steps will be repeated as long as is necessary. Another alternative or following step to the above in case no resistance is found at the F_1 level will be to advance the F_1 crosses to F_2 's and send them to the testing sites. This segregating generation would be handled as suggested above. A third possibility, perhaps less desirable, would be to test the F_2 generation in the problem areas. Resistant families could be determined and remnant seed back-crossed to the respective pool.

7.4.6 PRODUCTION AGRONOMY AND PEST MANAGEMENT

Pesticides tests will continue with the aim of developing ecologically selective techniques. Systemic insecticide seed dressings and hill soil treatment at planting time have proved to be efficient during the first weeks of plant growth, contributing to the establishment of almost perfect stands.

However, there is a need to identify appropriate coating materials that (a) prevent dislodging of the insecticide seed dressing, (b) do not affect viability if seed is to be stored for relatively long periods of time, and (c) favor a slow release of the systemic insecticide to extend its protective action.

Working closely with the pesticide industry, we hope to contribute to the development and evaluation of granular insecticides with slow release properties. These products need to be formulated with inert materials whose particles are heavy enough to be retained or rolled back into the whorl as the plant grows.

There is a need to determine the value of naturally occurring biological control of maize insect pests; and to assess the impact of production practices and selective chemical control measures in the population of parasites, predators and other entomophagous agents.

In closing, I would like to restate that to develop a successful pest management approach in the maize agroecosystem, we need to clearly understand the interactions among (a) maize cultivars when grown alone or in association with other crops (b) tillage practices, (c) plant densities, (d) fertility levels, (e) pesticide levels and (f) other cultural practices that may influence pest incidence.

Each aspect of the above plant protection activities represents the joint efforts of the total plant protection staff at CIMMYT with Drs. Carlos De León, Gonzalo Granados, and Richard Wedderburn as professional participants.

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Table 7-1. Summary of grain yield data in kg/ha. at 15% moisture of half-sib families of four populations during the season 1973B.

Population/ Location	No. of families		Tested families		Selected families		CHECK VARIETIES					C. V.	L.S.D. (5%)
	Tested	Selected	Ranges	Means	Means	Selection Differential %	Turpeño-1	H-507	Mix. 1-Col. Gpo. 1xETO.	Mezcla Amarilla	ETO		
1. IDRN													
Poza Rica	250	57	1789-5136	3650	4304	18	3784(114)*	1464(294)	1765(244)	1966(219)	3785(114)	17	1272
Tlaltizapan	250	57	3421-9600	6346	7040	11	6248(113)	9235(76)	6133(115)	5142(137)	6462(109)	16	2076
Obregon	250	57	1275-3861	2514	2594	3	1905(136)	2561(101)	1148(226)	1961(132)	2674(97)	22	1102
Combined	--	--	-- --	4170	4646	11	3979(117)	4420(105)	3015(154)	3023(153)	4307(108)	--	--
2. Cogollero													
Poza Rica	250	52	1027-5274	3346	3996	19	2559(156)*	2814(104)	2205(181)	2925(135)	2631(152)	19	1258
Tlaltizapan	250	52	2514-9524	6363	7386	16	5131(144)	9000(82)	5789(127)	4447(166)	5177(142)	22	2737
Obregon	250	52	1450-3931	2557	2689	5	1237(217)	2005(134)	2584(104)	2288(117)	1306(206)	22	1138
Combined	--	--	-- --	4088	4690	15	2975(157)	4606(101)	3526(133)	3220(145)	3038(154)	--	--
3. Planta Baja x Cogollero													
Poza Rica	183	50	2191-5134	3651	4005	10	3286(122)*	2525(158)	2104(190)	2657(151)	2850(140)	21	2429
Tlaltizapan	183	50	1814-11015	6306	7943	26	3136(253)	4449(178)	5219(152)	3913(203)	4879(163)	19	1310
Combined	--	--	-- --	4978	5974	20	3211(186)	3487(171)	3661(163)	3285(183)	3864(154)	--	--
4. World Composite													
Poza Rica	250	50	1443-5209	2809	3418	21	3058(112)*	2830(121)	3428(96)	3379(101)	3132(109)	25	1406
Tlaltizapan	250	50	1314-8274	4956	5944	19	4354(136)	4669(127)	5572(107)	4139(144)	4437(134)	24	2359
Combined	--	--	-- --	3882	4681	20	3706(126)	3749(124)	4500(104)	3759(124)	3784(124)	--	--

* Selected family mean as % of check in the respective locations.

Table 7-2. Percent emergence of maize weevils and anguimoid grain moths, from Normal, Opaque and Modified endosperm versions of four maize populations. El Batán, México. 1972

WEEVIL, <u>Sitophilus zeamais</u>				
Maize Population	Endosperm Version			Maize Population Means
	Normal	Modified	Opaque	
Compuesto K Yellow Hard Endosperm Composite	5	13	15	11.0
Compuesto CIMMYT Ver. 181 x Ant. Gp. 2 x	17	18	29	21.3
Venz.	8	19	56	27.6
	16	20	55	30.3
Endosperm Version Means				
	11.5	17.5	38.7	
MOTH, <u>Sitotroga cerealella</u>				
Compuesto K	65	72	74	70.3
Compuesto CIMMYT	70	66	79	71.7
Yellow Hard Endosperm C.	83	60	74	72.4
Ver. 181 x Ant. Gp. 2 x Venz.	69	87	93	83.0
Endosperm Version Means				
	71.7	71.2	80.0	
Average of four replications				

TABLE 7-3. Efficiency of two Diplodia spp. artificial inoculation techniques and spore concentration in maize ear rots, when inoculated 10 days after silking. Poza Rica, Veracruz, 1973 A and B.

Spores/ml.	Mean values of rotten ears <u>1/</u>	
	Spray (arcsin %)	Injection (%)
Original (2.0×10^6)	95 a	- - -
1:10	76 b	68 a
1:100	58 c	62 ab
1:1000	- - -	58 bc
1:10000	- - -	50 cd
1:100000	- - -	41 de
Check (no spores)	33 d	11 f

1/ Differences at 1% level of significance
Mean values of 3 replications

TABLE 7-4. Reaction of five maize varieties to Diplodia ear rot when spores are sprayed or injected 10 days after silking, and to stalk rotting organisms. Poza Rica, Veracruz 1973A and B.

Variety	Mean values of rotten ears <u>1/</u>		Mean <u>1/</u> index of stalk rots
	Spray(arcsin %)	Injection (%)	
Cogollero	45 a	42 a	2.7 a
Tropical Early Composite	49 a	50 b	3.3 c
(Ver. 181 x Ant. Gpo. 2) Ven. 1 opaque-2	52 ab	54 b	2.9 b
Tuxpeño 1	65 bc	50 b	2.8 ab
Zapalote Chico (suscept. check)	77 c	63 c	2.9 b

1/ Differences at 1% level of significance
Mean values from 3 replications

TABLE 7-5. Means of budworm (*Spodoptera frugiperda*) damage to maize leaves rated with a visual scale 1-5 (1:no damage, 5:heavily damaged), and actual leaf area removed in percentage. Tlaltizapan, 1973A.

Varieties	4 weeks	6 weeks	8 weeks	Middle row	All rows	% Leaf area removed Leaf # 7
	Jan. 31/73	Feb. 16/73	Feb. 26/73			
1. Tuxpeño 1 x Cogollero	2.46	1.67	1.45	1.76	1.81	0.535
2. Cogollero	2.37	1.60	1.53	1.61	1.56	0.438
3. Mezcla Amar. P.B. x Cogollero	2.22	1.80	1.56	1.72	1.62	0.488
4. (Tuxpeño br ₂ x Ant. Gpo.2) x Cogollero	2.31	1.71	1.37	1.50	1.52	0.335
5. Phil.DMR 5 x Cogollero	2.03	1.67	1.70	2.04	1.89	0.770
LSD .05	0.20	N.S.	0.26	0.22	0.24	N.S.

TABLE 7-6. CORRELATIONS (r) BETWEEN DIFFERENT METHODS OF
MEASURING CORN BORER DAMAGE. POZA RICA 1971B.

M E T H O D S	
Number of damaged internodes vs. number of holes	0.7432 **
Number of damaged internodes vs. number of internal galleries	0.8068 **
Number of internal galleries vs. number of holes	0.7805 **

** Significant at 1% level

TABLE 7-7. Ingredients and quantities used in preparing the diet for mass rearing the sugar cane borer (*Diatraea saccharalis*) and the budworm (*Spodoptera frugiperda*) at CIMMYT.

Ingredient	Amount in grams
Dry soybean coarsely ground	50.00
Dry opaque-2 maize coarsely ground	96.00
Dry brewer's yeast	40.00
Ascorbic acid	4.00
Sorbic acid	1.25
Formaldehyde (40%)	2.50
Agar	16.00
Methyl parahydroxybenzoic acid	2.50
Vitamin complex	5.00
Choline chloride	2.00
Wheat germ	2.00
Water	<u>1000.00</u>
Total	<u>1220.75 grs.</u>

The procedure to prepare the diet is as follows:

1. The agar is melted in 500 grams of warm water and cool for 15 minutes.
2. The brewers yeast is placed in 100 grams of water and mixed for 2 to 3 minutes in a small stirrer.
3. The yeast suspension, opaque-2 maize and soybean flours are placed in 400 grams of water and mixed for 10 minutes in a large mixer.
4. The melted agar is then added to ingredients in step 3, and mixed for 10 minutes. At the end of this period the temperature of the diet should be below 50°C.
5. The remaining ingredients are added and mixed for 10 minutes. The 1.25 grams of sorbic acid need to be dissolved in 6 ml of ethyl alcohol slightly heated.
6. The diet is then to be poured immediately in the rearing containers. After half an hour it can be infested.

TABLE 7-8. Percent mortality of *Sitophilus zeamais* on corn grain treated with three different dosages of Malathion, Gardona and Baythion at El Batan, México (high-altitude environment, temperate).

Days after treatment	Date of observation	Malathion ppm			Gardona ppm			Baythion ppm		
		7.5	10.	15	7.5	10	15	7.5	10	15
Observed mortality at indicated dates										
6	Sept. 1/69	100	100	100	72	81	74	100	100	100
43	Oct. 13/69	99	100	100	64	80	77	100	100	100
90	Nov. 24/69	26	35	100	21	31	27	100	100	100
132	Jan. 5/70	25	34	100	19	34	46	100	100	100
174	Feb. 16/70	10	19	30	12	24	22	100	100	100
216	March 30/70	32	57	74	49	77	93	100	100	100
238	May 11/70	20	24	44	74	81	85	100	100	100
300	June 22/70	18	18	22	45	65	79	100	100	100
344	Aug. 5/70	6	17	31	39	52	75	100	100	100
384	Sept. 14/70	12	22	23	51	54	60	100	100	100
426	Oct. 26/70	8	19	35	20	23	30	100	100	100
468	Dec. 7/70	2	4	7	4	7	9	100	100	100
573	March 22/71	0	1	2	0	3	3	100	100	100
617	May 5/71	1	3	4	4	5	9	100	100	100
653	June 10/71	0	3	3	49	40	46	100	100	100
708	Aug. 4/71	5	5	10	4	7	33	100	100	100
769	Oct. 4/71	5	4	9	8	15	19	100	100	100
804	Nov. 10/71	6	0	10	4	4	8	89	98	98

Subsamples transferred from El Batan (temperate) to Tlaltizapan (subtropical) and Poza Rica (tropical).

Days after treatment	Date of observation	Malathion ppm			Gardona ppm			Baythion ppm			Malathion ppm			Gardona ppm			Baythion ppm			
		7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	
Observed mortality at indicated dates											Mortality on emerging adult insects									
El Batán — Tlaltizapan											El Batán — Tlaltizapan									
431	Oct. 31/70	21	46	49	33	47	84	96	80	100	100	N	N	N	N	N	100	N	N	N
503	Jan. 11/71	20	20	44	31	51	44	100	100	100	50	67	100	100	100	83	N	N	N	N
610	April 28/71	54	58	64	37	64	94	100	100	100	75	100	100	100	100	N	N	N	100	
683	July 10/71	0	0	0	0	1	8	100	100	100	58	91	82	50	82	66	N	N	N	
811	Nov. 15/71	0	10	5	0	0	0	94	97	99	3	36	21	13	66	83	N	N	N	
El Batán — Poza Rica											El Batán — Poza Rica									
431	Oct. 31/70	50	65	85	63	71	86	100	99	100	N	N	N	N	N	N	N	100	N	
503	Jan. 11/71	4	5	13	7	8	16	100	100	100	100	100	100	N	N	100	100	100	100	
610	April 28/71	3	16	22	0	6	24	100	100	100	67	82	85	27	71	75	100	100	100	
683	July 10/71	0	0	1	0	0	1	82	93	99	11	24	74	2	6	29	100	100	N	
811	Nov. 15/71	—	—	—	—	—	—	43	66	62	D	D	D	D	D	D	84	99	100	

Poza Rica, Mexico (wet, tropical environment).

Days after treatment	Date of observation	Malathion ppm			Gardona ppm			Baythion ppm			Malathion ppm			Gardona ppm			Baythion ppm		
		7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15
Observed mortality at indicated dates											Mortality on emerging adult insects								
94	Nov. 28/69	99	99	100	95	96	97	100	100	100	—	—	—	—	—	—	—	—	—
179	Feb. 21/70	13	24	88	24	37	97	100	100	100	87	50	73	70	89	67	N	N	N
239	April 22/70	97	100	100	81	91	98	100	100	100	70	100	92	70	83	79	100	100	100
307	June 29/70	4	27	85	16	26	78	98	99	100	74	73	80	73	79	78	67	N	N
400	Sept. 30/70	3	4	7	0	2	5	60	88	98	3	25	44	2	10	49	86	100	100
468	Dec. 7/70	D	3	8	D	2	0	51	76	83	D	1	10	D	0	1	96	75	100
564	Mar. 13/70	—	D	D	—	D	D	28	24	43	—	D	D	—	D	D	92	100	100
652	June 9/71	—	—	—	—	—	—	0	28	27	—	—	—	—	—	—	38	31	35
750	Sept. 15/71	—	—	—	—	—	—	8	25	27	—	—	—	—	—	—	53	88	96
809	Nov. 13/71	—	—	—	—	—	—	D	D	17	—	—	—	—	—	—	0	58	86

Tlaltizapan, Mexico (subtropical environment).

Days after treatment	Date of observation	Malathion ppm			Gardona ppm			Baythion ppm			Malathion ppm			Gardona ppm			Baythion ppm		
		7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15	7.5	10	15
Observed mortality at indicated dates											Mortality on emerging adult insects								
81	Nov. 15/69	95	100	100	89	94	99	100	100	100	—	—	—	—	—	—	—	—	—
142	Jan. 15/70	19	27	45	62	75	85	100	100	100	50	N	N	100	86	N	N	N	N
307	Mar. 21/70	39	44	57	89	96	98	99	100	99	59	100	60	75	90	77	N	N	N
274	May 27/70	37	35	53	93	100	99	100	100	100	75	N	N	100	100	100	N	100	N
375	Sept. 5/70	20	23	23	84	95	98	97	100	100	73	100	100	N	N	N	N	N	N
431	Oct. 31/70	24	32	39	55	78	88	100	100	100	13	43	100	100	100	100	67	100	N
503	Jan. 11/71	11	14	25	14	18	35	72	84	98	6	44	31	37	100	67	N	100	N
610	April 28/71	0	6	18	20	36	53	89	93	100	2	26	59	65	73	100	100	N	N
683	July 10/71	D	D	0	0	0	0	70	90	95	1	35	81	64	77	75	N	N	N
811	Nov. 15/71	—	—	0	D	0	1	42	58	49	D	D	9	3	15	21	84	84	100

D: Grain destroyed by insect activity.

N: No emergence took place.

Data based on four replicates.

TABLE 7-9. Ear rot incidence in three opaque-2 varieties grown at two nitrogen levels. Poza Rica, Veracruz. 1973A.

	Nitrogen kg/ha	Ear rots* scale 1-5
Tuxpeño 1 x La Posta O ₂	150	1.48
	300	1.41
Compuesto K	150	1.28
	300	1.52
(Ver.181 x Ant. Gp. 2)Venz.1 O ₂	150	1.31
	300	1.38
LSD 5%	- -	0.01

TABLE 7-10. Ear rot and earworm incidence at three different plant densities. Poza Rica, Veracruz. 1973A.

Nominal Plant Density/ha :	Ear rots (trial 1)* scale 1-5	Earworms (trial 2)* scale 1-5
34700	1.46	1.39
78000	1.72	1.40
113000	2.14	1.42
LSD 5%	0.10	0.05

*1 = clean; 5 = severely damaged

TABLE 7-11.- Total number of budworm (*Spodoptera frugiperda*) damaged plants of Eto blanco x Tuxpeño 1, and percentage based on nominal plant density. Poza Rica, Veracruz. 1973 A.

Nominal Plant density/ha	budworm						stalk rot			
	No. damaged plants/ha		No. damaged plants/ha		No. damaged plants/ha		No. damaged plantas/ha		No. damaged plantas/ha	
	1st. week	%	3rd. week	%	5th. week	%	(trial 1)	%	(trial 2)	%
43400	5989	14	16973	39	11750	27	32754	75	33032	76
78000	5397	7	26933	34	15257	19	50622	65	44538	57
113000	9345	8	34126	30	17063	15	63506	56	38872	34
LSD 5%	-----	NS	-----	8	-----	8	-----	12	-----	29

1/ 2/

Table 7-12. The relative Prevalence and Importance of Maize Diseases of the world. (Source: Renfro and Ullstrup, 1973. See reference.)

Disease	Temperate (outside 34° lat.)	Sub-tropi cal (with in 34° lat)	Tropical (within 23.5° lat.)		
			Highland 1000+ M	Lowland Winter 1000(-)M	Summer 1000(-)M
I. Foliar diseases					
1. Northern leaf blight	+++ 3	++ 1	+++ 3	++ 2	+1
2. Southern leaf blight	+++ 3	+++ 3	+1	++ 2	+++ 3
3. Helminthosporium leaf spot (<i>H. carbonum</i>)	++1	+ 1	++1	+1	+1
4. Bacterial wilt	++1	+ 1	- 0	- 0	+1
5. Yellow leaf blight	++2	- 0	- 0	- 0	- 0
6. Eyespot	++1	- 0	- 0	- 0	- 0
7. Tar spot	+0	+ 1	+1	- 0	+1
8. Leaf shredding	- 0	+ 1	- 0	- 0	++1
9. Curvularia leaf spot	- 0	++ 1	++1	+1	+++ 3
10. Brown spot	+1	++ 2	+1	+1	++1
11. Banded leaf and sheath blight	- 0	+ 1	- 0	- 0	++1
12. Zonate leaf spot	- 0	+ 1	- 0	- 0	+1
II. Smuts and rusts					
13. Head smut	+1	++ 2	++1	+1	++1
14. Common smut	+++1	++ 1	++1	+1	+1
15. False smut	- 0	+ 1	+1	- 0	+1
16. Common rust	+++2	++ 2	+++2	++1	+1
17. Southern rust	- 0	++ 2	+1	+1	+++3
18. Tropical rust	- 0	+ 1	- 0	+1	+1
III. Downy Mildews					
19. Sorghum (<i>S. sorghi</i>)	+1	++ 2	- 0	+++2	+++3
20. Java (<i>S. maydis</i>)	- 0	- 0	- 0	+++3	+++3
21. Philippine (<i>S. philippinensis</i>)	- 0	++ 2	- 0	+++3	+++3
22. Sugarcane (<i>S. sacchari</i>)	- 0	+++2	- 0	+++3	+++3
23. Graminicola (<i>S. graminicola</i>)	+1	- 0	- 0	- 0	- 0
24. Spontanea (<i>S. spontanea</i>)	- 0	- 0	- 0	+1	++2
25. Crazy top (<i>S. macrospora</i>)	+1	+ 1	- 0	- 0	+1
26. Brown stripe (<i>S. rayssiae</i>)	- 0	+++ 3	- 0	- 0	++2
IV. Virus and Mycoplasma - like entities					
27. Maize streak	- 0	++ 2	+1	++2	+++3
28. Sugarcane and Maize dwarf mosaic	+++3	+++ 3	+1	++2	++2
29. Wheat streak mosaic	+1	- 0	- 0	- 0	- 0
30. Maize leaf fleck	+1	- 0	- 0	- 0	- 0
31. Bromegrass mosaic	+1	- 0	- 0	- 0	- 0
32. Cucumber mosaic	+1	+ 1	- 0	- 0	- 0

Table 7-12. Continued.

Disease	Temperate (outside 34° lat.)	Sub-tropi cal (with in 34° lat)	Tropical (within 23.5° lat.)		
			Highland 1000+ M	Lowland Winter Summer 1000(-)M 1000(-)M	
33. Corn stripe	- 0	+ 1	- 0	+ 1	+ 1
34. Maize rough dwarf	++ 2	++ 2	- 0	- 0	- 0
35. Corn Stunt	+ 1	+++ 3	+ 1	+++ 3	+++ 3
V. Stalk rots					
36. Diplodia	+++ 3	+++ 3	+ 1	- 0	- 0
37. Gibberella	+++ 3	++ 2	+ 1	- 0	- 0
38. Fusarium	+++ 2	+++ 2	++ 1	++ 1	+++ 2
39. Charcoal rot	++ 1	++ 1	+++ 2	+++ 2	+++ 2
40. Black bundle	++ 1	+++ 2	+ 1	++ 1	++ 2
41. Late wilt	- 0	+++ 3	- 0	+++ 3	+++ 3
42. Pythium	++ 1	+++ 3	- 0	+ 1	+++ 3
43. Bacterial	+ 1	+++ 3	+ 1	+ 1	+++ 3
44. Anthracnose	- 0	+ 1	- 0	++ 1	+++ 3
VI. Ear and Kernel Diseases					
45. Diplodia	++ 2	+++ 2	+ 1	- 0	- 0
46. Gibberella	+++ 2	++ 1	+ 1	- 0	- 0
47. Diplodia macrospora	- 0	++ 1	- 0	- 0	+ 1
48. Rhizoctonia	- 0	++ 1	- 0	- 0	++ 1
49. Botryodiplodia	- 0	+ 1	- 0	- 0	+++ 2
50. Gray ear rot	- 0	++ 1	- 0	- 0	++ 1
51. Nigrospora	++ 1	++ 1	+ 1	++ 1	+ 1
52. Fusarium	+++ 2	+++ 2	+++ 2	++ 2	++ 2
53. Ergot	- 0	- 0	++ 1	- 0	- 0
VII. Seedling blights	++ 2	+ 1	++ 2	+ 1	+ 1
(Mainly species of Pythium, Fusarium, Cephalosporium, Rhizoctonia, Diplodia, Nigrospora, Penicillium, Helminthosporium, and Curvularia).					
VIII. Nematodes	+ 1	++ 2	+ 1	+ 1	+ 1
(Mainly species of Pratylenchus, Helicotylenchus, Tylenchorhynchus, Trichodorus, Heterodera, and Belonolaimus).					
IX. Striga (<i>S. asiatica</i>).	- 0	+ 1	- 0	++ 1	++ 1

1/ Prevalence
 +++ = Abundantly present
 ++ = Commonly present
 + = Occasionally present
 - = Not present

2/ Importance
 3 = Major importance
 2 = Moderate importance
 1 = Minor importance
 0 = Absent or rarely found.

Table 7-13. Maize Insect Pests and Diseases in Tropical Africa, America and Asia. 1971 ^{1/}

DISEASES			
	(L) = Low	(M) = Moderate	(S) = Severe
Africa			
VIRUS DISEASES			
Mosaic Egypt.	(L)		(L) (S) <i>Puccinia polysora</i> South Africa, Nigeria.
Maize streak disease South Africa, Nigeria.	(M) (S)		LEAF BLIGHTS
STALK ROTS			
<i>Sclerotium bataticola</i> South Africa, Egypt.	(L) (S)		<i>Helminthosporium turcicum</i> South Africa, Egypt, Nigeria. (M) (S)
<i>Diplodia maidis</i> South Africa.	(S)		<i>H. maydis</i> South Africa, Egypt, Nigeria. (L) (S)
<i>Gibberella zeae</i> South Africa.	(S)		<i>Piricularia oryzae</i> , <i>Curvularia</i> spp. <i>Colletotrichum</i> spp., <i>Rhizoctonia</i> spp. Nigeria. (L)
<i>Pythium arrhenomanes</i> South Africa.	(L)		DOWNY MILDEWS
<i>P. debaryanum</i> Egypt, Nigeria.	(L)		<i>Sclerospora sorghi</i> South Africa, Egypt. (M) (S)
			<i>S. rayssiae</i> Egypt. (L)
EAR ROTS			
<i>Diplodia</i> spp. South Africa, Nigeria.	(L) (M) (S)		BROWN SPOT
<i>Gibberella zeae</i> South Africa, Nigeria.	(M) (S)		<i>Physoderma maidis</i> Nigeria. (L)
<i>Fusarium moniliforme</i> South Africa, Nigeria.	(M) (S)		LATE WILT
<i>Rhizoctonia</i> sp. Nigeria.	(L)		<i>Cephalosporium maidis</i> South Africa, Egypt. (L) (S)
SMUTS			
<i>Ustilago maidis</i> South Africa, Nigeria.	(L) (M) (S)		ROOT ROTS
<i>Sphacelotheca reiliana</i> South Africa.	(M) (S)		<i>Helminthosporium pedicellatum</i> South Africa. (S)
			<i>Fusarium moniliforme</i> South Africa. (S)
			<i>Fusarium</i> spp. South Africa. (S)
			<i>Aspergillus flavus</i> South Africa. (S)
RUSTS			
<i>Puccinia sorghi</i> South Africa, Egypt, Nigeria.	(L) (M)		<i>Mycena</i> root rot Egypt. (L) (M)

America

VIRUS DISEASES

Corn stunt	(L) (S)
Guatemala, México, El Salvador, Costa Rica, Nicaragua, Bolivia, Colombia, Uruguay, Brazil.	
Corn mosaic	(M)
Nicaragua, Brazil, Guatemala, México.	
Streak mosaic V	(L)
Brazil.	
Maize Dwarf mosaic V	(L)
Brazil.	
Others, nonidentified	(L)
México, Argentina.	

STALK ROTS

Gibberella zeae	(L) (S)
Ecuador, Bolivia, Colombia, Perú, Uruguay, Brazil, Argentina, Costa Rica.	
Diplodia maidis	(L) (S)
Bolivia, Colombia, Perú, Brazil, Argentina, Nicaragua.	
Sclerotium bataticola	(L) (S)
Colombia, Argentina, México.	
Pythium butleri	(L)
Brazil, Argentina, Costa Rica, Guatemala.	
Rhizoctonia spp.	(M)
Argentina.	
Fusarium graminearum	(M) (S)
Chile.	
Pythium spp.	(L) (M)
México, Argentina.	
Xanthomonas stewartii	(L)
México.	
Fusarium moniliforme	(L)
Brazil, Argentina.	
Helminthosporium spp.	(L) (M)
Argentina.	
Nigrospora, spp.	(L)
Argentina.	

EAR ROTS

Diplodia spp.	(L) (S)
Guatemala, México, Costa Rica, Nicaragua, Brazil, Colombia, Perú, Uruguay, Argentina, Bolivia.	
Gibberella zeae	(L) (S)
Guatemala, Costa Rica, Ecuador, Bolivia, Colombia, Uruguay, Brazil, Argentina, México.	
Fusarium moniliforme	(L) (S)
Guatemala, Costa Rica, Nicaragua, Bolivia, Colombia, Perú, Brazil, Argentina, Chile, México.	
Penicillium verdicatum	(L)
Argentina.	
Aspergillus spp.	(L)
Argentina.	
Fusarium graminearum	(L)
Argentina.	
Cephalosporium acremonium	(L)
Argentina.	
P. oxalicum	(L)
Argentina.	
Sclerotium bataticola	(L)
México.	

SMUTS

Ustilago maidis	(L) (M)
Guatemala, México, Costa Rica, Nicaragua, Ecuador, Bolivia, Argentina, Colombia, Brazil, Perú, Uruguay.	
Sphacelotheca reiliana	(L) (M)
Costa Rica, Colombia, Brazil, Argentina, Guatemala, México	

RUSTS

Puccinia sorghi	(L) (S)
Costa Rica, Nicaragua, Ecuador, Bolivia, Colombia, Perú, Brazil, Argentina, Guatemala, México.	
P. polisor	(L) (S)
Costa Rica, Colombia, Uruguay, Argentina, Guatemala, México.	
Physopella zeae	(M) (S)
Costa Rica, Guatemala, México.	

LEAF BLIGHTS

Helminthosporium turcicum	(L) (S)
Costa Rica, Nicaragua, Ecuador, Colombia, Perú, Uruguay, Brazil, Argentina, Guatemala, México.	
H. maidis	(L) (S)
Costa Rica, Nicaragua, Bolivia, Colombia, Uruguay, Brazil, Argentina, México.	
H. carbonum	(M) (L)
Colombia, Argentina, México.	
Cercospora maydis	(L)
Brazil, México.	

DOWNY MILDEWS

Scleroththora macrospora	(L)
Colombia, México.	
Sclerospora sorghi	(M) (S)
México, Argentina.	
S. graminicola (?)	(L)
Brazil.	

ROOT ROTS

BROWN SPOT	
Physoderma zeae	(L) (M)
Perú, Brazil, México, Argentina, Guatemala.	

LATE WILT

Cephalosporium maidis	(L) (M)
Nicaragua, Colombia, Brazil, Argentina, México.	

OTHER DISEASES

Physalospora zeae	(L)
Brazil.	
Phyllachora maidis (tar spot)	(S)
Colombia, México.	
Cladosporium herbarum	(L) (M)
Brazil, Ecuador, Colombia.	
Septoria maydis	(L)
Brazil, México.	
Scolecotrachelum graminis	(L)
Brazil.	
Phyllosticta hispida (maidis)	(L)
Brazil, México.	
Basidiosporium gallarum (ear rot)	(L)
Brazil, Colombia.	
Curvularia spp.	(M) (L)
Guatemala, México.	
Nigrospora oryzae (ear-rot)	(M)
México.	

<i>Gleocercospora zeae</i> (zonate leaf spot) México.	(L) (M)	<i>Helminthosporium carbonum</i> Thailand.	(L)
<i>Ustilagoidea virens</i> (false smut) México.	(L)	<i>Botryodiplodia phaseoli</i> Thailand.	(L)
		<i>Fusidium</i> sp. Thailand.	(L)
Asia		SMUTS	
VIRUS DISEASES		<i>Ustilago maidis</i> Thailand, India.	(L)
Corn stunt Thailand.	(L)	<i>Sphacelotheca relliana</i> Thailand, India.	(L)
Sugar cane mosaic V (SCMV) Thailand.	(L)	RUSTS	
Corn stripe V Thailand.	(L)	<i>Puccinia sorghi</i> Thailand, India.	(M) (S)
Maize mosaic (strain of SCMV) India.	(L)	<i>Puccinia polysora</i> Thailand.	(M) (S)
STALK ROTS		LEAF BLIGHTS	
Charcoal rot (<i>Sclerotium bataticola</i>) India.	(L) (M)	<i>Helminthosporium turcicum</i> Thailand, India.	(M) (S)
<i>Diplodia maidis</i> India.	(L)	<i>H. maydis</i> Thailand, India.	(M) (S)
<i>Gibberella zeae</i> Thailand, India.	(L)	<i>H. carbonum</i> India.	(L)
<i>Pythium aphanidermatum</i> Thailand.	(L)	<i>Curvularia lunata</i> Thailand.	(M) (S)
<i>Pythium butleri</i> Thailand, India.	(L) (S)	<i>Xanthomonas rubrilineans</i> (?) Thailand, India.	(L)
<i>Pythium arrhenomanes</i> Thailand.	(L)	<i>Helminthosporium rostratum</i> India.	(L)
<i>Colletotrichum graminicolum</i> Thailand.	(L)	DOWNY MILDEWS	
<i>Botryodiplodia phaseoli</i> Thailand.	(L)	<i>Sclerospora sorghi</i> (?) Thailand.	(M)
<i>Erwinia carotovora</i> f. sp. <i>zeae</i> Thailand, India.	(L) (S)	<i>S. philippinensis</i> Thailand, India.	(L)
<i>Xanthomonas stewartii</i> Thailand.	(L)	<i>S. sacchari</i> Thailand, India.	(L)
<i>Rhizoctonia zeae</i> Thailand.	(L)	<i>S. spontanea</i> Thailand.	(L)
<i>Nigrospora oryzae</i> Thailand.	(L)	<i>Sclerophthora rayssiae</i> var. <i>zeae</i> Thailand, India.	(L) (S)
<i>Ascochyta zeicola</i> Thailand.	(L)	<i>Physoderma maidis</i> (brown spot) Thailand, India.	(L) (M)
<i>Pseudomonas lapsa</i> India.	(L)	LATE WILT	
EAR ROTS		<i>Cephalosporium maydis</i> Thailand, India.	(L)
<i>Diplodia macrospora</i> India.	(L)	<i>Cephalosporium acremonium</i> India.	(M) (S)
<i>Gibberella zeae</i> India.	(L)	OTHER DISEASES	
<i>Fusarium moniliforme</i> Thailand, India.	(M)	Alternaria leaf spot (<i>Alternaria tenuis</i>) Thailand.	(L)
<i>Cephalosporium acremonium</i> Thailand, India.	(M) (S)	Phaeosphaeria leaf spot India.	(L)
<i>Aspergillus</i> spp. Thailand.	(L)	<i>Gleocercospora sorghi</i> India.	(L) (M)
<i>Penicillium</i> spp. Thailand.	(L)	Nematodes (4 genera involved) India.	(L) (S)
<i>Rhizopus</i> spp. Thailand.	(L)	False smut (<i>Ustilagoidea virens</i>) India.	(L)

INSECTS

(L) = Low (M) = Moderato (S) = Severe

Africa

STEM BORERS

Busseola fusca (L) (S)
Nigeria, South Africa, Kenya, Tanzania,
Uganda.

Eldana sacharina (L)
Nigeria, Uganda, Tanzania.

Coniesta igneifusalis (M)
Nigeria.

Chilo partellus (L) (S)
Egypt, Uganda, Kenya, Tanzania.

Ostrinia nubilalis (S)
Egypt.

Sesamia cretica (S)
Egypt, Kenya, Uganda.

S. calamitis, *S. poepitaga* (L) (S)
Nigeria, South Africa, Uganda, Tanzania,
Kenya.

S. penniseti, *S. nonagrilodes* (L) (S)
Nigeria.

Chilo traxa argyrolepta (L) (S)
East Africa.

Marasmia spp. (L) (S)
East Africa.

ARMYWORMS AND CUTWORMS

Spodoptera litralis (S)
Egypt, Uganda, Kenya, Tanzania.

S. exigua (L) (S)
Egypt, South Africa, Uganda, Tanzania.

S. exempta (L) (S)
Nigeria, South Africa, Kenya, Tanzania.

Agrotis ipsilon (L)
Egypt, Kenya.

A. segetis (M)
South Africa, Kenya, Tanzania.

EARWORMS

Heliothis armigera (L) (S)
Nigeria, Egypt, South Africa, Kenya,
Tanzania, Uganda.

Busseola fusca (L) (S)
Nigeria Uganda.

Sesamia spp. (L) (S)
Nigeria Uganda.

Argyroproce leucotreta (L) (M)
Nigeria Uganda.

SUCKING INSECTS

Rhopalosiphum maidis (L) (S)
Nigeria, Egypt, South Africa, Uganda,
Kenya, Tanzania.

Peregrinus maidis (L) (S)
Kenya, Tanzania, Uganda, Nigeria.

Cicadullna spp. (L) (S)
Nigeria, Uganda, Tanzania, Kenya.

Dysdercus superfluosus (L) (M)
Nigeria Uganda.

ROOTWORMS

Elatridae (L)

Heteronychus spp. (L) (S)
South Africa, Kenya.

Astylus astromaculatus (L) (S)
South Africa.

Phyllophaga spp. (L)
Egypt.

Termites (L) (S)
Kenya, Tanzania, Uganda.

GRASSHOPPERS AND OTHER FOLIAGE FEEDERS

Epilachna sp. (L) (S)
East Africa.

Zonoceros varigatus (L) (S)
Nigeria, Uganda.

Locusta migratoria (L) (S)
Nigeria, Kenya.

Schistocerca gregaria (L) (S)
Kenya.

STORED-GRAIN PESTS

Ephestia cautella (L) (S)
Egypt, South Africa, Uganda, Kenya,
Tanzania.

Plodia interpunctella (L) (S)
Egypt, South Africa, Uganda, Kenya,
Tanzania.

Rhyzopertha dominica (L) (S)
Egypt, South Africa, Uganda, Kenya,
Tanzania.

Strophilus granarius, *S. oryzae* and *S. zeamais* (L) (S)
Egypt, South Africa, Uganda, Nigeria, Egypt,
South Africa Kenya, Tanzania and Uganda.

Tribolium spp. (L) (S)
Egypt, South Africa, Nigeria, Kenya,
Tanzania, Uganda

Sitotroga cerealella (L) (S)
Kenya, Tanzania, Egypt, South Africa,
Uganda

Cathartus quadricollis (L) (S)
Nigeria.

Mussidia nigrivenella (S)
Nigeria.

America

STEM BORERS

Chilo plejadellus (L) (M)
México.

Nomophila noctuella (L)
Brazil.

Diatraea saccharalis (L) (S)
Southern U.S.A. to northern Argentina,
including Caribbean area.

Zeadiatraea lineolata (L) (S)
México, Central America, Colombia,
Venezuela, Caribbean area.

Z. grandiosella (L) (S)
México, U.S.A.

Elaeopalpus lignosellus (L) (M)
Nicaragua, Perú, Brazil, Argentina, Chile,
México, U.S.A.

Ostrinia nubilalis (L) (M)
U.S.A., Canada.

ARMYWORMS AND CUTWORMS

<i>Marasmia trapezalis</i> Perú.	(M)
<i>Prorachia daria</i> México.	(M) (S)
<i>Prodenia ornithogalli</i> Costa Rica, Colombia.	(L) (S)
<i>P. eridania</i> , <i>P. sunia</i> , <i>P. latistascia</i> Costa Rica, Colombia, Perú.	(M) (S)
<i>Pseudaletia unipuncta</i> , <i>P. adultera</i> Costa Rica, Argentina, U.S.A.	(M) (S)
<i>Agrotis ipsilon</i> Costa Rica, Ecuador, Bolivia, Colombia, México, Perú, Brazil, Argentina, Chile.	(M) (S)
<i>Spodoptera frugiperda</i> Southern U.S.A. to northern Argentina and Chile, including the Caribbean area.	(M) (S)
<i>Mocis latipes</i> , <i>M. repanda</i> Ecuador, México, Brazil.	(L) (M)
<i>Dargida grammivora</i> , <i>Feltia anexa</i> Colombia.	(M)

EARWORMS AND EAR MAGGOTS

<i>Heliothis zea</i> Canada to Argentina and Chile, including the Caribbean area.	(L) (S)
<i>Pyroderces</i> sp. Colombia.	(L)
<i>Pococera atramentalis</i> Perú.	(S)
<i>Protoleucania albilinea</i> Argentina.	(S)

ROOTWORMS

<i>Diabrotica</i> spp. Costa Rica, Bolivia, Ecuador, México, Colombia, Perú, Brazil, Argentina, U.S.A.	(L) (S)
<i>Phyllophaga</i> spp. Costa Rica, Nicaragua, México, U.S.A.	(L) (M)
<i>Chaetocnema</i> spp. Perú, México, U.S.A.	(L) (S)
<i>Dyscinetus</i> , <i>Ligyris</i> , <i>Eutheola</i> Argentina.	(M) (S)

GRASSHOPPERS

<i>Melanoplus</i> spp. U.S.A., México.	(L)
<i>Schistocerca paranensis</i> Bolivia, Colombia, Perú.	(L) (S)
<i>S. impleta</i> Colombia.	(L)

SUCKING INSECTS

<i>Dalbulus</i> spp. Costa Rica, Nicaragua, Bolivia, Colombia, México, Brazil, U.S.A.	(L) (S)
<i>Peregrinus maidis</i> Central America, México, U.S.A.	(L)
<i>Bilissus leucopterus</i> Costa Rica, U.S.A.	(L)
<i>Rhopalosiphum maidis</i> Nicaragua, Ecuador, Bolivia, Colombia, México, Perú, Brazil, Argentina, Chile, U.S.A.	(L) (S)
<i>Hemiothrips fasciatus</i> Bolivia.	(M)
<i>Frankliniella</i> spp. México, Colombia, Perú, Chile.	(L) (S)

STORED-GRAIN-INSECTS

<i>Sitotroga cerealella</i> Costa Rica, Nicaragua, Ecuador, Bolivia, México, Colombia, Perú, Brazil, Argentina, Chile, U.S.A.	(S)
<i>Sitophilus</i> spp. Costa Rica, Nicaragua, Ecuador, Bolivia, México, Colombia, Perú, Brazil, Argentina, Chile, U.S.A.	(M) (S)
<i>Carpophilus dimidiatus</i> Costa Rica, Colombia, Perú, México, Nicaragua.	(L)
<i>Tribolium</i> spp. Nicaragua, Ecuador, Bolivia, México, Colombia, Peru, Brazil, Chile, U.S.A.	(L) (M)
<i>Cathartus quadricollis</i> Costa Rica.	(S)
<i>Dinoderus</i> spp. México, Colombia, Perú.	(L) (M)
<i>Oryzaephilus surinamensis</i> México.	(L) (M)
<i>Plodia interpunctella</i> Colombia, México, Perú, Brazil, Chile.	(M) (S)
<i>Rhyzopertha dominica</i> Colombia, México, Perú, Brazil, Chile.	(L) (M)
<i>Anagasta kuehniella</i> Colombia, México, U.S.A.	(M)
<i>Pagiocerus frontalis</i> Perú.	(M)
<i>Araeocerus fasciculatus</i> Brazil.	(M)

Asia

STEM BORERS

<i>Ostrinia salentialis</i> Thailand, Philippines, Malaya.	(S) (M)
<i>Chilo partellus</i> India, Pakistan.	(S) (M)
<i>Sesamia inferens</i> India.	(L) (M)

ARMYWORMS AND CUTWORMS

<i>Agrotis</i> sp. India.	(M)
<i>Marasmia trapezalis</i> India.	(M)
<i>Spodoptera exempta</i> <i>Plusia chalytes</i> Philippines. Philippines.	(S) (M) (M)
<i>Prodenia litura</i> Philippines, Thailand.	(S) (M)
<i>Pseudaletia</i> spp. Thailand.	(S) (M)
<i>Mylocerus</i> spp. India.	(M)
<i>Tanymecus indicus</i> India.	(M)

EARWORMS

<i>Heliothis armigera</i> Philippines.	(S) (L)
<i>Ostrinia salentialis</i> Philippines.	(S) (M)

ROOTWORMS AND MAGGOTS

Holotrichia consanguinea (M)
India.

Odontotermes spp. and *Microtermes* spp. (L) (M)
India.

Leucopholis irrorata (S) (M)
Philippines.

Atherigona spp. (M) (S)
India, Pakistan, Indonesia, Philippines.

SUCKING INSECTS

Peregrinus maydis (L)
India.

Cicadulina sp. (L)
India.

Rhopalosiphum maydis (M)
Philippines.

Aphis sacchari (M)
Philippines.

Pyrilla perpusilla (L) (M)
India.

GRASSHOPPERS

Hieroglyphus nigrorepletus (M)
India.

Patanga succincta (S) (M)
Thailand.

Locusta migratoria (S) (M)
Philippines

STORED-GRAIN INSECTS

Sitotroga cerealella (L) (S)
India.

Sitophilus oryzae (L) (S)
Philippines, Thailand.

Rhyzopertha dominica (L) (S)
Philippines, Thailand.

Tribolium castaneum (L) (S)
Philippines, Thailand.

Oryzaephilus surinamensis (L) (S)
Philippines.

Carpophilus dimittatus (L) (S)
Thailand.

Cryptolestes pusillus (L) (S)
Thailand.

Trogoderma granarium (L) (S)
India.

Table 7-14. Most important diseases and insect pests affecting world maize production^{1/}

World Wide Distribution

1. *Seedling blight, Pythium, Fusarium, & others (Temperate regions)
2. *Southern leaf blight, Helminthosporium maydis (Tropics)
3. *Northern leaf blight, Helminthosporium turcicum (Temperate regions)
4. *Curvularia leaf spot, Curvularia spp. (Tropics)
5. *Southern maize rust, Puccinia polysora (Tropics, W. Africa)
6. *Common maize rust, P. Sorghi (Temperate regions)
7. *Stalk rots, - Diplodia maydis, Gibberella zeae (Temperate regions)
 - Fusarium nonifforme
 - Pythium aphanidermatum
 - Erwinia chrysanthemi (Tropics)
 - Pseudomonas lapsa
 - Cephalosporium acremonium
8. *Ear rots - Gibberella zeae, Diplodia maydis (Temperate regions and tropics)
 - Fusarium moniliforme
9. *Maize mosaic, (Virus) (Tropics)
 - *Corn plant hopper, Peregrinus maidis (Tropics)
 - *Corn leaf aphid, Rhopalosiphum maidis (Temperate & Tropics)
10. European corn borer, Ostrinia nubilalis (Temperate)
11. *Thrips, Frankliniella spp. (Tropics)

North, Central and South America

12. *Corn stunt, (Mycoplasma) (Tropical)
 - *Leaf hopper, Dalbulus spp. (Stunt vector) (Tropical)
13. *Borers, Zeadiatraea lineolata (Tropical)
 - Zeadiatraea grandiosella (Tropical)
 - Diatraea saccharalis (Tropical)
 - Elasmopalpus lignosellus (Temperate & Tropical)
14. *Ear worm, Heliothis zea (Temperate & Tropical)
15. *Fall armyworm, Spodoptera frugiperda (Temperate & Tropical)
16. *Armyworm, Pseudaletia unipuncta (Temperate & Tropical)
17. *Root worms, Diabrotica spp. (Temperate & Tropical)

Table 7-14. (Continued)

Africa and Middle East

18. Late wilt, Cephalosporium maydis (Egypt) (Tropical)
19. Maize streak, (Virus)
 Leaf hopper, Cicadulina mbila (Naude)(Streak Vector) (Tropical)
20. Borers, Chilo partellus (Tropical)
Sesamia cretica (Tropical & Mediterranean)
Busseola fusca (Tropical & Temperate)
Sesamia calamistis (Tropical)
Sesamia nonagrioides botanephaga (Tropical)
21. Armyworms, Spodoptera exempta (Tropical)
S. exigua (Tropical)
22. Earworms, Heliothis armigera (Tropical)

Indian Sub-Continent & S.E. Asia

18. Late wilt, Cephalosporium maydis (Tropical)
23. Downy mildews, Sclerospora spp. (Tropical)
Sclerosphthora spp. (Tropical)
24. Borers, Chilo partellus (India) (Tropical)
Sesamia inferens (Tropical)
Ostrinia furnacalis (S.E. Asia) (Tropical)
25. Armyworm, Mythimna separata (Tropical)
Spodoptera exempta (Tropical)

*Present in Mexico at one of CIMMYT's research stations.

1/ Prepared for the International Symposium, "World-Wide Maize Improvement in the 1970's and the Role for CIMMYT" El Baton-Mexico, April 22-26, 1974, by W.R. Young, Rockefeller Foundation, Bangkok, Thailand.

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<u>Figure</u>	<u>Title</u>
7-1	CIMMYT maize improvement role world-wide context.
7-2	Percent ears damaged by <u>Fusarium moniliforme</u> in different maize populations and their opaque-2 versions when planted in four different environments.
7-3	<u>Fusarium</u> ear rot, <u>Diplodia</u> ear rot, earworms damage, foliar stemborer and budworm damage, and average damage of these agents to normal, opaque, and modified opaque endosperm versions of four maize populations.
7-4	Percentage of budworm (<u>Spodoptera frugiperda</u>) damaged plants (means of three opaque-2 varieties), Poza Rica, Veracruz. 1973A.

**Fig. 7-1 CIMMYT MAIZE IMPROVEMENT ROLE
WORLDWIDE CONTEXT**

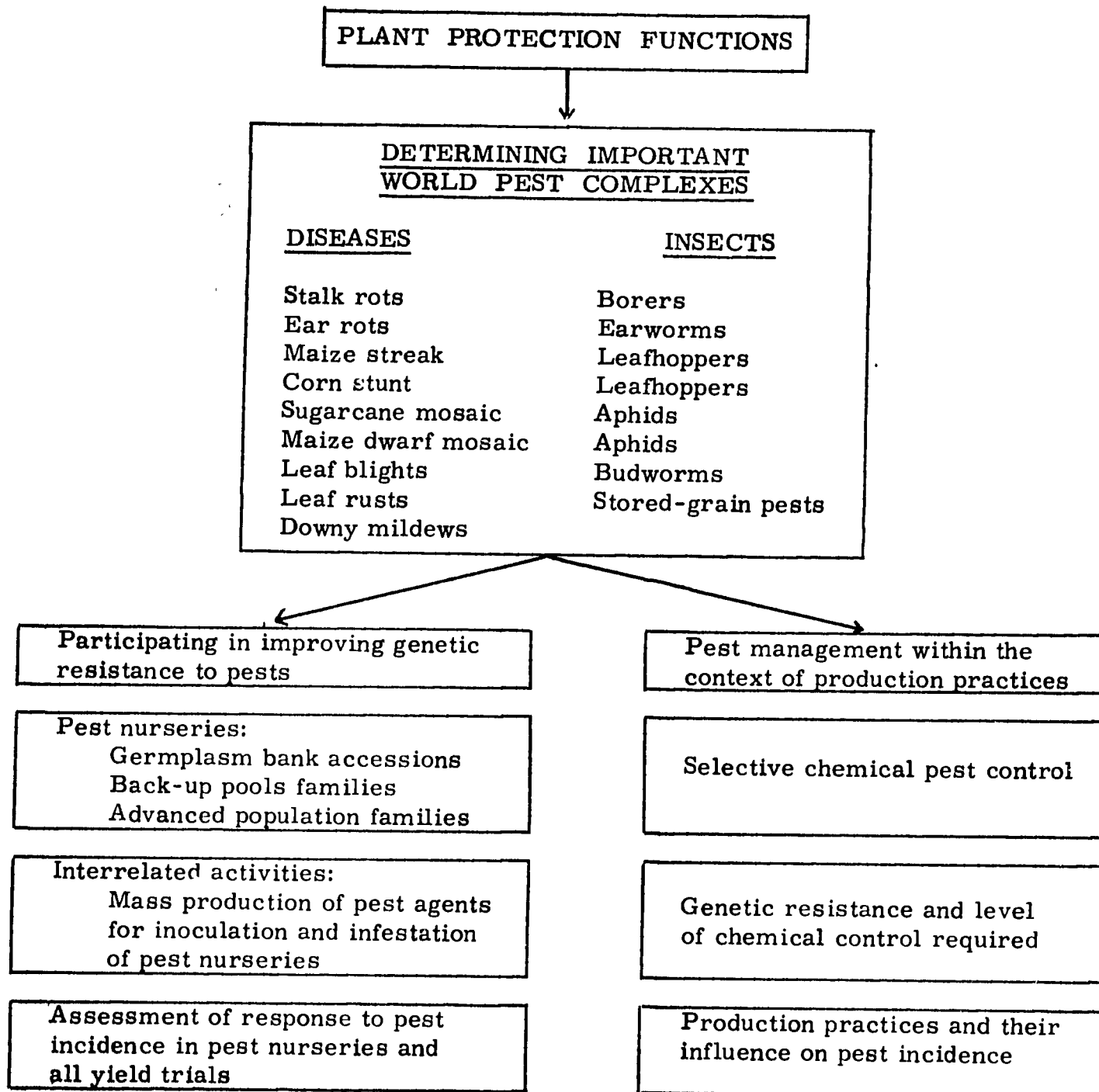


FIGURE 7-2. Percent ears damaged by *Fusarium moniliforme* in different maize populations and their opaque-2 versions when planted in 4 different environments.

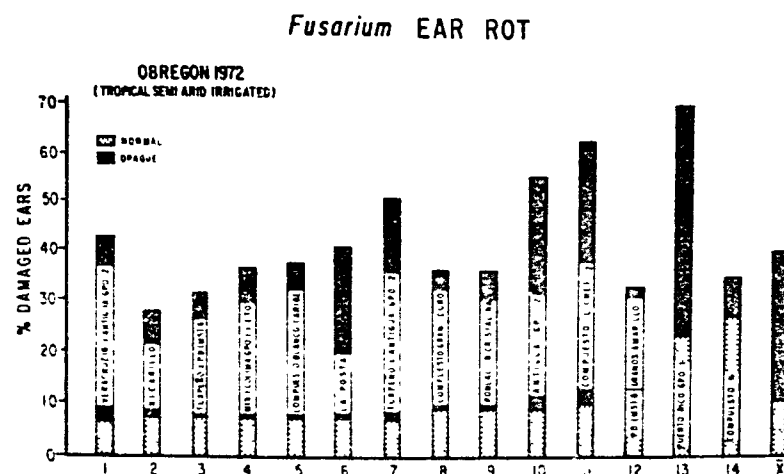
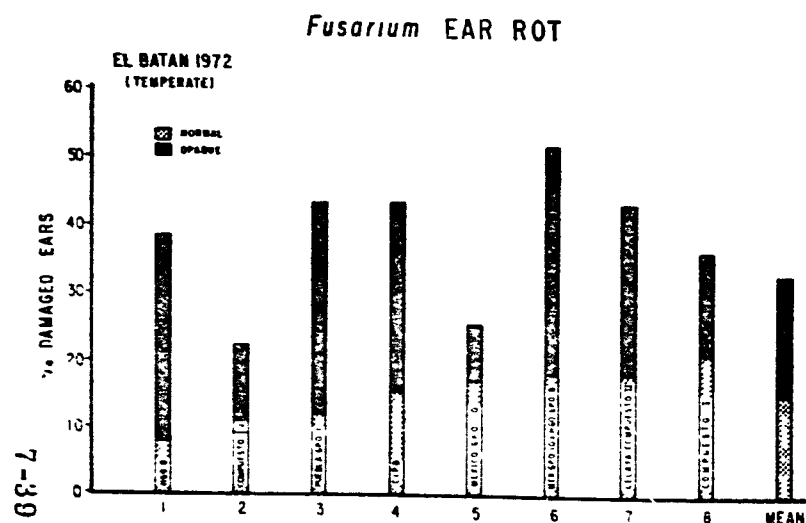
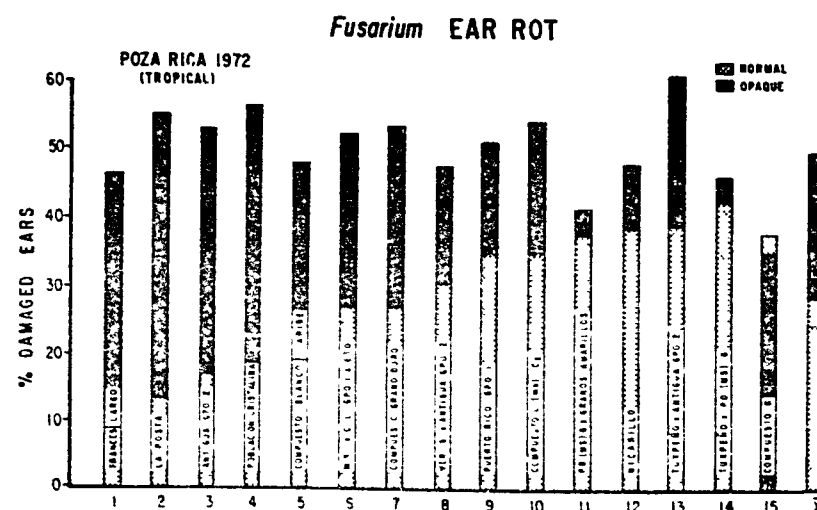
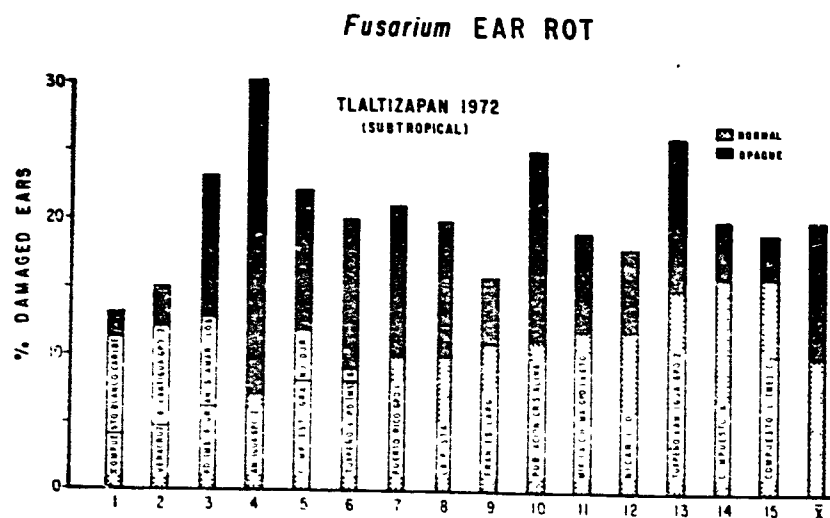
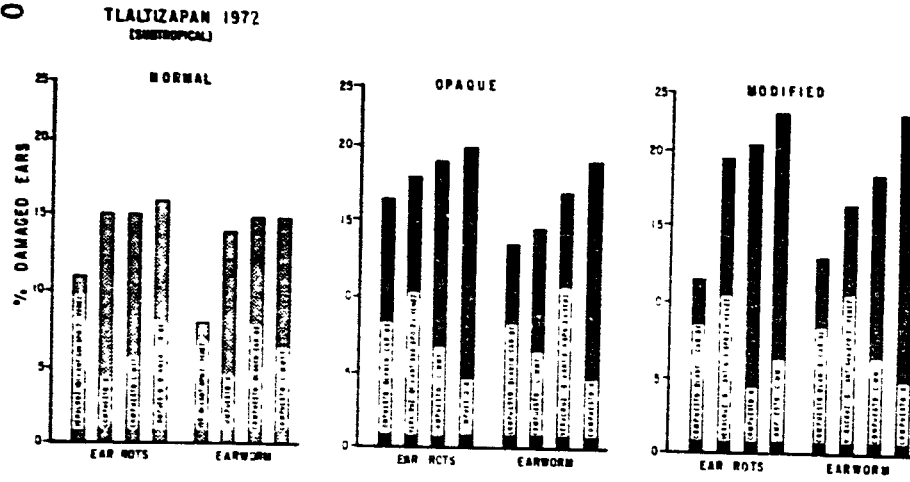


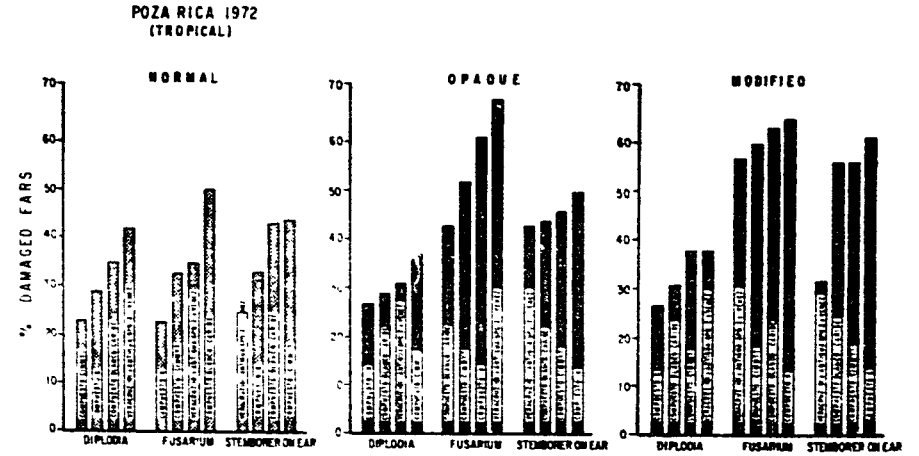
FIGURE 7-3. *Fusarium* ear-rot, *Diplodia* ear-rot, earworms damage, foliar stemborer and budworm damage and average damage of these agents to normal, opaque and modified opaque endosperm versions of four maize populations.

7-40

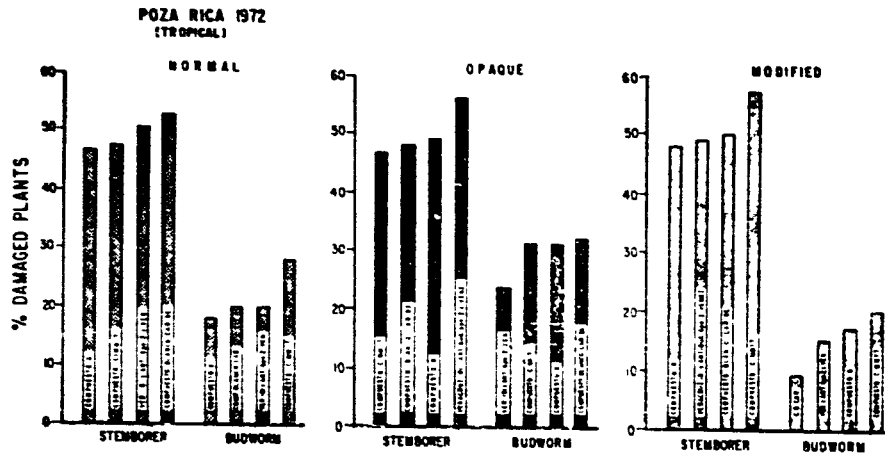
***Fusarium* AND *Diplodia* EAR ROTS AND EARWORM**



***Diplodia*, *Fusarium* EAR ROTS AND STEMBORER EAR DAMAGE**



STEMBORER AND BUDWORM ON FOLIAGE



AVERAGE DAMAGED EARS ON FOUR MAIZE POPULATIONS EACH REPRESENTED BY THE NORMAL, OPAQUE-2 AND MODIFIED VERSIONS 1972

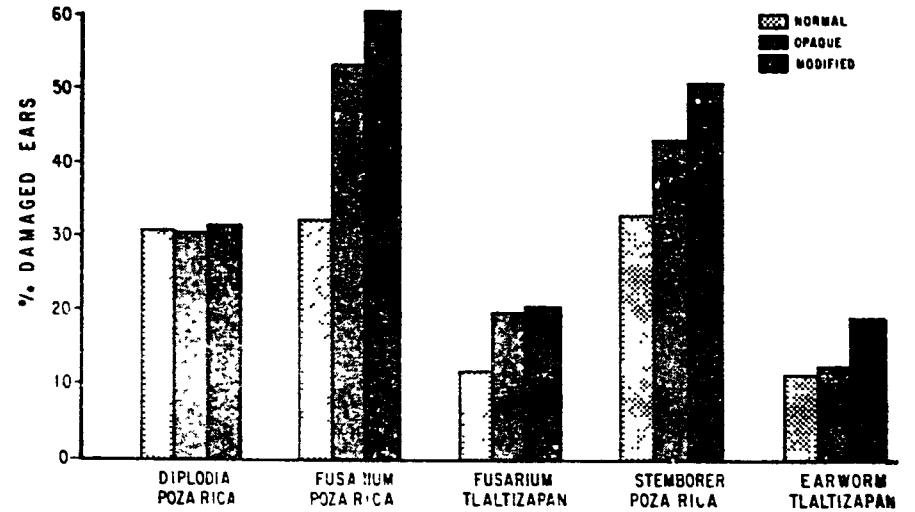
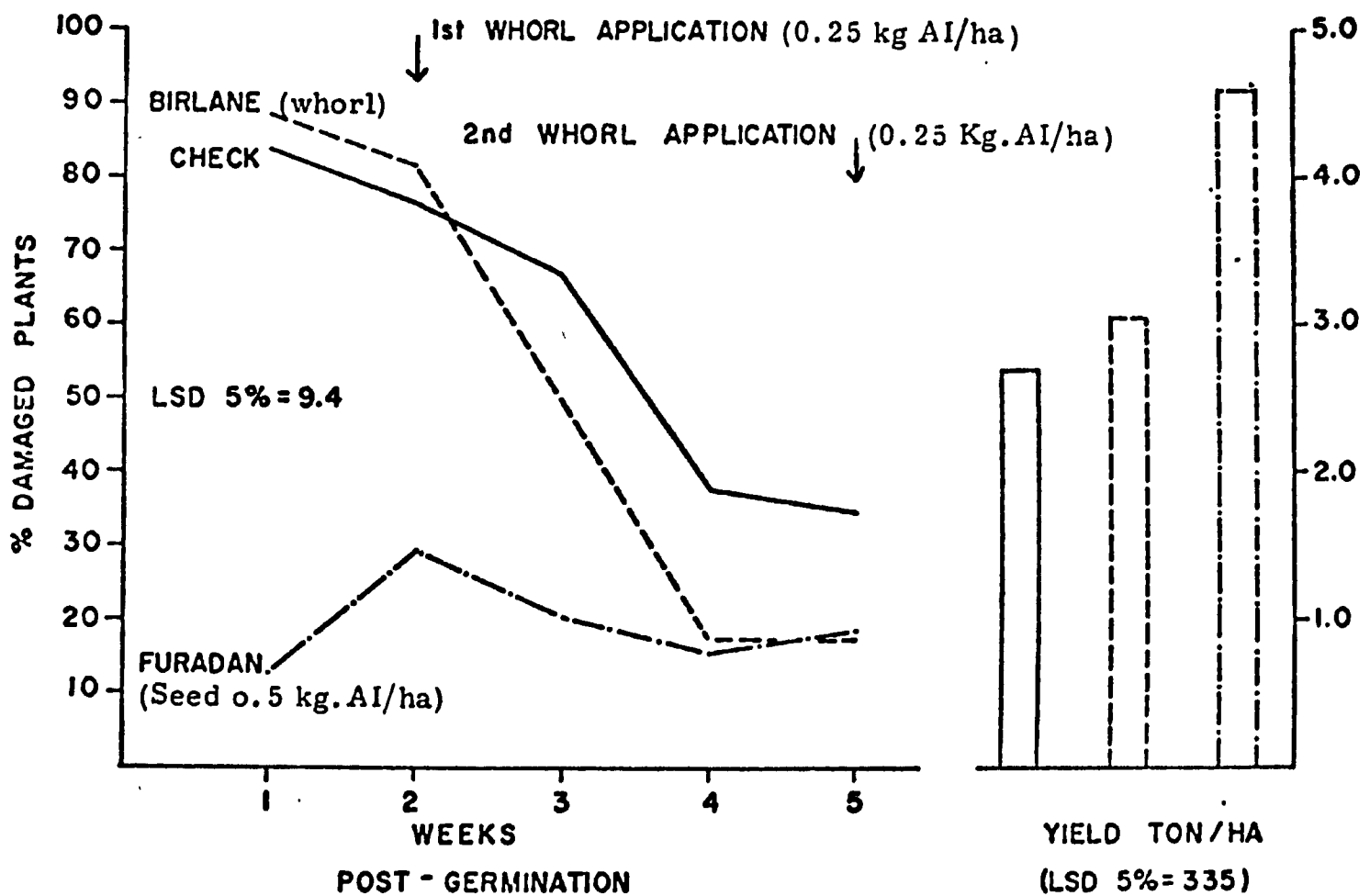
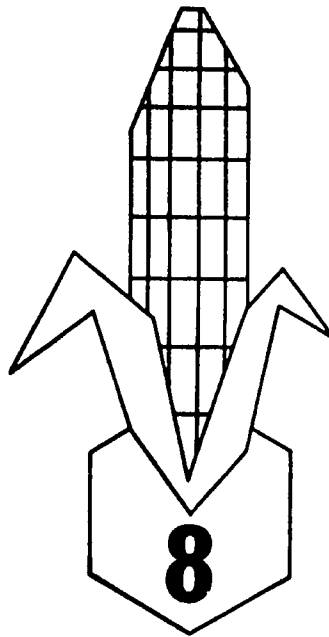


FIG.7-4. PERCENTAGE OF BUDWORM (*Spodoptera frugiperda*) DAMAGED PLANTS (MEANS OF THREE OPAQUE-2 VARIETIES), POZA RICA, VER., 1973A





**AGRONOMIC ASPECTS OF
MAIZE IMPROVEMENT**

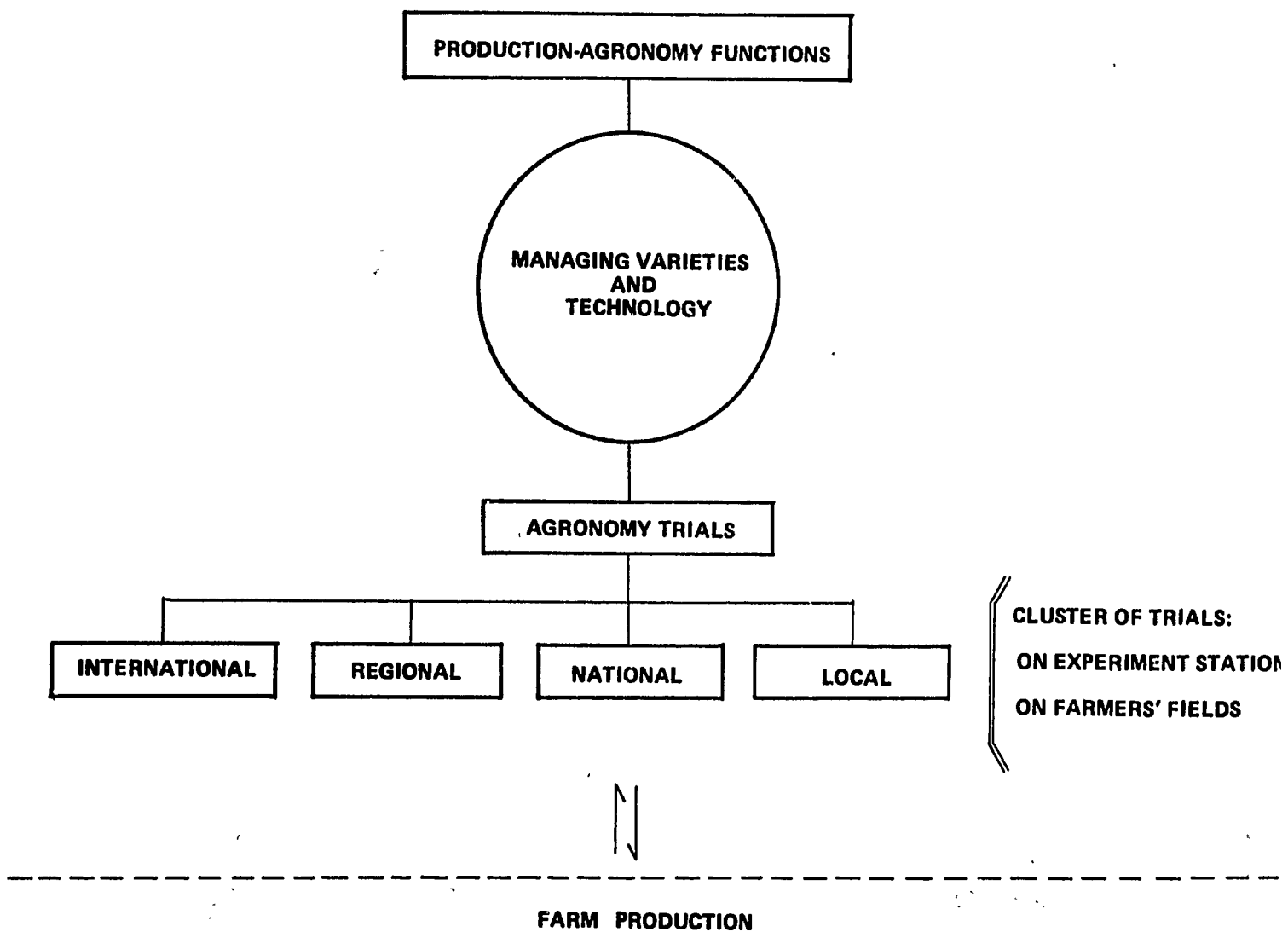
by
A. F. E. Palmer, CIMMYT

**Lead Discussant:
Dr. A. Y. Allan
Maize Research Station
Kitale, Kenya**

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**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



8.0

AGRONOMIC ASPECTS OF MAIZE IMPROVEMENT

by
A. F. E. Palmer

8.1 INTRODUCTION

Good maize varieties and improved packages of practices have been developed on experiment stations in many of the developing nations. Their adoption at the farm level is, however, frequently limited to a few percent of the maize acreage. Thus, one of the greatest jobs still to be done is to convince the maize growers to adopt the new varieties and technology. Yield achievements on the experiment station are often suspect in the eyes of farmers. Therefore, the suitability of varieties and practices must be demonstrated at the farm level; only by on-farm trials and demonstrations in which they participate can farmers learn and be convinced that the new technology is both applicable in their situation, and profitable for them. CIMMYT's efforts in research and production agronomy form the basis of this paper.

Agronomic research objectives are: (1) to discover how to use the best varieties available, as well as those being developed, and (2) to develop and transmit the technology needed to the farmer, working through regional and national programs.

8.2 ORGANIZATION OF AGRONOMIC ACTIVITIES

Fig. 8-1 is a flow chart of how new germplasm from the breeding nurseries progresses to production trials. It illustrates the relationship between the breeding program and the agronomy trials that support it. The process includes the following:

Source of New Materials: For the most part, the experimental and elite experimental varieties generated through the international progeny testing trials will be the materials used in production agronomy trials.

Experimental Varieties: On the basis of progeny performance within and across sites, a series of experimental varieties will be generated from each advanced population. These will be compared with experimental varieties derived from other populations in the advanced unit of the breeding program. At first, new materials are included in these trials only at selected sites. Those which show promise are then introduced into a larger, more widely distributed series of variety trials of the same type. The varieties included in these trials change progressively. Even at the selected sites, only a small proportion of the varieties are new. Other varieties might be included for several seasons, each as a more advanced selection from the breeding program in each cycle.

The data obtained from these experiments over sites and seasons can provide a measure of the progress in yield improvement and of the extent and limits of varietal adaptation. Detailed descriptions of how these trials are organized and how the information is used are presented next.

Agronomy Trials: The best varieties available are selected for the production trials. These are of two kinds: (1) international and regional (confined mainly to experiment stations) that develop and test the management needed to get the best performance from the best varieties; and (2) national and local (forming part of regional or national production programs) with the aim of developing and transmitting the technology needed to obtain consistently profitable grain yields from the best varieties available for a given region. These are planted in farmers' fields and distributed to cover the soils and ecological areas of importance. The treatments and designs are chosen so that estimates can be made of the input costs. This kind of trial is indispensable in the development of national or regional crop production programs.

Some Questions for Consideration: The following questions are presented for discussion in this session:

1. What kinds of trials and organization are needed to develop and test new varieties and the production practices that will help regional and national programs?
2. Does the need for uniformity in the International series of trials conflict with the needs for regional and national programs? If so, is it possible to devise trials that serve both needs?
3. How could CIMMYT most effectively assist national maize agronomy programs? Are there aspects that

have been omitted in which you would expect CIMMYT to provide services or support in agronomy?

8.3 TESTING NEW MATERIALS

As indicated by the flow chart (Fig. 8-1), a primary objective is systematic evaluation of elite material from the population improvement program. The ultimate aim is to provide national and regional programs with the best proven varieties, with background data on how to use them. Fig. 8-1 indicates where the agronomist begins his contribution to this development.

8.3.1 EXPERIMENTAL VARIETY TRIAL

CIMMYT's population improvement program is responsible for progeny testing; however, the agronomy section is participating with that program in a series of trials to test and compare the performance of the advanced unit populations. These trials, and the progeny tests, provide initial data for defining varietal response to environments.

The population improvement program will select families for recombination in the breeding nursery, on the basis of performance in progeny tests at six locations. Reserve seed of the selected families will be used to make up balanced composites from each population. The composites will be handled as "experimental varieties."

An experimental variety may be made up of the best progeny families tested in the country or region in the initial work to meet the needs of national programs. Thus, a number of experimental varieties may be derived from the same advanced population, each variety consisting of a different set of progenies. In addition, however, one experimental variety of each population would be made up by combining families that performed well at a number of sites, combined with the best family from each site. These experimental varieties will be included in the series of experimental variety trials; at first on a few selected sites, but ultimately in a widely distributed series of trials.

In beginning this work, 49 populations were selected for trials at Poza Rica, Obregón, and Tlaltizapán in 1973B. Of these, 16 are now included in the list of 28 advanced unit populations that will be tested during 1974B. Twenty-five of the advanced unit populations were placed in trials at Poza Rica and Tlaltizapán during 1974A. It is expected that from 100 to 150 of these trials will be completed in different parts of the world in the summer season of 1974.

Data accumulated over successive cycles of improvement in these trials will provide comparisons among the populations in the advanced unit and a measure of the progress being made in their improvement. It will also provide the information for determining the extent and the limits of adaptation of each population in the manner discussed earlier.

8.4 INTERNATIONAL AND REGIONAL AGRONOMY TRIALS

8.4.1 INTERNATIONAL TRIALS

After the trials listed previously, the next step is to select the best varieties from the experimental variety trials for more intensive agronomic and management studies. About eight to ten varieties have been included in agronomic studies of this kind on CIMMYT experiment stations in Mexico, and in a series of international agronomy trials sent to 17 locations in 14 countries in 1972 and 1973. In these first trials, there was no background data on which to base the selection of varieties; however, the experimental variety trials will produce the data in the future.

In the absence of an international network of maize variety trials, comparison of varieties formed a major component of the first CIMMYT international agronomy trials. The experimental variety trials now proposed by CIMMYT provide a much better opportunity to (1) identify the best of the advanced populations from regional or CIMMYT breeding programs, and (2) determine the bases and the extent of their adaptation over a wide range of environments. Thus, they will replace the international agronomy trials in this function. Should an international cooperative agronomy trial be needed in the future, a new approach is indicated and some of the possible approaches were discussed at the maize workshop at CIMMYT in September 1973.

Michael Harrison of IITA suggested a series of multi-factor experiments distributed over sites representing a wide range of environments. This method would determine which factors of production are important and distinguish factors that are of general importance across environmental areas or regions as opposed to factors that are location specific. A series of production agronomy trials conducted in Kenya and described by Alistair Allan provide an example of a successful application of this kind of approach.

Discussions during the IACP meeting in Kuala Lumpur in December 1973, provide an example of another situation in which the

above approach may be useful. The discussion was prompted by a proposal from Dr. Samonte of UPCA, Department of Soils, suggesting that an effort be made to collect and summarize existing information on soils and soil fertility factors affecting production in IACP countries. While the project proposed by Dr. Samonte seemed worthwhile, it was felt that soil fertility represented only one factor of production. (Traditionally, it has been given weight in agronomy production programs at the expense of other, probably equally important factors.) Thus, in the future, some means of determining the importance of other factors in addition to soil fertility and fertilizers seems to be needed.

Workshop participants indicated the need for more extensive investigation of production problems. Yields of 5.5 and 6.0 tons, na. were reported in several trials from Farm Suwan, compared with a national yield average of 2 or 2.5 tons in Thailand. What factors account for this difference?

Antonio Mercado reported trial yields of about 5 tons/ha. with improved varieties in the Philippines, but national average yields are 1 ton/ha. or less. He listed factors that contribute to this difference, but his results emphasize the need for further investigations to determine the relative importance of these factors and how to overcome them. It seems probable that a series of multi-factor trials of the kind described could be an effective tool for this task in the Philippines, and throughout the maize-growing areas of Southeast Asia, Asia, and probably in other regions.

The agronomist's choice of factors to be investigated is determined in part by experimental design limitations, particularly when some factors are to be included at three or more levels. He would be helped in this choice if he knew (1) which factors were the most important; (2) which of these he could consider as equally important over the whole area he is studying; and (3) which he expects to be more important at some locations than others. A series of trials of the kind suggested offers one means of providing this information. If coordinated over a wide area, these trials would have the additional important advantage of providing the agronomist with a basis for comparing his situation with that indicated by results from other parts of the same region or from other regions.

A trial design with six factors, each at two levels (2^6), might be used in an investigation of this sort. By confounding high order interactions, this design can be arranged in a square of 64 plots, giving information on all main effects, two-factor interactions, and on 12 out of the 20 three-factor interactions. However, even this arrangement might be difficult to accommodate on a producer's field. Any other

arrangement of six factors would involve the sacrifice of a large part of the information for a comparatively small saving in size. Since the value of the investigation would depend on its close relation to existing production problems, most of the trials would need to be planted on farmers' land.

Some of the ways these trials might be done are:

1. Rather than use a square, rows or columns of the square could be laid out as blocks of eight plots, singly or in groups, on different land around a village site. The data from separate blocks could then be analyzed as a randomized block and the analysis of the confounded degrees of freedom modified accordingly (degrees of freedom confounded with rows, or columns, of the square would be pooled with error).
2. Alternate designs for five factors (2^5) or four factors (2^4) could be provided for situations where the six factors could not be accommodated. The choice of factors to be retained could be made locally.

The results of these smaller trials would be compatible with the corresponding factors in the larger design. The total series of experiments might thus consist of several components of different size: six-factor experimental trials laid out as squares where space and facilities permitted; similar experiments but separated into blocks of eight plots; smaller experiments with only four or five of the six factors included.

Experiments in the series might be analyzed individually and then in groups. The structure of the groups could be determined from the distribution of the trials. An analysis of data from groups of trials would provide the means to distinguish factors that are of importance across sites. (Factors that are important across sites would be expected to give large and significant effects in such an analysis. Conversely, factors of variable importance from site to site would be expected to give inconsistent and insignificant effects.)

Proposals similar to the above have been sent to maize staff in Asia and Africa for discussion, with a request for comments and suggestions. CIMMYT has considered an approach of this kind to replace the international agronomy trials. Alternatively, it might be adopted, with or without modification, by an existing regional program such as the IACP where there is a well-established cooperative structure. CIMMYT could assist where appropriate, for example, by providing designs for trials, by analyzing data for regions or countries, and by making available results from one area to another.

8.4.2 OTHER ON-STATION AGRONOMY TRIALS

Another group of trials being developed on CIMMYT's stations in Mexico forms part of the agronomy program, and also serves an important role in training young agronomists.

During 1972 and 1973, 18 such trials were completed at Poza Rica and Tlaltizapán. The trials included an examination of:

Variety x planting densities

Variety x planting densities x N levels x P_2O_5 levels

Variety x N levels x time of N application

Variety x insecticide materials

Insecticide x planting densities x N levels

Herbicide x planting densities x N levels

Variety x management represented the largest component of the trials. On-station trials such as these, using the best varieties available, would form part of most national or regional maize production programs. It is here that the agronomist can study the potential of new varieties as they become available to him and compare the response of new and older materials to intensive management.

In all these trials, zero levels of the management factors under study were generally included in the treatment design. The top level of each factor was at or above the level considered to be an economic level of management. All management factors other than those under study in a particular experiment (including irrigation) were carried out at the level recommended by the station. Under these controlled conditions of intensive and timely management, a good indication of the yield potential of the varieties can be obtained. Water management, planting date, and land preparation methods are other factors that may be included in these trials on experiment stations.

Many of the factors mentioned above need to be initially investigated under the controlled conditions existing on experiment stations. The findings of the on-station trials may then be verified in relatively few trials on farmers' land in the principal maize growing areas of the country or region. Planting densities, insecticide materials, and herbicide treatments would be factors falling into this category.

Other factors require more extensive testing on farmers' land, after the initial trials on experiment stations, in order to establish the suitability of the findings for the existing farming system and to determine economic levels of inputs. Included in these trial categories would be variety, fertilizer levels, and an overall insect control procedure. More will be said about these trials in section 8.5.

At CIMMYT, an added component of these on-station trials is related to CIMMYT's in-service training program. The trials are used to show the trainees a well-grown crop--maybe the first such crop they have seen in their careers. In addition, the trainees are involved in the design of the trials, in the planting and management through the growing season, in the data collection, and in the analysis and interpretation of the data. The experimental designs in use in the trials will be directly applicable for use in similar trials when the trainees return to their home countries.

8.5 NATIONAL AND LOCAL AGRONOMY TRIALS

The final step of the flow diagram shows the national and local coverage of trials, in which the newly developed varieties and practices are grown and evaluated in the farmer's field.

Within a region served by the experimental variety trials, international agronomy trials, and a well-coordinated series of on-station agronomy trials, the agronomist who carries the production practices to the farmer already has a lot of background information to guide him on the performance of his varieties, their response to fertilizer, and the crop protection needed.

8.5.1 CIMMYT'S ON-FARM TRIALS IN MEXICO

As part of the training for young agronomists in the CIMMYT maize program, a series of trials and demonstrations is being developed in cooperation with the agricultural extension service in Mexico. They are situated on farmers' land in the State of Veracruz, near CIMMYT's experiment station at Poza Rica. Trainee production agronomists are responsible for these trials and for organizing field days and discussions in which the new varieties and technology are demonstrated to groups of farmers. This activity provides a valuable teaching ground to help the trainee understand the relationship between on-station trials and trials that are conducted on farmer's land, and how to decide what kind of trial is appropriate for each situation.

In most developing countries, research at the experiment stations is not sufficient to influence the farmers' adoption of technological packages. Thus, a large gap exists between yields attainable on experiment stations and those obtained on farmers' fields in the same region. The main purpose of the off-station trials is to familiarize the trainees with the latest ideas on how this gap may be closed. Farmers' participation in the sowing, management, and harvesting of simple experiments permits them to make their own evaluation of the inputs such as improved varieties, fertilizers, and pesticides. Other factors of management are performed using whatever resources the farmer has.

During each crop cycle, sets of simple experiments are established in four to eight new sites within the region represented by the Poza Rica station. A set of experiments consists of:

1. **A simple variety trial with two replications comparing three or four new varieties with the farmer's, or local, variety. During 1973, the improved varieties were INIA hybrids, commercial seed company hybrids, or CIMMYT populations for lowland tropical conditions. The local Tuxpeño varieties were much taller and tended to lodge more than the improved varieties, and generally produced lower yields than the improved varieties. Data from these trials are presented in Tables 8-1 through 8-3.**
2. **A simple 3 x 3, or 4 x 3, nitrogen x phosphate fertilizer trial with two replications. The levels of nutrients were 0, 50, 100, and 150 kg N/ha. and 0, 40, and 80 kg P₂O₅/ ha.**

Yields in these trials during the two crop cycles in 1973 showed large responses to added nitrogen but no response to phosphate (see Figs. 8-2 and 8-3). The trials demonstrated that large increases in yield can be obtained with relatively small amounts of nitrogen, no phosphate, and good management in this particular area. The economic optimum nitrogen application (corresponding to the point on the nitrogen response curve where the slope of the return from grain equals the slope of the cost of nitrogen line) was estimated graphically as 100 kg N/ha. in the 1973A cycle, and 75 kg N/ha. in the 1973B cycle. In the Poza Rica area, the A cycle is the major maize-growing cycle. It is cooler, with fewer heavy rain and wind storms than during the B cycle. Lodging is greater in the B cycle. The longer growing season in the A cycle and less lodging account for the response to more nitrogen in the A cycle.

3. A simple insecticide trial, which included the following treatments:

- a. Check--no insecticide.
- b. Granular Aldrin (20%), 1 kg active ingredient/ha. applied in the bottom of the furrow at planting time.
- c. Granular Aldrin applied as above, plus granular Birlane (2%) applied in the whorl, at dosages of 0.2g/plant, in two applications: two to three weeks after planting, and two weeks later.
- d. No soil treatment, but Birlane applied in the whorl as described above.

Although budworm damage was clearly evident, especially in the treatments with no Birlane, this was not significantly reflected in yield at any location, nor was the number of plants per plot significantly affected.

4. A demonstration containing four large plots (10 rows x 30 m.) with the following treatments:

- a. Farmer's variety + farmer's technology
- b. Improved variety + farmer's technology
- c. Farmer's variety + recommended technology
- d. Improved variety + recommended technology

Data from these trials are presented in Figs. 8-4 through 8-6 in the "Maize Diamond" format.

On the average, in ten such demonstrations carried out during the two crop cycles of 1973, the yields from treatments b, c, and d were 23, 64, and 75% greater than the yield from treatment a, respectively. At individual sites, the yield from treatment d was 35 to 421% greater than that from treatment a.

Thus, although improved varieties are important for increased yield, important increases in grain production can be achieved with good agronomic management on existing varieties. The greatest benefit is realized by combining an improved variety and improved agronomic

practices. With improved technology, the improved varieties outyielded the farmers' varieties, which were very susceptible to lodging.

Participation in the execution of these trials by the farmers of the district has been an important element. This is important at all stages of crop growth, when important cultural operations are being performed, but it is especially important at the field days held at harvest time. In this way, the farmers decide which variety and practices best fit their situation and they convey their opinions to the production agronomists and extension agents.

The enthusiastic participation in these demonstrations by the farmers in Veracruz is encouraging. We believe that the same degree of enthusiasm can be generated among farmers elsewhere in the world if the correct approach is used.

8.5.2 ON-FARM TRIALS IN THE NORTHWEST FRONTIER PROVINCE OF PAKISTAN

The Northwest Frontier Province (NWFP) of Pakistan is an example of a national maize program, involving active participation by CIMMYT Outreach staff, where a series of off-station trials is an integral part of the program.

The NWFP lies between latitudes 31° and 37° N. About 325,000 ha. of maize are grown in the NWFP during the summer monsoon season, with an average yield of 1 ton/ha. This is about one-half the maize acreage in Pakistan. Maize is grown under widely varying conditions in the NWFP, ranging from the hot dry plains in the south at about 300 m. elevation, up to an altitude of about 2,500 m. in the Himalayan foothills to the north. Water regimes range from completely rainfed, with far from adequate rainfall, to complete control of irrigation. Under such variable ecological conditions, a wide network of on-farm testing is required.

In 1974, the third year in which off-station trials have held a prominent place in the program, the following activities are being carried out at the farm level:

1. Varietal screening and progeny testing is an off-shoot of the breeding program, but the work is largely done by agronomy staff stationed around the province. Such

work is on farmers' land, because there is not an adequate series of substations, particularly at the higher elevations. It is felt that four varieties, varying widely in maturity can serve the needs of the NWFP. Three of the four varieties presently recommended would not have survived if selections had been made on the basis of experiment station data alone. This illustrates the importance of this kind of on-farm selection work in this particular situation.

2. Simple variety trials are conducted along much the same lines as those in Mexico. Such tests are being run at about 60 sites in the NWFP. The distribution of sites roughly corresponds to the acreage of maize in the districts of the province. The data from these trials for 1972 and 1973 are presented in Tables 8-4 and 8-5.
3. Simple fertilizer trials are conducted on each of the above 60 sites adjacent to the variety trial. In 1972, these were 4 x 2 nitrogen x phosphate trials (N levels were 0, 56, 112, and 168 kg/ha. and P_2O_5 levels were 0 and 56 kg/ha.). Because there was a small response to phosphate and no nitrogen x phosphate interaction in most of the province, the same levels of N at the upper rate of P_2O_5 were included in 1973 (see Figs. 8-4 and 8-5). During 1974, the levels will be as in 1972. Considering the prices for maize grain and fertilizer, and the data from these trials, a general fertilizer recommendation of 60-30-0 has been developed for maize in the NWFP. This is about one-half the previous recommendation, which is reserved for the better farmers in areas with better irrigation control. The 2:1 ratio of N to P_2O_5 is a long-standing recommendation for all cereals in Pakistan. Although there has been little response to phosphate, we do not want to repeat the experience with wheat during the last five years in Pakistan, where a depression in yields was experienced due to inadequate phosphate supply, after a few years of heavy nitrogen applications on the high yielding varieties.
4. At about 20 of the above 60 sites, two other trials will be conducted. The first will be a simple comparison of the latest insecticide recommendation for control of stem borer versus a control plot. The second will be on experimental production plot, one-half ha. in size, where the latest recommended variety and production package will be tested under farmers' conditions.

All the above trials will be conducted by the staff of the Maize and Millets Research Institute (MMRI). Also, the Rapid Soil Fertility Scheme of the Soil Chemistry Department will run more complex fertility trials and maximum potential trials on farmers' land.

5. A total of 640 extension demonstrations of the type described above under the program in Mexico will be conducted by the extension service of the Department of Agriculture. The four plots in each trial will occupy about one-fifth of a hectare. These demonstrations will be distributed throughout the maize-growing areas of the province.
6. The extension service will carry out about 450 seed multiplication plots each one-half ha. in size. These plots will be handled in the same manner as the experimental production plots, and it is intended that they should serve as sources of seed of the new varieties for farmer-to-farmer seed sales.

With the above series of trials and demonstrations, it is anticipated that the farmers will decide to adopt the improved varieties and practices, and that seed of the varieties will be available throughout the province. Historically, the government system for procurement, processing, and distribution of seed has been woefully inadequate.

In 1974, for the first time, active cooperation is being sought between the research and extension wings of the Department of Agriculture. It is hoped that such a program will continue, with new varieties entering the varietal pipeline and further refinements being made to the cultural recommendations. It is intended that an individual farmer, who cooperates in the on-farm variety and fertilizer trials or extension demonstration plots, will grow a seed multiplication plot the following year.

8.6 OBJECTIVES AND METHODS TO 1980

The overall strategy behind CIMMYT's work in maize agronomy has been outlined. The work carried out in Mexico to test the validity of this strategy, and to train agronomists, has been described. The manner in which this strategy is being applied in a national program has been outlined for the case of the Northwest Frontier Province of Pakistan. CIMMYT Outreach staff are directly involved in similar efforts in Zaire, Nepal, Egypt, and Tanzania. Many other countries are trying the same strategy as a result of their staff having ties with CIMMYT. The programs are at various stages of development. By 1980, it is anticipated that the strategy will prove its effectiveness in raising national average maize yields above the dismal 1 ton/ha. so common all over the world today.

Of prime importance in this effort is the training of maize workers at all levels, including degree training and in-service training at CIMMYT. Because of limitations in funding and the limited ability of the international centers to handle large numbers of trainees, more and more training must be carried out in domestic training programs in many countries. Many production agronomists can be trained by this means using CIMMYT Outreach staff in the country concerned, our core and regional staff, and in-service trainee alumnae, as instructors.

One of the questions we address to participants at this meeting is: What more can and should CIMMYT agronomists do to help these programs? Our most direct contribution at present is in the scheme of testing outlined in this paper and at least as important, in training young agronomists to design, conduct, and interpret the kind of field experiments needed in large numbers in most national programs.

ACKNOWLEDGMENT

The work described in this paper and the preparation of the paper itself have been a joint effort by the CIMMYT Agronomy staff, including Michael Colegrove, Peter Goldsworthy, and Alejandro Violić.

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TABLE 8-1 Grain yield kg/ha at six sites in Veracruz 1973 A.

Varieties	Xuchil	Copal	Paises Bajos	San Pablo	Agua Dulce	Paso Correo	Variety mean
H507	3138	2850	5635	1587	6127	4516	3975
H503	2827	1813	4297	2827	5440	4301	3584
T 27	2519	2331	4019	1966	4958	3559	3225
Tuxpeño 1	2834	2710	5266	2921	3763	3128	3438
Criollo	---	2655	3365	----	4430	3831	3570
\bar{X} Localities	2263	2476	4516	2325	4944	3867	
LSD 5%	NS	NS	1377	NS	1326	1261	
C.V.	9	25	13	51	10	13	

TABLE 8-2 Grain yield kg/ha at four sites in Veracruz 1973 B.

Varieties	La Colmena	Rfo Claro	La Isla	Castillo de Teayo	Variety mean
Tuxpeño 1 (50000 pl/ha)	4338	3172	5587	3463	4152
Tuxpeño 1 La Posta o ₂	3965	3142	4265	4171	3885
Tuxpeño 1 (75000 pl/ha)	5290	2656	5701	4285	4482
TC 17	3841	2542	4059	3973	3603
White hard endosperm	3199	1865	4118	4410	3398
T 27	3799	2383	5874	3793	3962
H507	3386	1919	4563	3334	3300
Criollo	----	----	3588	2552	3070
\bar{X} Localities	3981	2526	4719	3747	
LSD 5%	NS	NS	1622	NS	
C.V.	25	24	14	32	

TABLE 8-3. Plant and ear height (cm) and percentage of root lodging of the varieties tested in cycle 1973 A (6 locations) and 1973 B (4 locations), Veracruz.

Varieties Cycle 1973 A	Plant height cm	Ear height cm	Lodging %
H507	268	169	8
H503	264	167	13
T27	248	140	15
Tuxpeño 1	216	127	6
Criollo	315	203	30
<u>Cycle 1973 B</u>			
Tuxpeño 1 (50000 pl/ha)	249	145	9
Tuxpeño 1 x La Posta o ₂	253	153	7
Tuxpeño 1 (75000 pl/ha)	256	156	6
TC 17	229	118	5
W.H.E.o ₂	271	161	13
T27	270	153	13
H507	262	157	20
Criollo	335	210	75

Table 8-4. Yield of grain kg/ha. in on-farm varietal performance trials, NWFP, Pakistan, 1972

District	No. of trials	Variety			
		Zia	Changez	Khyber	Local
Peshawar	6	5000	5200	5600	3500
Mardan	12	3900	4600	5300	4300
Kohat	2	-	3000	4000	1600
Bannu	4	-	5200	4100	4200
Swat	5	-	7900	7900	6600
Hazara	10	-	2100	3500	3700
D.I. Khan	2	-	3400	4300	2200

Table 8-5. Yield of grain kg/ha. in on-farm varietal performance trials, NWFP, Pakistan, 1973

District	No. of trials					
		Shahsen	Zia	Changez	Khyber	Local
Peshawar	4	-	4100	4300	-	3900
"	5	-	-	-	5100	4300
Mardan	8	-	3900	3900	-	3600
"	4	-	-	-	4600	3700
Kohat	3	5900	5500	5700	-	2900
Parachinar	1	4400	5300	5300	-	2200
Upper Swat	6	7300	8500	8900	-	6700
Lower Swat	3	-	-	-	6300	6800
Hazara	10	-	3000	3800	-	3300
"	3	-	-	-	4800	4200

Table 8-6. The yield response to nitrogen, value of the response, cost of nitrogen, and profit per hectare at 1973 prices for maize and urea, and benefit:cost ratios for total nitrogen applied (on-farm fertilizer trials, NWFP, Pakistan, 1972) No phosphate applied

N Applied kg/ha.	Response to N kg/ha.	Value of Re- sponse in \$/ha.	Cost of N \$/ha.	Profit \$/ha.	Benefit:Cost Ratio
50	795	53.74	11.89	41.85	3.5:1
100	1,290	87.20	23.78	63.42	2.7:1
150	1,590	107.48	35.67	71.81	2.0:1

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8-8	Relationship between the value of the extra maize produced by nitrogen fertilizer (gross return), cost of the fertilizer, and profit obtained (net return) at December 1973 prices for maize and fertilizer (urea), NWFP, Pakistan (1972 trial data)

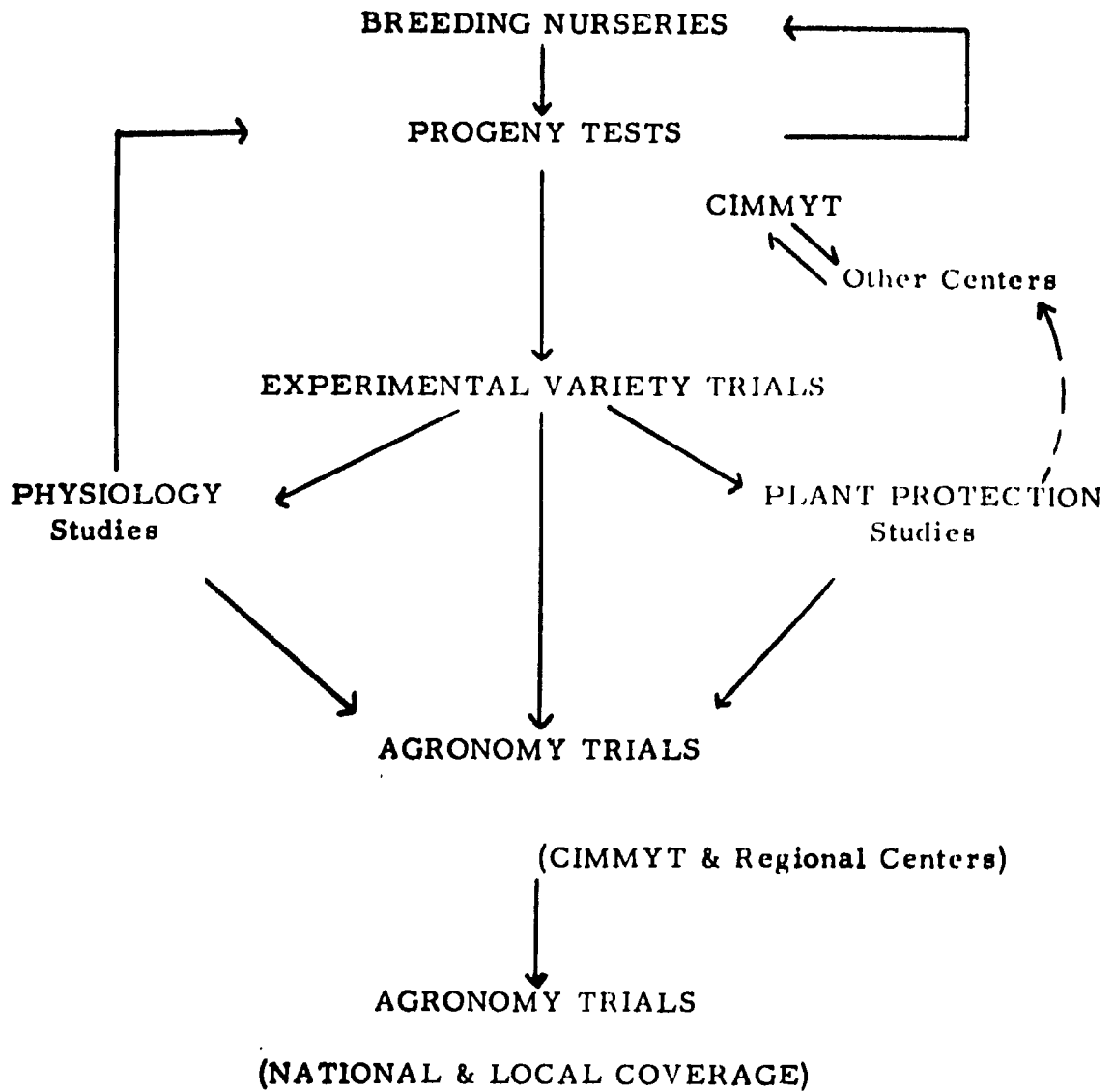


Fig. 8-1. CIMMYT maize program organizational scheme.

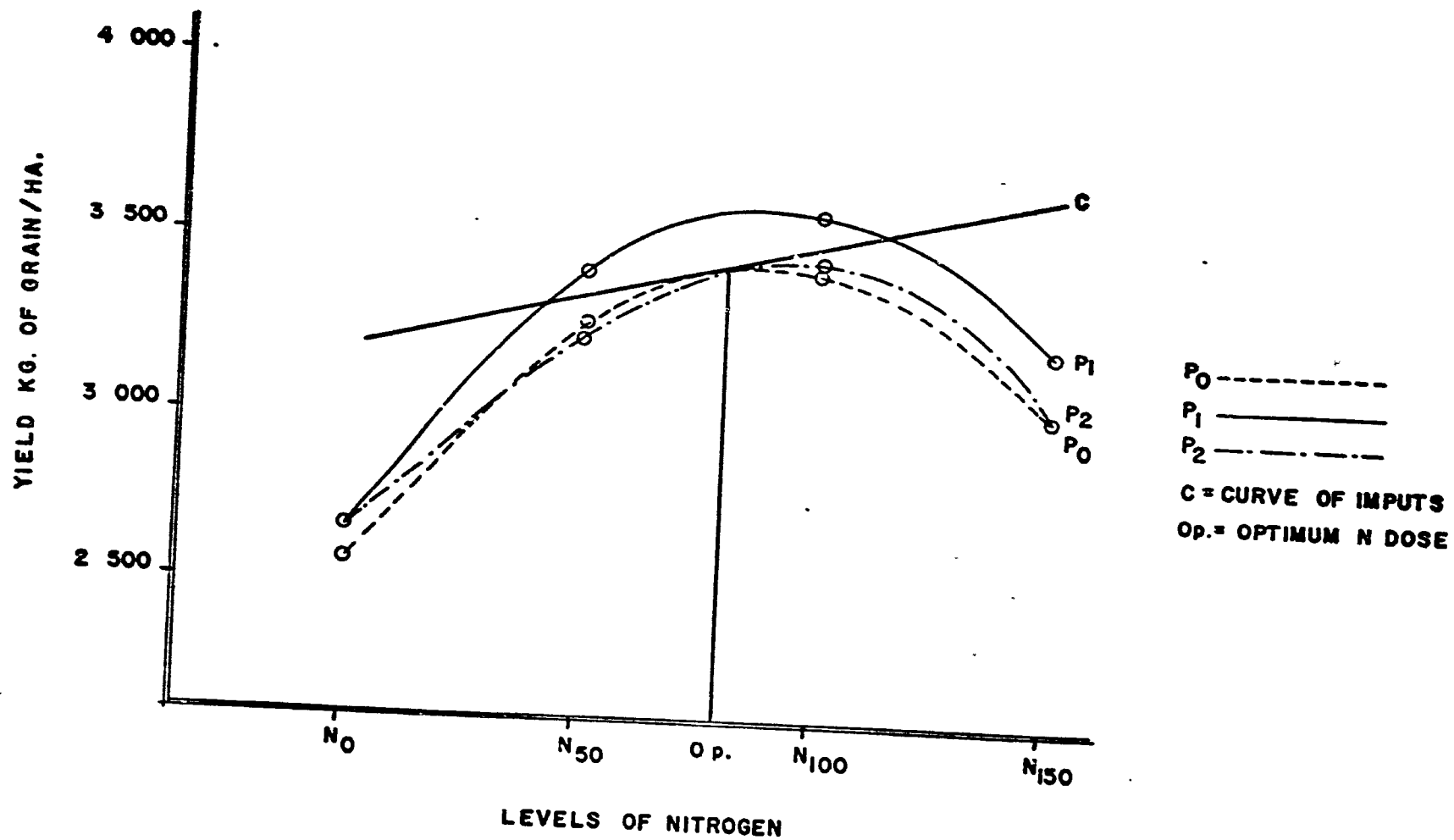
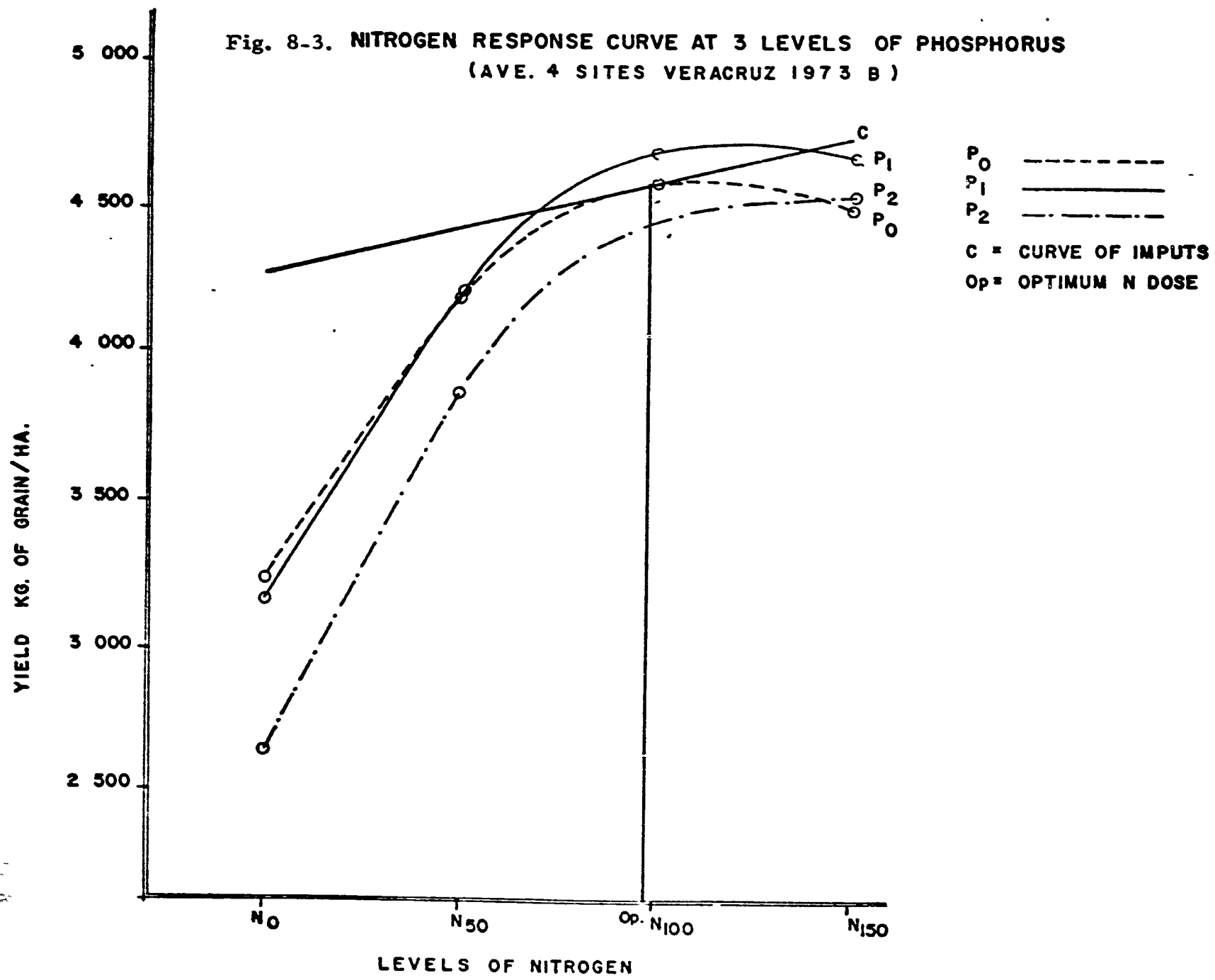
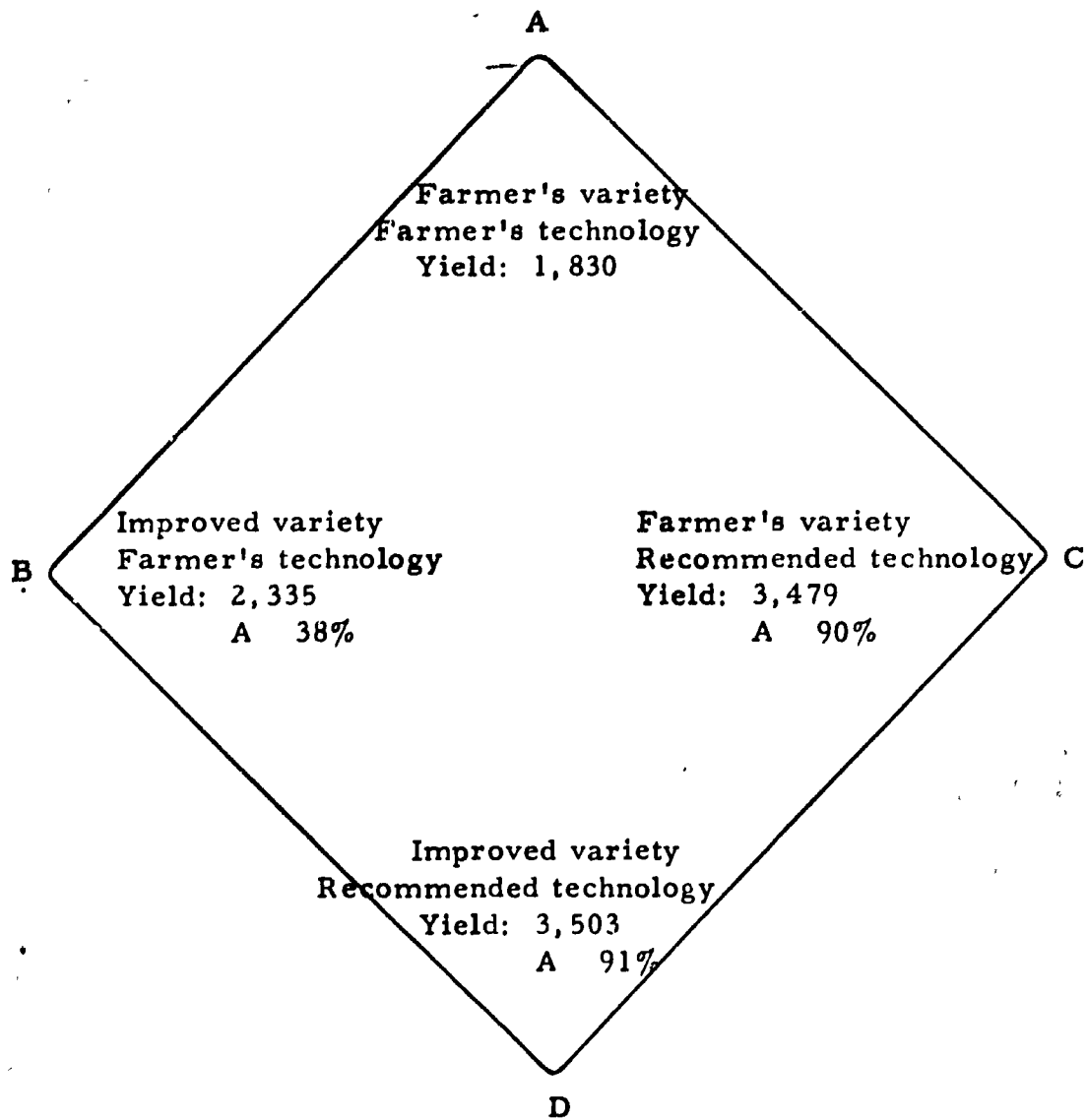


Fig. 8-2. Nitrogen response curve at three levels of phosphorus (Ave. 7 sites, Veracruz, 1973A)

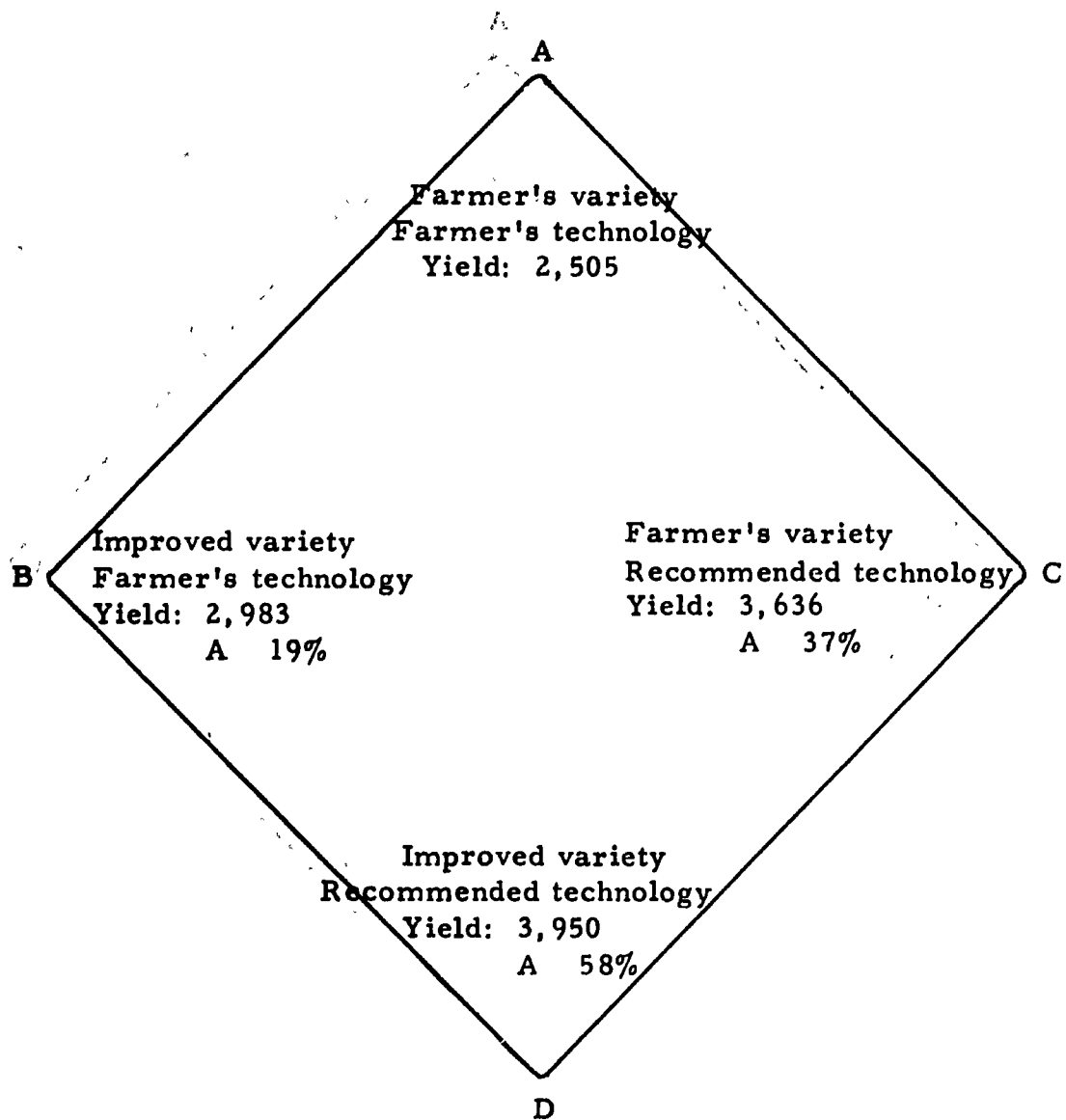
Fig. 8-3. NITROGEN RESPONSE CURVE AT 3 LEVELS OF PHOSPHORUS
(AVE. 4 SITES VERACRUZ 1973 B)





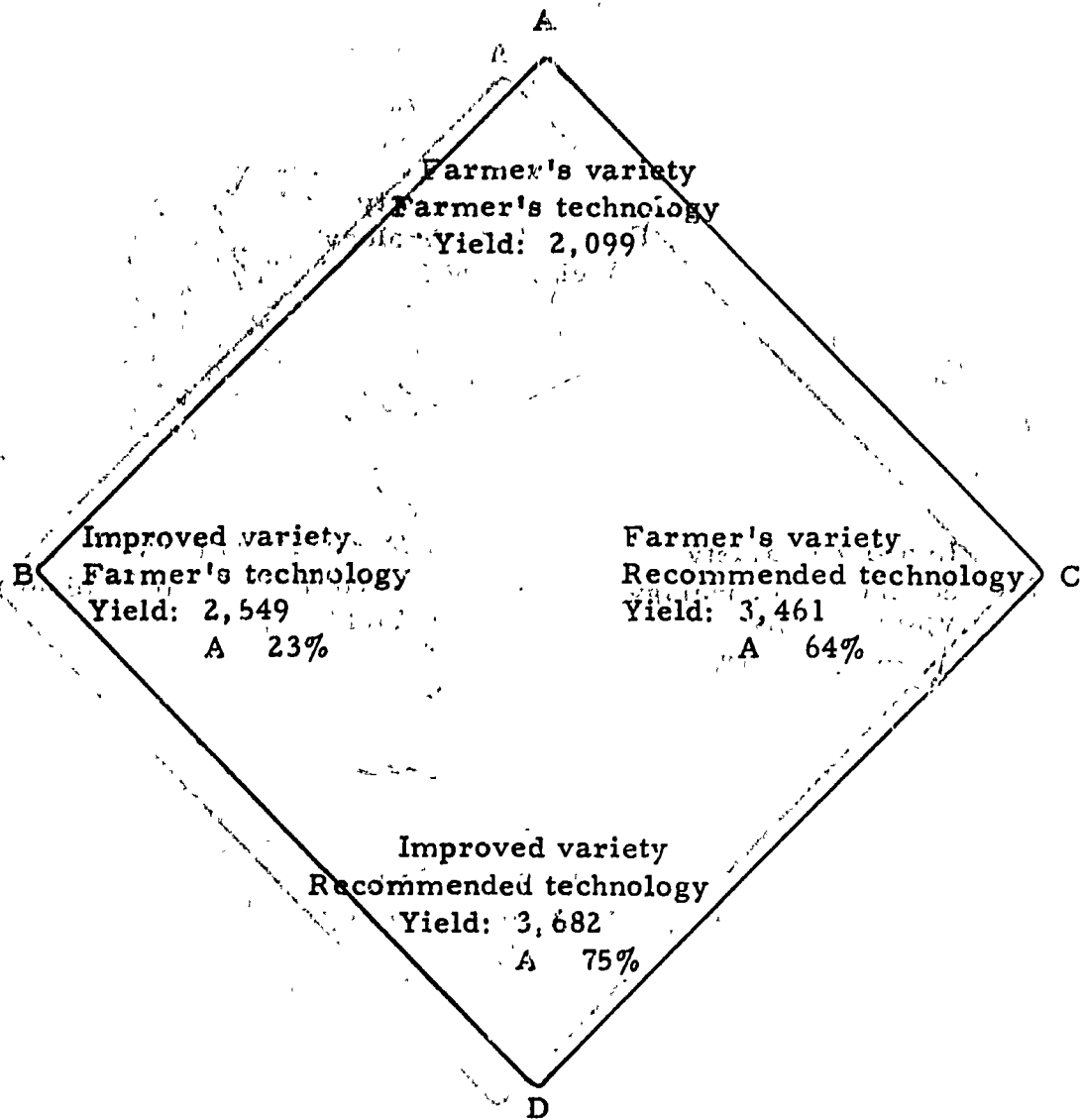
Improved variety is H507.

Fig. 8-4. Grain yield kg/ha. in demonstration plots of local and improved varieties with and without technology, and percentage yield increase due to improved variety and technology (mean of six sites, Veracruz, 1973A)



Improved variety is Tuxpeño 1.

Fig. 8-5. Grain yield kg/ha. in demonstration plots of local and improved varieties with and without technology, and percentage yield increase due to improved variety and technology (mean of four sites, Veracruz, 1973B)



... ..

Fig. 8-6: Grain yield kg/ha. in demonstration plots of local and improved varieties with and without technology, and percentage yield increase due to improved variety and technology (mean of ten sites, Veracruz, 1973A and 1973B)

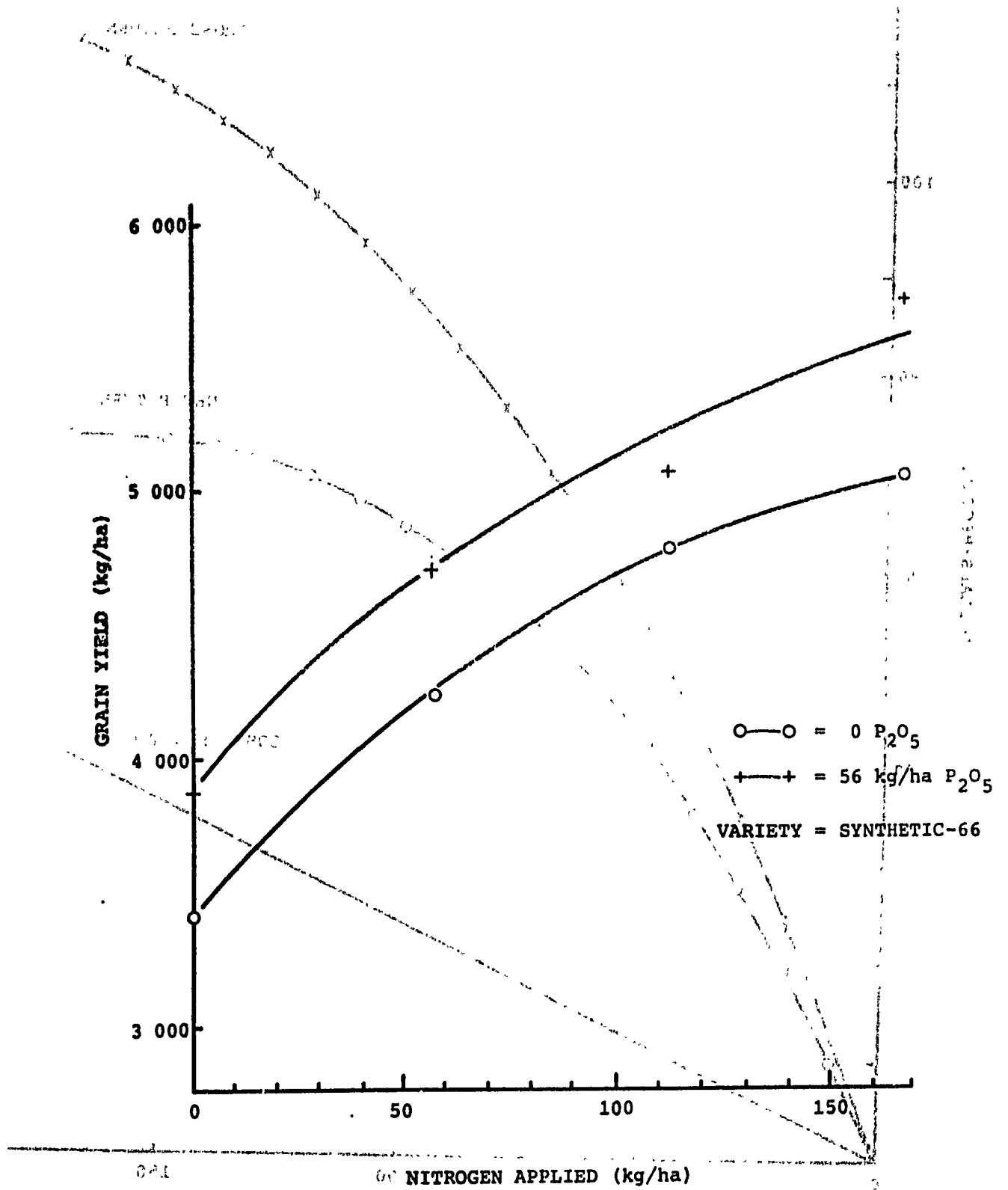


Fig. 8-7. Yield response to nitrogen and phosphate in on-farm fertilizer trials on maize in NWFP, Pakistan in 1972 (all data are the means from 40 trials)

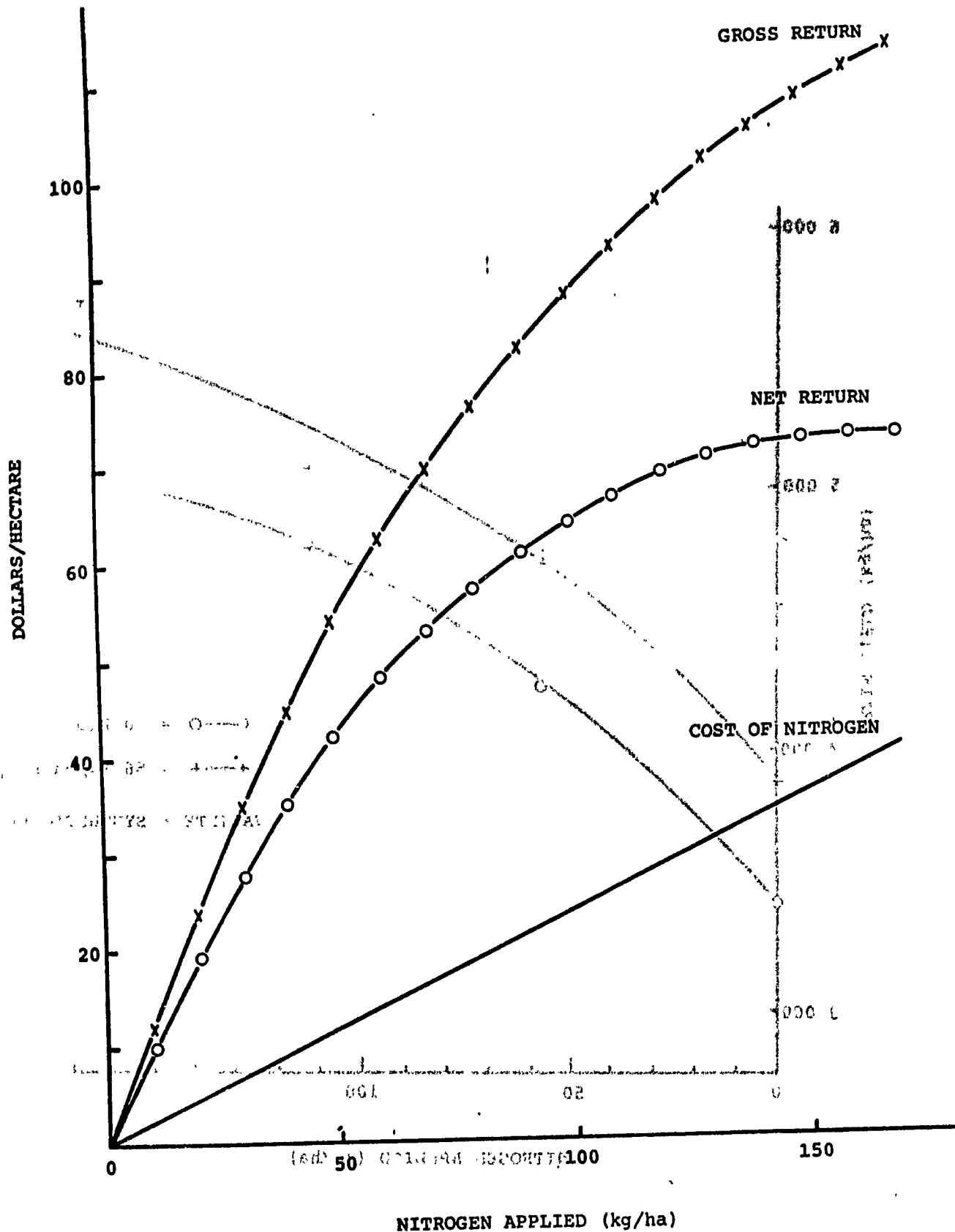
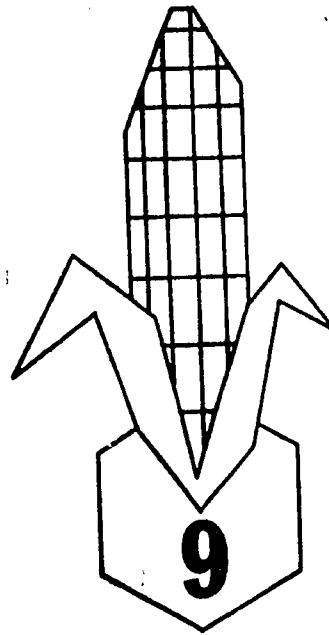


Fig. 8-8. Relationship between the value of the extra maize produced by nitrogen fertilizer (gross return), cost of the fertilizer, and profit obtained (net return) at December 1973 prices for maize and fertilizer (urea), NWFP, Pakistan (1972 trial data)



MAIZE PHYSIOLOGY

by
Peter Goldsworthy, CIMMYT

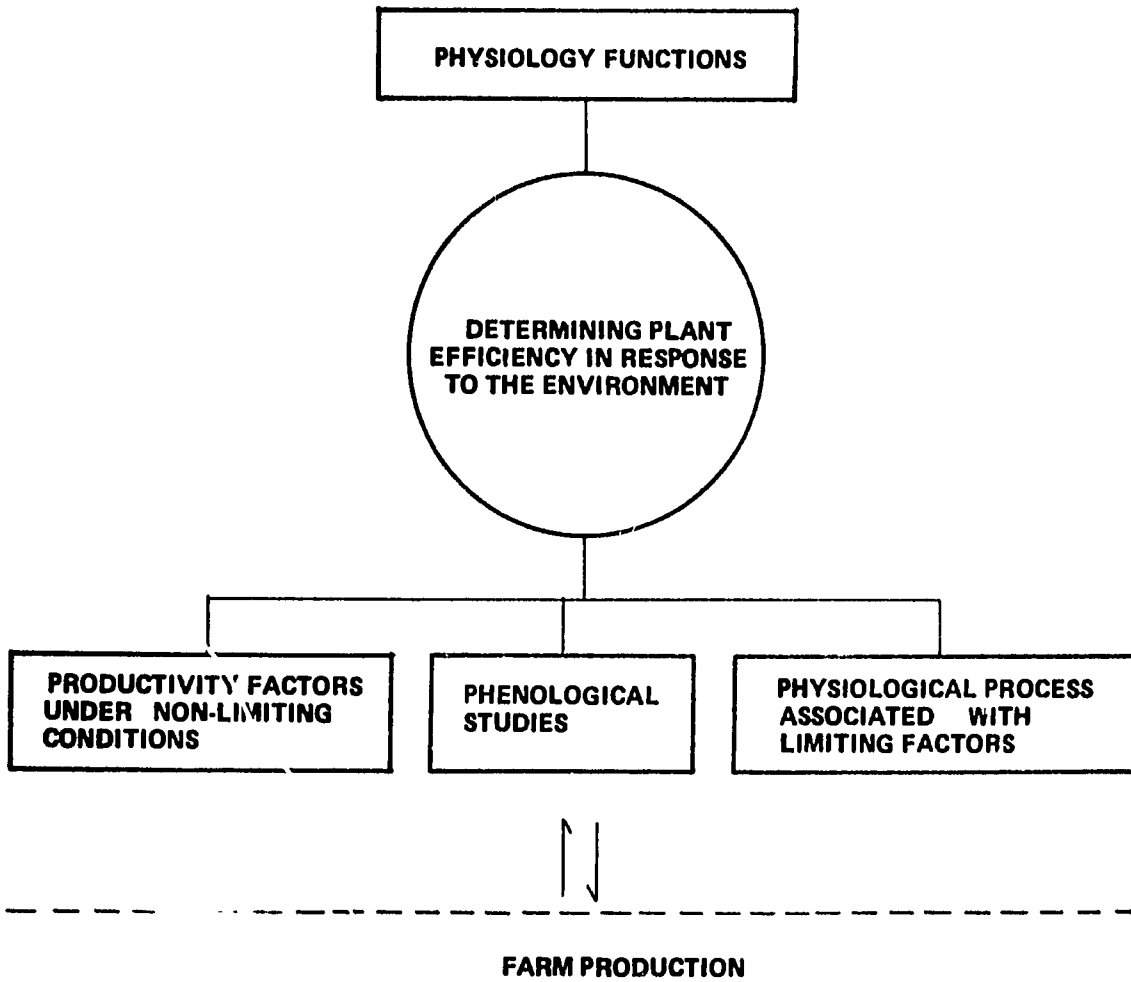
Lead Discussant:
Dr. Lloyd T. Evans
CSIRO
Canberra, Australia

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T Y M M L A

**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



9.0

MAIZE PHYSIOLOGY

by
Peter Goldsworthy

9.1 INTRODUCTION

CIMMYT's physiology program investigates genetic and environmental factors that now limit maize grain yields. The identification and understanding of these factors provide a framework for developing improved genetic research and selection practices.

Fig.9-1 shows the relationships between breeding, physiology, and agronomy within the program. Because of the nature of the measurements involved, it is impractical to examine the limitations of more than a small fraction of the wide range of breeding materials; thus, materials must be selected carefully. It is expected that most future selections will be made on the basis of data from experimental variety trials that have been conducted over a broad range of environments. The proposed structure for multi-location testing also will be used to complement studies on plant responses to the environment. Since CIMMYT materials are selected under good management (well-watered) conditions, additional studies are planned to evaluate these materials under dry-land conditions.

The program described next consists of three main parts: (1) studies of factors that determine productivity of maize grown under non-limiting cultural conditions, (2) studies of maize development in response to the environment, and (3) studies of maize response to water stress. An account will be given of some of the work that has been completed in the first part of the program. In developing the other study areas, an attempt is made to indicate a probable order of priorities that will make best use of the limited resources available.

9.2 PRODUCTIVITY STUDIES

9.2.1 GRAIN YIELD IN THE TROPICS

Estimates of the mean yield of maize grown in the three main climatic regions of the world are: (1) temperate regions, 3.5 tons/ha.; (2) subtropical regions, 1.8 tons/ha.; and (3) tropical regions, 1.0 ton/ha. (World Production Figures (F.A.O., 9)).

For the temperate region, some of the highest yields reported are from the United States, with maximum values of 19 tons/ha. (Cuany et al., 7) and yields of 10 tons/ha. are not uncommon (Frey, 12).

In tropical latitudes, most of the high yields reported are confined to intermediate or high altitudes: 12 tons/ha. at Salisbury, Rhodesia, 18°S latitude at 1,500 m. elevation (Allison, 1); 10 tons/ha. at Kitale, Kenya, 2°N at 1,890 m. elevation (Harrison, 15).

Highland varieties in Mexico will yield from 5 to 9 tons/ha. with good management. The corresponding figures are about 2 to 5 tons/ha. in the lowland tropics.

9.2.2 CROPS AS SYSTEMS FOR PRODUCING GRAIN

The economically useful part of a cereal crop is usually the grain. Because grain is a particular fraction of the whole plant, grain yield will depend on processes affecting (1) total plant productivity and (2) those determining the distribution of this material to, and storage as, grain.

A sensible approach to increasing yield must be based on a knowledge of those factors which determine the capacities for storage and supply. Because these processes are dynamic and may be interdependent, information is required on what changes occur throughout the growth of the crop, how these changes respond to the environment, and how they are related to final yield. It is useful to consider the crop as a system to supply assimilates, the main source being the leaves, with a series of sinks where the assimilate is used initially for growth and later for storage as grain dry matter.

The source (photosynthetic system) can be described in terms of: its size (leaf area index, L), duration (D , the integral of L over time), and its efficiency, which can be measured as net assimilation rate (E). Thus, L and D will depend on the initial plant population, the rate of leaf development (which is largely dependent on temperature),

and the incidence of leaf pathogens. The efficiency of L depends on its spatial distribution and arrangement and the radiation environment.

The crop growth rate (C) is the rate of increase in dry weight of the whole crop and is equal to the sum of the growth of all sinks. After anthesis, the major metabolic sinks are the developing grains; thus, the capacity for grain storage will be determined by their number and potential size. The potential for grain storage, then, is dependent on the rate and duration of the development of spikelets and the young fruit. Realization of this potential will depend on the supply of grain-filling assimilates.

An ideal crop would be one in which the size and distribution of L is such as to use all available light efficiently, with sufficient active sinks to use all the carbohydrate produced. The expenditure of dry weight on parts of this ideal plant, other than the grain, would be no more than is needed to maintain an efficient canopy.

9.2.3 SOME RECENT CIMMYT STUDIES

Some of the studies that have been carried out during the past three years in the CIMMYT maize program are summarized here to illustrate the methods being used and the results obtained. A more detailed account will be available in two research reports that have been prepared and submitted for publication (13, 14).

9.2.3.1 The Growth and Yield of Highland Maize

The first of the above reports (13) describes experiments in which the growth and yields of five highland varieties of maize grown at El Batán, Mexico (2,250 m. elevation), were examined and compared with those of a high-yielding hybrid (SR52) grown at a similar latitude, but south of the Equator (18°S), at Salisbury, Rhodesia (1,500 m. elevation), as reported by Allison (1).

Grain yields of the Mexican varieties were between 4.7 and 8.8 tons/ha. compared with 12 tons/ha. for SR52 (Table 9-1).

Total crop and grain dry matter accumulations over time for SR52 and for one of the Mexican highland materials (H. 28) are shown in Fig. 9-2. Total dry weight (23.5 tons/ha.) was similar in the two crops and increased with increase in plant density in H. 28. Maximum dry weight was reached at harvest in SR52; in H. 28 it was reached before harvest. Fig. 9-3 shows crop growth rates (C) and grain growth rates, derived from the functions describing the dry weight changes of crop and grain, respectively.

In the Mexican varieties, crop growth rates (C) increased to a maximum of between 25 and 35 g/m²/day at silking and then declined. Grain growth rates (maximum, 21 g/m²/day) exceeded current C during most of the grain filling period. After silking, when C was in excess of grain growth rate, dry matter accumulated in the stem and husk resulting in an increase of from 200 to 600 g/m². Later, as grain growth rate increased and exceeded current C, some of this accumulated material was incorporated into the grain and stem weight decreased.

To estimate the probable magnitude of the storage and retranslocation involved, growth after silking was divided into three periods. Examples of the dry weight changes that occurred in the three periods are shown in Fig.9-4. In the first period, before dry weight increase in the grain began, assimilates accumulated in the stem and husk. During the second period, the crop dry weight increase was larger than the increase in grain weight and the difference represents further storage in the stems. During the third period, the increase in grain weight was larger than the increase in crop dry weight, and the difference provides an estimate of the probable contribution to grain from material that was retranslocated.

The smaller grain yields of the five Mexican varieties, when compared with the Rhodesian hybrid SR52, were associated with smaller grain growth rates and a larger accumulation of dry weight after flowering in other parts of the plant, mainly the stem and husk. Direct measurement of the percentage sugar in the stems of some of these materials in the field in 1973 indicates that much of this change in dry weight is due to the accumulation of soluble solids.

Allison and Watson (2) have shown that when the grain sink is removed by preventing pollination, the dry matter that would have passed to the grain accumulates in the stem and husks. They also found that when the source of assimilate is restricted by removing leaves, stem weight decreases as previously stored dry matter moves to the grain.

The pattern of growth and dry weight distribution observed in the tropical varieties described, and the accumulation of sugars in plant parts other than the grain during the grain filling period, strongly suggest that the capacity of the grain sink is limiting grain production.

Table 9-2 shows the proportion of the total dry weight of the crop that is partitioned into grain (harvest index). The values are based on the dry weight of the crop at grain maturity. In most cases, maximum biological yield was attained prior to maturity (see Fig. 9-2). The harvest indices shown may thus be overestimates of the true partitioning of the total biological mass. The mean value for the Mexican

material grown at two plant populations was 0.35 compared with a value of 0.53 for the Rhodesian hybrid.

9.2.3.2 The Growth and Yield of Lowland Maize

The second report mentioned earlier (14) describes experiments in which three tropical varieties (Tuxpeño, Tuxpeño x Eto, and Compuesto K) were studied at two sites (Tlaltizapán, 940 m. and Poza Rica, 60 m. elevation).

The grain yields of these three varieties are shown in Table 9-2. Yields were larger at Tlaltizapán than at Poza Rica. At both sites, Tuxpeño yielded more than either of the other varieties. Yields increased with plant population up to 150,000 plants/ha.

The accumulation of total crop and grain dry weight over time is shown in Fig. 9-5 for Tuxpeño and in Fig. 9-6 for Tuxpeño x Eto. All of the varieties produced less total dry weight at Poza Rica than at Tlaltizapán, and this difference was mainly in dry weight accumulated before flowering. Thus, at silking (94 days after sowing), the crop at Tlaltizapán had produced between 1,200 and 1,600 dry matter g/m² (depending on plant population); the corresponding values (silking 78 days) at Poza Rica were from 800 to 1,200 g/m². The smaller dry weight at Poza Rica was due to a shorter growth period, since crop growth rates were similar (Figs. 9-7 and 9-8). Maximum growth rates of about 35 g/m²/day occurred 75 days after sowing at both sites (this coincided with silking at Poza Rica, but was 12 to 14 days before silking at Tlaltizapán).

Analysis of the dry weight changes after silking was made in the manner described for the highland varieties (data not shown). This analysis indicated that, immediately after silking and before grain growth began, the accumulation of dry weight in the stems and husks ranged from 150 to 250 g/m² at Poza Rica and from 200 to 350 g/m² at Tlaltizapán. As with the highland varieties, there was further, substantial accumulation of dry weight, mainly in the stems after grain growth began. Only part of this stored material was eventually translocated to the grain. Harvest indices for these materials ranged from 0.26 to 0.36.

The patterns of growth and dry weight distribution observed in the tropical varieties studied so far strongly suggest that the capacity of the grain sink is limiting. This is further illustrated in a series of graphs prepared by Dr. W. Duncan in which he compares data from the trials at the three sites in Mexico (El Batán, Tlaltizapán, and Poza Rica) with that for a U. S. hybrid (Pioneer 3369A) grown at Wooster, Ohio (8).

The graphs (Figs. 9-9 to 9-11) show dry matter accumulation plotted against accumulated degree days from planting.

Ear growth and yield of the U. S. hybrid and of a highland material (Hidalgo 8) grown at El Batán, were similar, but stem dry weight was much larger at flowering in the highland material and more dry weight accumulated in the stem after flowering (Fig. 9-9). The larger total dry weight at El Batán was associated with high radiation. The evidence indicates that potential yields at El Batán are probably much higher than the yields actually attained and that yield is limited by the capacity of the grain sink.

Stem weights of Tuxpeño at Poza Rica and of the U. S. hybrid were similar, but ear growth rate and final weight of the ear was much smaller in Tuxpeño (Fig. 9-10). At Tlaltizapán, Tuxpeño had a lower rate of ear growth, as well as more dry weight in the stem (Fig. 9-11).

The evidence suggests that total dry matter production is not limiting, and that net photosynthetic production compares favorably with that of U. S. hybrids grown in temperate regions. Maximum crop growth rates (C) were approximately 35 g/m²/day at all three sites in Mexico, compared with peak growth rates of 49, 40, 32, and 28 g/m²/day for maize grown in the U. S. A., as reported in the literature (26). This represents an efficiency of conversion of visible radiation into dry matter (assume 4,000 cal/g dry matter, visible radiation 45% of total) of 5.5% for El Batán, 7.2% for Poza Rica, and 5.1% for Tlaltizapán, as compared with U. S. values of 4.6 to 6.4% (26). Thus, the process for the accumulation of total biological mass in the Mexican materials seems as efficient as those of the higher grain yielding U. S. types.

9.2.3.3 Suggested Courses of Action

CIMMYT's breeding program is using the information now available in an attempt to overcome the shortcomings of tropical materials in the following ways.

(1) Sources of U. S. and tropical germplasm are being combined to determine whether the pattern of growth and distribution observed in high yielding U. S. materials is heritable and can be introduced into tropical material--and conversely, whether the disease and insect tolerance of tropical materials can be introduced into the U. S. germplasm.

(2) Breeders are exploring more fully the potential for improving the yield of early tropical varieties which exhibit a more favorable pattern of dry weight distribution than do the traditional, tall,

late, tropical materials. Since these materials perform best at high plant densities, observations at high plant populations also are being incorporated into the selection procedure of the breeding program.

(3) The incidence of barren plants at high populations has been identified in the growth studies as an important factor limiting "sink" size of the crop, particularly in the lowland tropics. Preparation has begun for progeny testing of the advanced units of the breeding program at high populations as a means of identifying and eliminating families with a high frequency of barren plants.

(4) There is evidence that there may be a causal relationship between stalk-rot resistance and the accumulation of soluble solids in the stem. Koehler (17) states that there is strong evidence that susceptibility is associated with high yield potential (i. e., plants that appear to be more active in translocating sugars from the stalks to the ear). Since one index of storage limitation by the grain is an accumulation of sugars in the stem after flowering (Fig.99), there is a need to evaluate the effects on sink capacity of selection for resistance to stalk rot. And, because there are other aspects of stalk rot resistance (biochemical), it may not be incompatible to select for both resistance and high yield potential. While a consideration of resistance and yield in selection procedures should obtain this information, there may be a need to develop a non-destructive field technique which would determine sugar accumulation as related to "sink" capacity.

(5) Growth analysis studies are being continued and serve, in part, for the training of production officers. Trials currently being conducted by trainees address themselves to two questions: Are there differences in the growth and dry matter distribution in U. S. hybrid, U. S. varieties (open pollinated), and tropical materials grown under the same environment (free of pests and disease)? What has been the effect of selection for plant height in the tropical materials on the dry matter distribution pattern?

(6) Continued study is planned for some of the current, elite experimental varieties of the program to evaluate the magnitude and direction of population improvement.

(7) These current and future studies differ little in procedure from those already described. However, in the studies summarized, the analyses were of the crop and did not distinguish between producing and non-producing (barren) plants. Some of the increase in stem dry matter, which has been used as evidence for a storage limiting process, is due to the presence of barren plants in the crop. For a better understanding of processes occurring in the individual plant, future analysis

will separate changes in dry weight that occur in barren plants from those that occur in plants with ears. The soluble solid content of the stem, along with dry matter will also be measured.

(8) The results of the growth analysis indicate a need for further studies on the control and development of the female inflorescence (as the grain storage site). An understanding of the control and development of the components of yield (and thus the grain as a metabolic "sink") will initially involve studies to describe the development of the inflorescences. These will be followed by studies to ascertain the critical stages for this development and how the environment and internal plant factors regulate the distribution of assimilates to the developing inflorescence.

(9) A macroscopic (length and dry weight) description of the development of each of the side meristems (potential ears) has been made, but the data has yet to be analyzed. A familiarization with microscopic techniques has begun to document the beginning of spikelet primordia differentiation and the rate and termination of the laying down of spikelet primordia in the lateral meristems.

(10) In conjunction with these descriptive analyses, studies have been designed to manipulate either the plant or its environment to provide differing amounts of assimilates at various plant developmental stages. The first two trials of this kind were completed during the year: one at Tlaltizapán, the other at Poza Rica. To study the effect of plant population on the components of grain yield, two varieties were grown at 33, 66, and 133 thousand plants/ha. Ears from plants grown at any two populations were compared at harvest with ears from plants in stands which had been thinned from the higher to the lower population, to determine how plant population affected the number of female flowers formed at initiation and the number that persisted at anthesis. Comparisons were made at three stages of growth: at initiation (30-35 days after sowing); 62 days after sowing; and at anthesis (95 days after sowing). Analysis of the data has not been completed; however, preliminary results from trials indicate that grain size tended to decrease with increase in plant population--although more than 80% of the differences in yield between plant populations were accounted for by differences in the number of grains per plant. The decrease in grain number with increase in plant population (from 680 to 303 grains per plant in Tuxpeño-1 at Tlaltizapán) seems to be due to a decrease in the number of ears (from 1.5 to 0.87 ears per plant) and in the number of grains per ear. The effect of the thinning treatments in these experiments suggest that plant population had little effect on the potential yield per plant up to 62 days after sowing. The yield per plant was similar, whether a stand of 33,000 plants ha⁻¹ was obtained by thinning from 66,000 or 133,000 plants ha⁻¹ up to 62 days after sowing, or was established at this density. Competition in the

second half of the period from initiation to anthesis affected grain yields more than in the first half of the period.

(11) Currently, studies are being carried out at Tlaltizapán to further manipulate the plant-environment during the developmental stage shown to be most responsive. Plants are being exposed permanently (thinning) and temporarily (trellising of neighboring plants) to higher radiation. Competition between developing meristems is being altered by the surgical removal of either the male inflorescence or one or more of the lateral meristems. The effect of these manipulations on the rate of development and size of yield components will be measured.

(12) Morphological and physiological traits associated with high-density tolerance to barrenness need to be identified for use as selection indices in the high-density nursery. Anderson (4) has suggested characters of tassel size, silking delay, multi-ears of similar size at anthesis and silking two to three days before anthesis, and high ear placement to be associated with tolerance. The effects of the manipulations of the meristems on some of these characters will be examined.

There is a need to understand the role of the apical meristem in determining the number and rate of development of lateral meristems. Some parts of this research should perhaps be conducted by other research centers.

9.3 MAIZE RESPONSES TO THE ENVIRONMENT

CIMMYT is concerned with the development of widely adapted maize varieties which will meet the varied climatic requirements of the world. To obtain more information on the basis of maize adaptation, a study is being made of the effects on maize development of variation in day length and temperature with season and site. Most of the observations are being made at three main experiment stations in Mexico at approximately the same latitude (about 20°N), but differing in altitude. Limited additional observations have been taken at sites 4°N in Colombia in cooperation with CIAT, and at 40°N in cooperation with Purdue University.

Specifically, the intent is to describe how the developmental characteristics (leaf number, plant height, and time to initiation, silking, and maturity (black layer)) are related to the environmental factors (temperature, radiation, and photoperiod). Information of this kind has been collected for a number of CIMMYT materials and others during the past two years and is now being collected for all of the 28 populations in the advanced unit of the breeding program. Some of the data now available was shown earlier in the Symposium (p. 6-4), with an indication

of how we believe it can be used to construct a predictive model that will provide a basis for selecting materials likely to be suitable to a given area.

Additionally, observations will be made of the number of lateral meristems and the rate and duration of spikelet differentiation of the meristems for a selected few of the materials now in the phenology study. Such information will increase understanding of the environmental effects on the development of the grain storage capacity of the plants.

The development of a systematic analysis of varietal adaptation (see 6.0) should lead to identification of materials, or groups of materials with differing responses to environments. The next logical development would be to attempt to identify the specific environmental factors associated with the responses and to understand the morphological and physiological processes which are the bases of the different responses of the materials.

For the purposes of this kind of study, some minimum of meteorological data will be needed to describe the environments of each test site. At many of the locations where CIMMYT trials are now conducted, this minimum often is not available. Remote sensing techniques (earth resources satellites) may be a source of this kind of information in the future.

We are only now beginning to develop the part of the program that is described in this section, thus the necessarily brief account. However, as the international series of progeny testing and experimental variety testing trials are established, it is expected to develop rapidly and become one of the most important of CIMMYT's maize physiology activities.

9.4 MAIZE RESPONSES TO WATER STRESS

The question has been asked: Do CIMMYT materials, selected under good management and well irrigated, withstand water limitations as well as locally adapted materials or materials developed under less favorable conditions?

Phrased another way, the question becomes: Is there a loss of genetic potential for wide adaptability to dryland conditions due to our present breeding and cultural practices?

In response to these questions CIMMYT plans to pursue two main lines of investigation; the first is concerned with obtaining mea-

asures of varietal adaptation to environments of limiting moisture; the second is to study the morphological and physiological processes associated with differences in varietal response to drought.

Levitt (20) described the mechanisms by which plants resist drought as drought escape, drought avoidance, and drought tolerance. Avoidance mechanisms include any means of maintaining a high water content in plant tissue, whether by the ability to obtain more water or by the ability to reduce water loss. Drought tolerance is the ability of the tissue to survive desiccation (Sullivan, 27). This terminology has been adopted in the account which follows.

9.4.1 MEASUREMENT OF VARIETAL ADAPTATION TO LIMITING MOISTURE

Drought escape may be one of the most important mechanisms of adaptation to limiting moisture that CIMMYT should explore. In many tropical monsoon climates, the probability of drought incidence is often greatest at the beginning and end of the season. "Improved" varieties that are later maturing than the local, traditional variety, are often unacceptable to the farmer for this reason. Their longer growing season means that there is an increased risk that they, or the crop that follows them, will be exposed to drought. This and other evidence suggest that more effort to develop productive, early varieties and the management practices to go with them would be an effective way of reducing the losses caused by perhaps the most common form of drought in many of the countries where CIMMYT is working.

The different methods of using genotype x environment interactions to provide estimates of varietal adaptation were discussed earlier (see Topic 6.0). One approach to measuring adaptation to dryland conditions is given by Laing (19). He used a regression analysis with data from the sixth I.S.W.N. He eliminated those sites that had irrigation, or severe biological limitation (disease, extreme temperatures). He considered that the maximum yield at each of the remaining sites, irrespective of variety, represented the minimum genetic limitation to yield; and thus was the most sensitive indicator of the environmental limitation. There was a strong correlation between maximum yield and seasonal rainfall at these sites, suggesting that availability of water was a major limiting factor. He concluded that the adaptation analysis (linear regression) of this data could provide information about specific adaptation to dryland conditions.

Whatever technique is used for the analysis of varietal response to environment, there is a need to characterize the environ-

ment in terms of water availability and to relate this to crop growth. Season rainfall as used by Laing (19) is an extremely crude index. Although there appears to be nearly sufficient basic information in the literature (Penman et al., 22; Tanner, 28; and Penman, 21) to describe the availability of water to plants from soil and meteorological data, there are a few examples of studies where these estimates have been related to crop productivity. Van Bavel (4) and others have used rainfall and potential evapotranspiration data estimated from temperature (Thornthwaite, 29) as well as plant-available soil moisture holding capacity, to calculate a water budget and predict the occurrence of drought stress days. (A drought stress day occurs when potential evapotranspiration exceeds available soil moisture). Sopher et al. (25) examined the relationship between "drought stress days" at four developmental stages and maize grain yield. The polynomial regressions describing this relationship for each growth stage were then used to provide a weighted equation to predict a "drought index" for the crop. Thus, it is feasible to characterize the effective water environment in terms of a single climatic variable from a consideration of soil and limited meteorological data from the test site, plus a knowledge of the crops response to limiting moisture at the various developmental stages.

Some meteorological data will be needed to describe the test environments in terms of availability of moisture, if CIMMYT is to use the data that is derived from progeny and variety trials as a source of information on varietal adaptation to environments of limiting moisture. For some sites, good weather records exist, but there will often be problems of lack of uniformity or unaccessibility of data. For many other sites, it may be necessary to establish simple meteorological stations to collect the data needed. In this event, the studies described by Fitzpatrick and Stern (11), in which they consider the minimal instrumentation needed to compute potential evapotranspiration, would provide a useful guide.

Appropriate meteorological data, in conjunction with results from studies relating phenology to the environment, can provide a basis for describing environments in terms of drought. Similarly, reliable long-term weather data, when available, is basic information that can be used for the following purposes:

1. To determine the feasibility of maize production using present genotypes for new areas.
2. To design new systems to escape drought in traditional areas.
3. To aid the interpretation of results from regional and international trials

4. To estimate the probability of reduced yields, and therefore risk involved in production.

9.4.2 PHYSIOLOGICAL PROCESSES ASSOCIATED WITH ADAPTATION TO LIMITING MOISTURE

Studies of the physiological processes associated with plant response to water limitation are currently being conducted for a limited number of the highland and lowland tropical materials. An understanding of the response of a few materials, common to all of the multi-location tests will aid the analysis and interpretation of data on adaptation to dryland conditions. The present studies also provide the opportunity for CIMMYT staff to become familiar with techniques which will be used to examine the physiological and morphological processes which are associated with dryland adaptation, if and when different varietal responses are identified. As discussed earlier, these responses can be considered as drought avoidance or drought tolerance mechanisms.

9.4.2.1 Drought Avoidance

Plant water status is controlled by the soil water potential, by the series of resistances to water movement in the soil-plant-atmosphere catenary and, particularly by the evaporative power of the atmosphere (Cowan, 6). Thus, plant water potential (ψ) is described by the function:

$$\psi_{\text{plant}} = f(\psi_{\text{soil}}, \psi_{\text{atmosphere}}, R_{\text{soil-atmosphere}})$$

At constant soil and atmospheric water potentials, differences in plant ψ between genotypes will reflect differences in R , described here as drought avoidance mechanisms.

CIMMYT will attempt to evaluate the role of some of the various component resistance (R_{soil} , R_{plant} , $R_{\text{atmosphere}}$) to water movement from the soil to the atmosphere in tropical maize. The first experiment in which this was attempted was at El Batán in the summer of 1973. The aim was mainly to develop techniques, in preparation for continuing the work at Tlaltizapán in the following season. The preliminary results suggest some interesting differences between varieties. A brief summary of some of these results is given below.

Stomatal Resistance (R_s): The relationships between water potential of the leaf (leaf ψ) and stomatal resistance (R_s) for five genotypes grown at El Batán are shown in Fig. 9-12. In using this kind of information, it is necessary to consider what characteristics are desired. Thus, a genotype in which the stomata remain open (low resis-

tance) at low water potentials (higher negative values) may have an advantage in a non-protracted period of drought stress. When stomata remain open, they allow for diffusion of CO₂ for photosynthesis and permit cooling of the leaf (transpiration), but this is at the expense of water use. The variety Zacatecas 58 behaved in this way, whereas the stomata of the Funk hybrid (U. S. hybrid) closed sooner in response to an increase in leaf water stress.

Plant Resistance (R_p): Sedgley et al. (24) described a field technique to measure the resistance to water flow from the soil to the plant leaf (R_{soil} + R_{plant}). At El Batán, measurements made with the soil at field capacity (R_{soil} ≈ 0), provided estimates of R_{plant} for the five varieties included in the study (Table 9-3). Again, there is evidence of varietal differences. A high resistance to water movement within the plant is another mechanism by which the plant can control transpiration. Thus, Zacatecas 58 (in which stomata remained open at low water potentials) exhibits a high plant resistance, conversely, the Funk hybrid exhibits a low resistance.

Soil Resistance (R_s): As the soil dries, the magnitude of resistances R_{soil} + R_{plant} increase due largely to a change in R_{soil}. R_{soil} will depend on the soil water potential (soil ψ) profile and the depth and profuseness of plant roots. Measurements of R_{soil} for varieties grown under the same soil water conditions will reflect varietal differences in root functionality (with respect to water uptake). As before, we need to consider what characteristics are desired. Under moderate drought or a short, severe drought, the profuse root system may continue to provide water to the shoot, whereas, in a protracted, severe drought, it may exhaust the available moisture and succumb to drought (Sullivan, 27).

9.4.2.2 Drought Tolerance

Drought tolerance includes the plants' ability to survive during drought, their ability to endure drought without injury (which implies the capacity to resume growth, development, and reproduction after relief of drought), and efficiency in use of water.

(NOTE: The mechanisms of drought tolerance relative to survival are not dealt with here. The program is concerned with only those properties that can enhance survival, without loss of production potential. In any event, where survival of the species becomes the relevant criterion, attention might best be given to alternative crop systems.)

The usefulness of the ability to endure drought without injury should be assessed in correct perspective, and this may best be seen

in terms of adaptability indices. Where the ratio of the yield under dry conditions to the yield under optimal conditions of water supply is used as a criterion of this drought tolerance, the relative magnitude of the optimum yield is of importance. That is, in the definition of adaptability, the genotype should not only be adaptive, but should also have high yield potential. There may be some exceptions where the probability of drought years is high, and where there is an economic risk factor such that the probability of obtaining a yield in any one year is paramount to maximizing yield in the long term.

Evaluation of genotypic difference for "drought" tolerance suggested here is analogous to the earlier descriptions of the response to drought or "drought stress days." The aim is to evaluate the yield effects of low plant water potential at various growth stages. Such an analysis will be shown to be an evaluation of "drought tolerance", that is, independent of drought avoidance mechanisms. (The earlier analysis of "drought days" involves both mechanisms of tolerance and avoidance.)

The initial requirement, then, is to determine plant water potential. However, cell water potential will depend on both the osmotic potential of the cell and its turgor potential. Turgor potential influences many growth processes. It is desirable to measure not only plant or cell water potential, but also osmotic potential (and by difference turgor). As suggested by the function, for any one-day period, there could be a range of plant ψ , and it is suggested that we use ψ plant minimum, ψ plant equil, and the integrated ψ plant (day^{-1}) as indices of plant water stress. (Under a drying cycle and similar atmospheric evaporative demands all these parameters will decrease (increase negative potential)).

This approach would relate these indices of plant water stress to yield for a limited number of genotypes in experiments conducted at CIMMYT research stations. Plant potentials can be determined, in the field, by the use of Scholander pressure chamber and possibly by in situ psychrometry (Hoffman and Rawlins, 16). Soil potential can be determined by tensiometers, resistance blocks, and the combination of neutron moisture meter and soil-moisture-tension curves.

To allow a more meaningful interpretation of the effect of plant water stress at various developmental stages on grain yield at maturity, CIMMYT will consider yield to be determined by those processes which determine the capacity for storage (as grain) and to supply assimilates (for grain filling). This would appear desirable in light of the other physiological studies (limitation to yield) and their implications discussed earlier.

Ignoring the probable interdependence of supply and storage demand, supply could be measured by the following:

- (1) Leaf Area Development:** Boyer (5) suggests for maize, development as determined by elongation of cells (rather than cell division) can be affected by leaf ψ of -4 bar and less. This may be a temporary phenomenon, with adequate recovery after alleviation of stress.
- (2) Leaf Area Persistence (Firing):** Permanent loss of effective leaf area. The equilibrium leaf potential causing 50% killing of the cells used by Sullivan (27) as an index to tolerance.
- (3) Efficiency of Net Photosynthesis:** The literature suggests that respiration may decrease more slowly than photosynthesis and thus exceed the rate of photosynthesis during drying (Laude, 18).

CIMMYT chooses to use growth analysis to resolve leaf area index (LAI) and net assimilation rate (E) (Crop growth rate (C) = LAI x E) to measure changes in supply. Photosynthesis will be impaired by increase stomatal resistance to CO₂ diffusion. The relationship between ψ leaf and stomatal resistance (R_s) also will be determined. Additionally, examinations will be made of the effect of plant water potential on the components of storage capacity. It is frequently stated that the tissues most injured are those growing the fastest at the time stress begins (Fischer, 10). Maize has been shown to have a critical period (a period particularly sensitive to water stress) at tasseling and silking (Robins and Domingo, 23) with the number of kernels being reduced.

The most promising and effective strategy in breeding for efficient water use would appear to be to increase the proportion of the total biological yield that is incorporated into grain. As indicated already, CIMMYT's materials are limited by their capacity to store dry matter as grain, with excess storage of dry matter in the stem. Research directed toward increasing the storage capacity of the ear would benefit production in both limiting and non-limiting water conditions. Only when the capacities to store and produce grain assimilates are in balance will there be the most efficient partitioning of biological yield into economic yield and thus the most efficient water use.

CIMMYT does not now plan to employ techniques for the screening of young plants for drought tolerance. However, close contact will be maintained with those research groups that are developing rapid indices for this purpose.

9.5 SUMMARY

Productivity studies on lowland and highland tropical maize material have indicated that grain yield is limited by the capacity for storage by the plant.

A number of procedures within the main program (breeding) have been initiated in an attempt to reduce this limitation. Temperate germplasm, which is more efficient in partitioning total biological yield to grain has been mixed with the less efficient but more resistant (disease and insects) tropical materials.

High population (80,000 plants ha.⁻¹) nurseries will be incorporated into the selection program, to provide cultural conditions favorable to the smaller, earlier materials, and to select those families showing a reduced tendency for barren plants (more crop storage) at high plant densities.

Research continues at Mexico sites to understand the control and development of the storage components of the plant. Some of the basic information for this understanding will necessarily have to come from other research institutions.

The physiology program plans to use much of the information obtained from multi-location testing of materials and the subsequent analysis of the data for varietal adaptation. Characterization of the environment (physically) for some sites and the identification of different responses by materials will provide the basis for understanding the morphological and physiological processes associated with the response. Characters associated with the desirable response may be identified for use in the breeding program.

In anticipation of the identification of materials worthy of further investigation, studies have begun on some of the lowland (tropical) material to understand the influence of the environmental parameters of temperature, photoperiod, and radiation on the development of the yield components. The effect of drought stress on the yield and the physiological response to low water potentials also is being investigated for three of these materials.

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Table 9-1. GRAIN YIELDS AND HARVEST INDICES OF
HIGHLAND MAIZE EL BATAN 1972

Variety	No. Plants m ⁻²	Grain Yield gm ⁻²	Total D.M. gm ⁻²	Harvest Index
C. I. P. A.	4.6	704	1879	0.37
	8.9	874	2173	0.40
HIDALGO 8	4.5	761	2481	0.31
ZACATECAS 58	4.6	531	1439	0.37
	9.4	703	1798	0.39
	14.0	766	1923	0.40
CRIOLLO BARAZA	4.4	473	1485	0.32
H 28	4.6	700	2038	0.34
	9.7	886	2565	0.34
	13.7	802	2758	0.29
SR 52	7.4	1200	2275	0.53

Table 9-2. GRAIN YIELDS OF LOWLAND TROPICAL MAIZE

POZA RICA AND TLALTIZAPAN 1972

VARIETY	<u>POZA RICA</u>		<u>TLALTIZAPAN</u>	
	No. Plants m ⁻²	Grain Yield gm ⁻²	No. Plants m ⁻²	Grain Yield gm ⁻²
TUXPEÑO	4.9	516	4.8	649
	9.6	543	9.3	769
	14.2	739	13.9	850
TUXPEÑO x ETO	4.9	466	4.8	653
	9.6	532	9.3	812
	14.2	619	13.9	730
COMPOSITE K	4.9	343	4.8	475
			9.3	500
			13.9	742

**TABLE 9-3. RESISTANCE TO WATER MOVEMENT FROM THE
ROOT SURFACE TO THE UPPER LEAF (. .).**

V a r i e t y	P L A N T R E S I S T A N C E (relative)	
	Sample Date 1 *	Sample Date 2
Amarillo Bajfo	7.8	7.3
Eto x Illinois	7.3	11.7
H 28	14.0	22.5
Zacatecas 58	13.3	21.9
Funk Hybrid	7.5	10.1

* Sample dates 1 and 2, 120 and 140 days from planting respectively.

Fig. 9-1. CIMMYT maize program organizational scheme

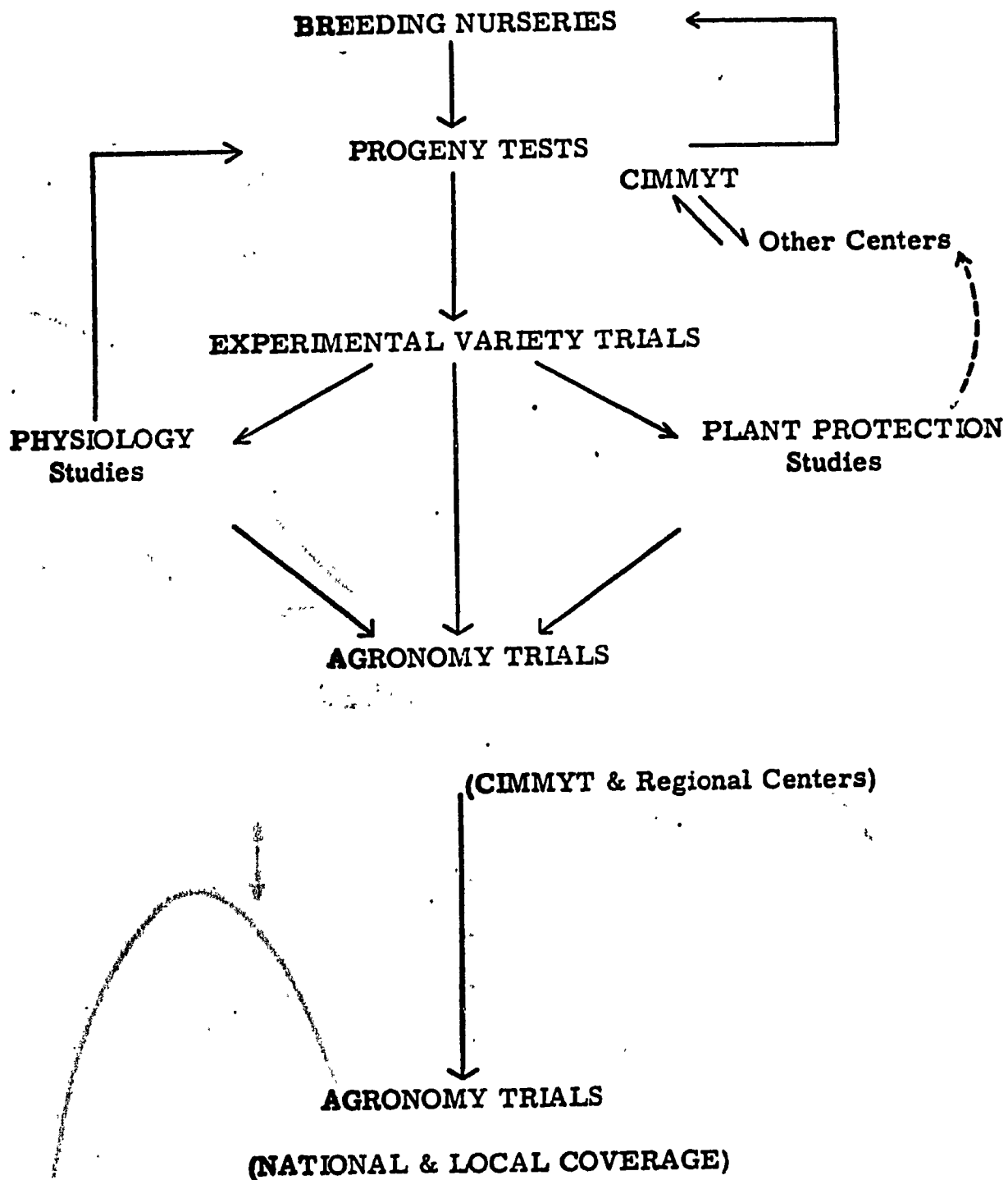
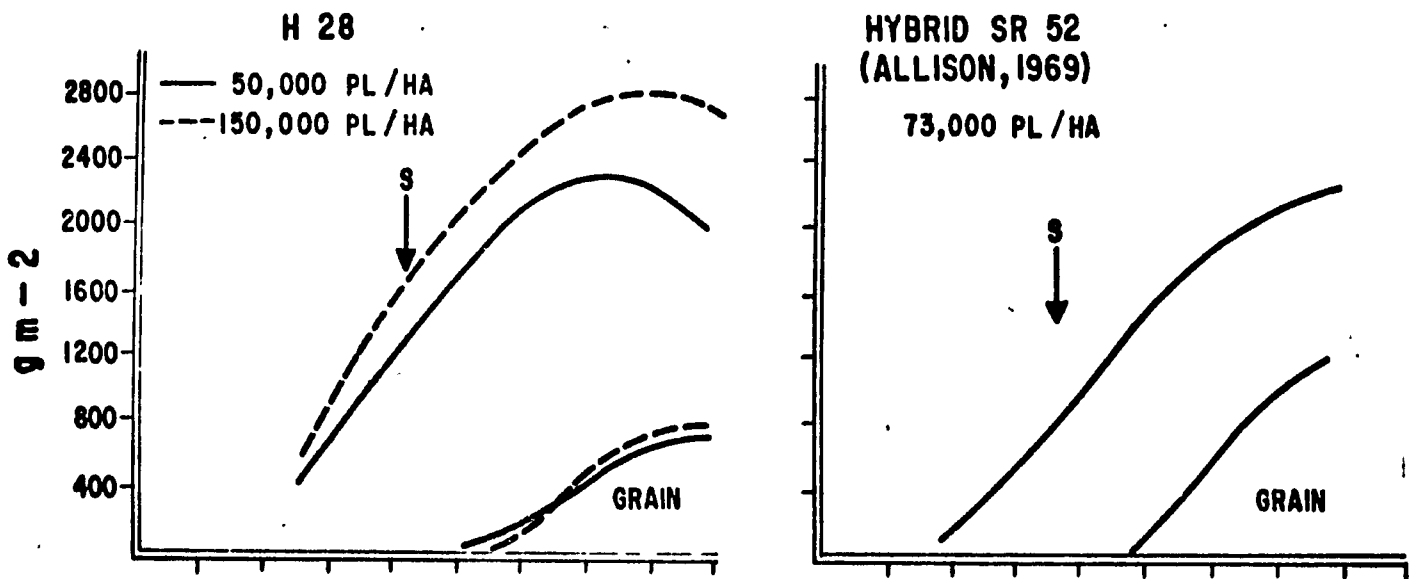


Fig. 9-2. DRY WEIGHTS OF CROP AND GRAIN



LEAF AREA INDEX

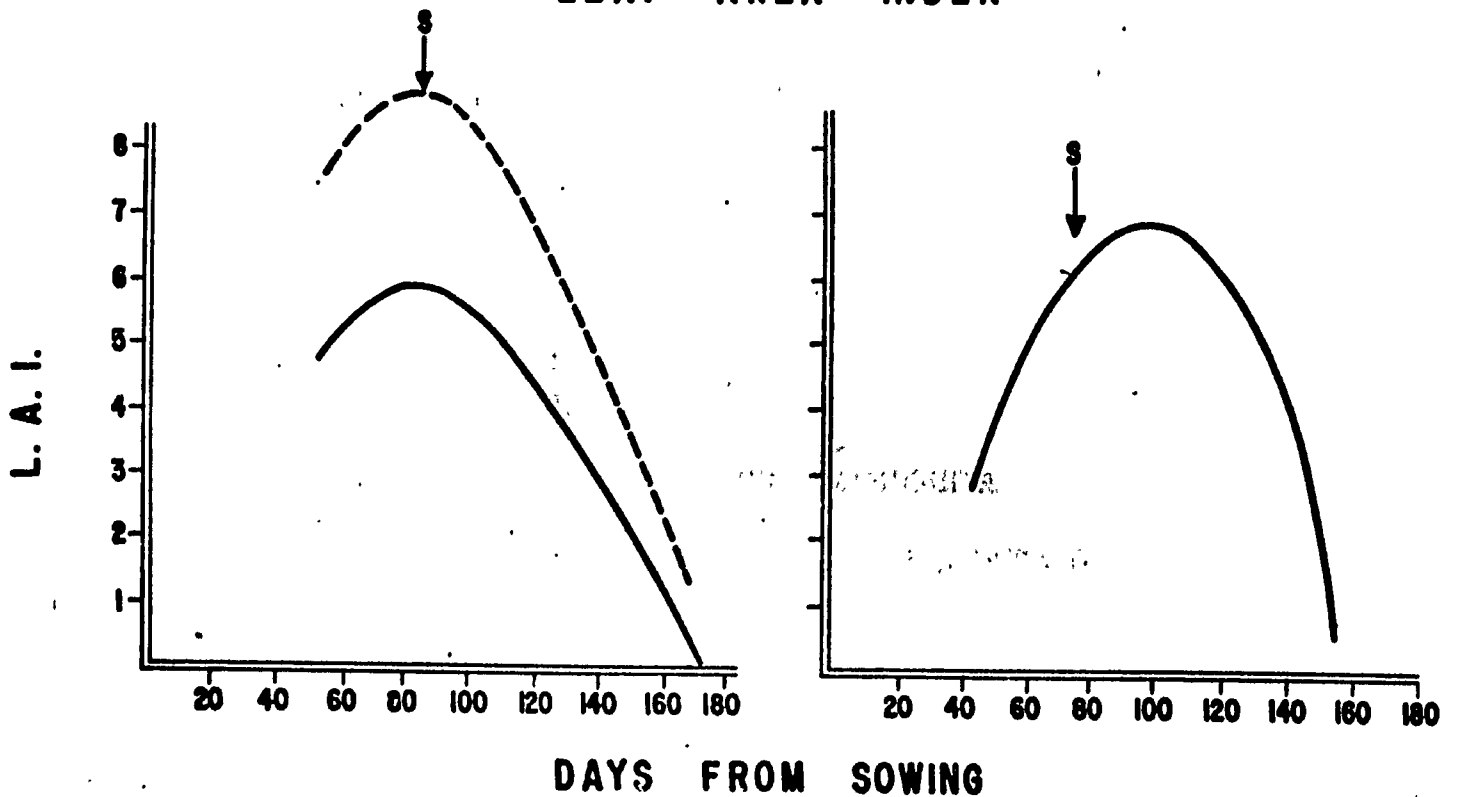


Fig. 9-3. GROWTH RATES OF CROP AND GRAIN

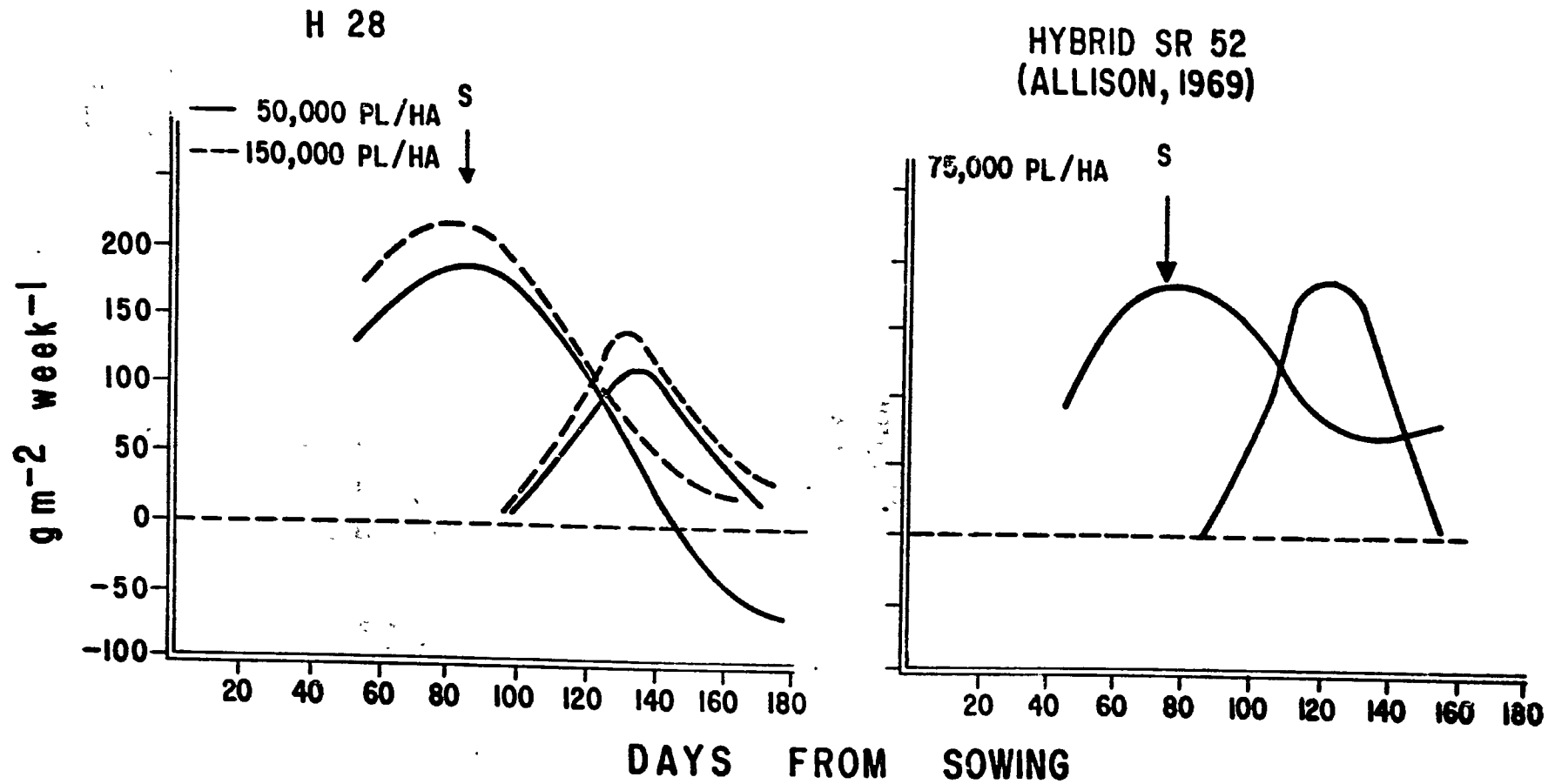


Fig. 9-4. THE ACCUMULATION AND DISTRIBUTION OF DRY WEIGHT IN MAIZE DURING THREE PERIODS AFTER SILKING.

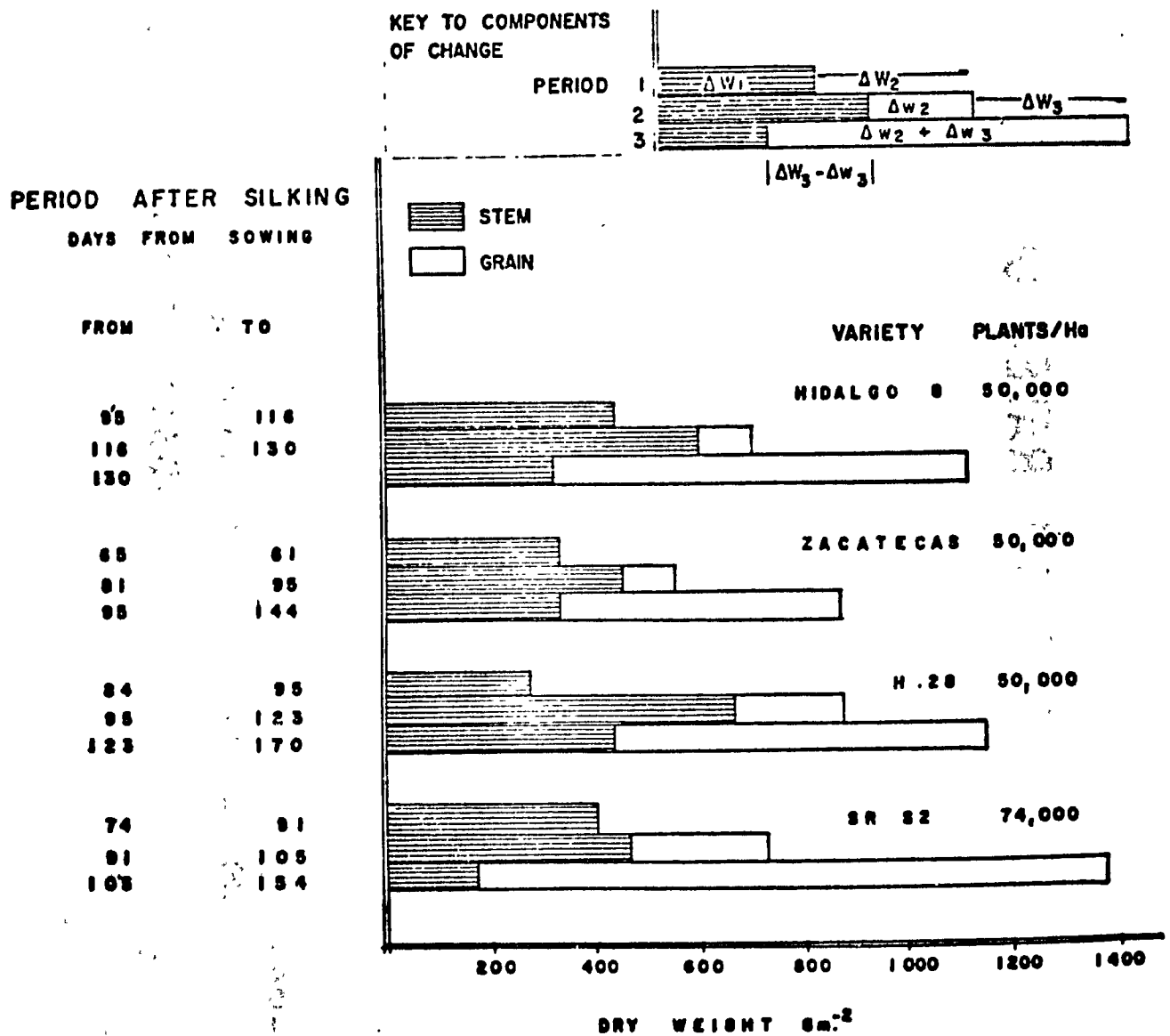


Fig. 9-5. DRY WEIGHTS OF CROP AND GRAIN

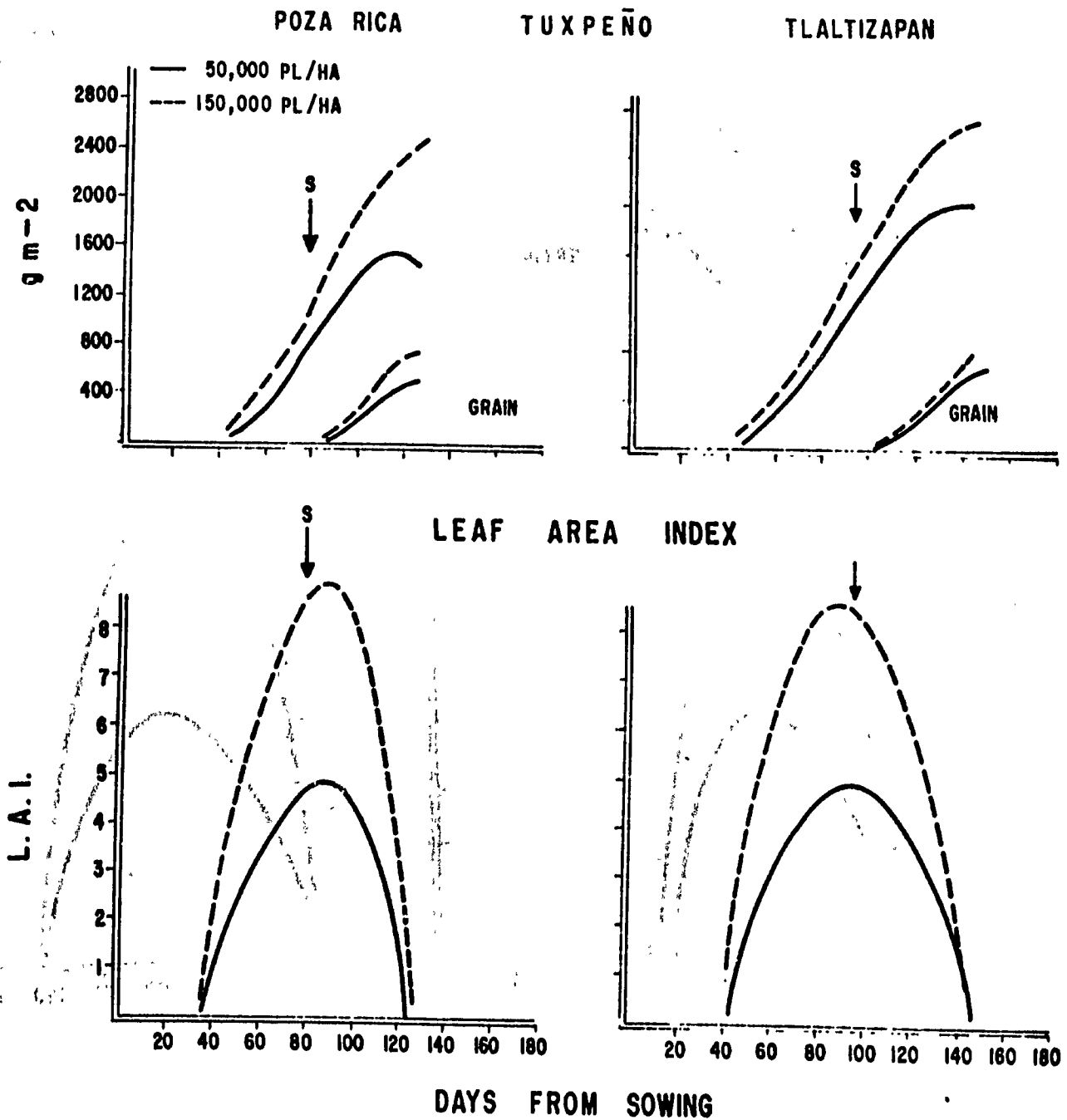


Fig. 9-6. DRY WEIGHTS OF CROP AND GRAIN

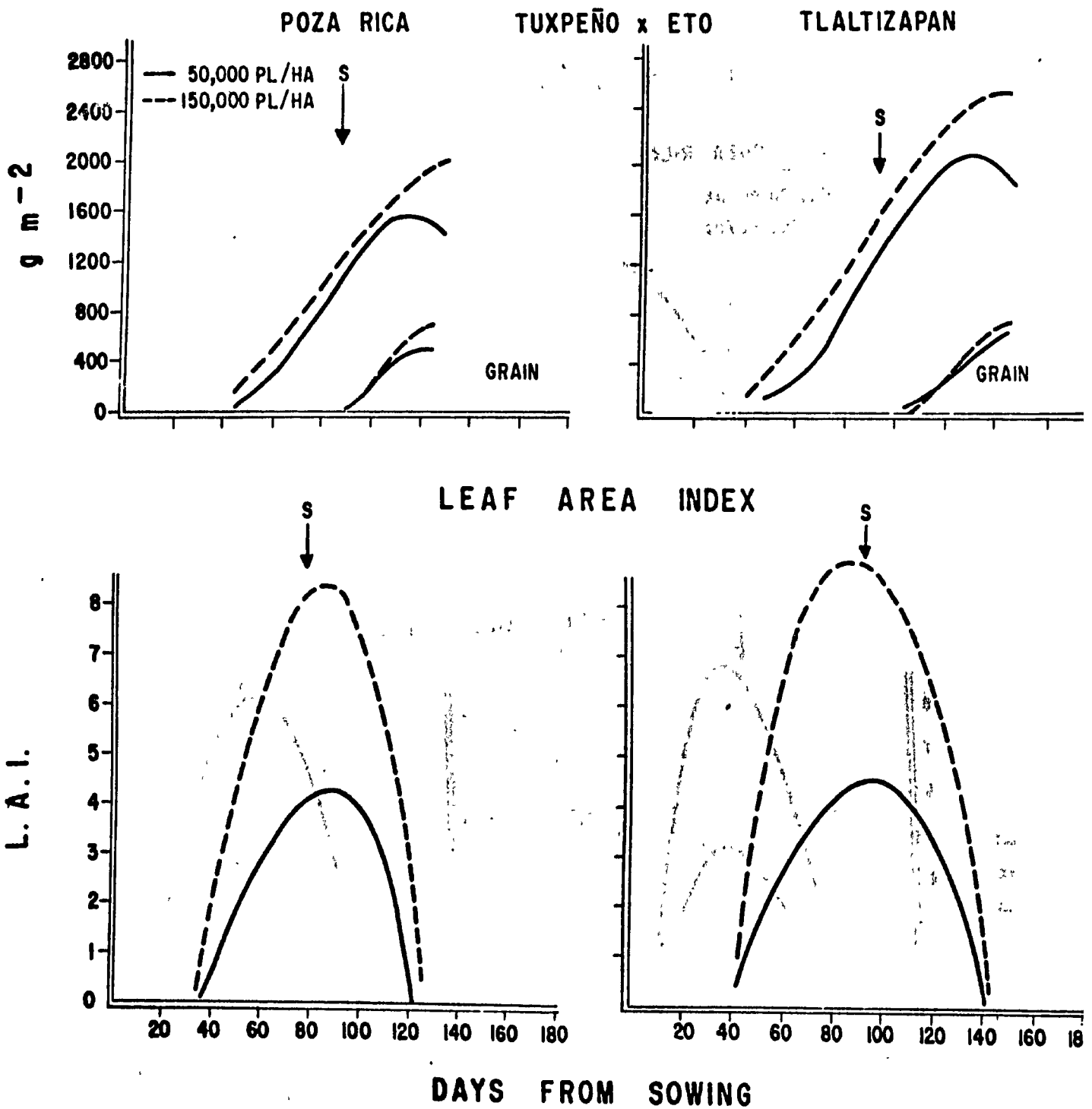


Fig. 9-7. GROWTH RATES OF CROP AND GRAIN

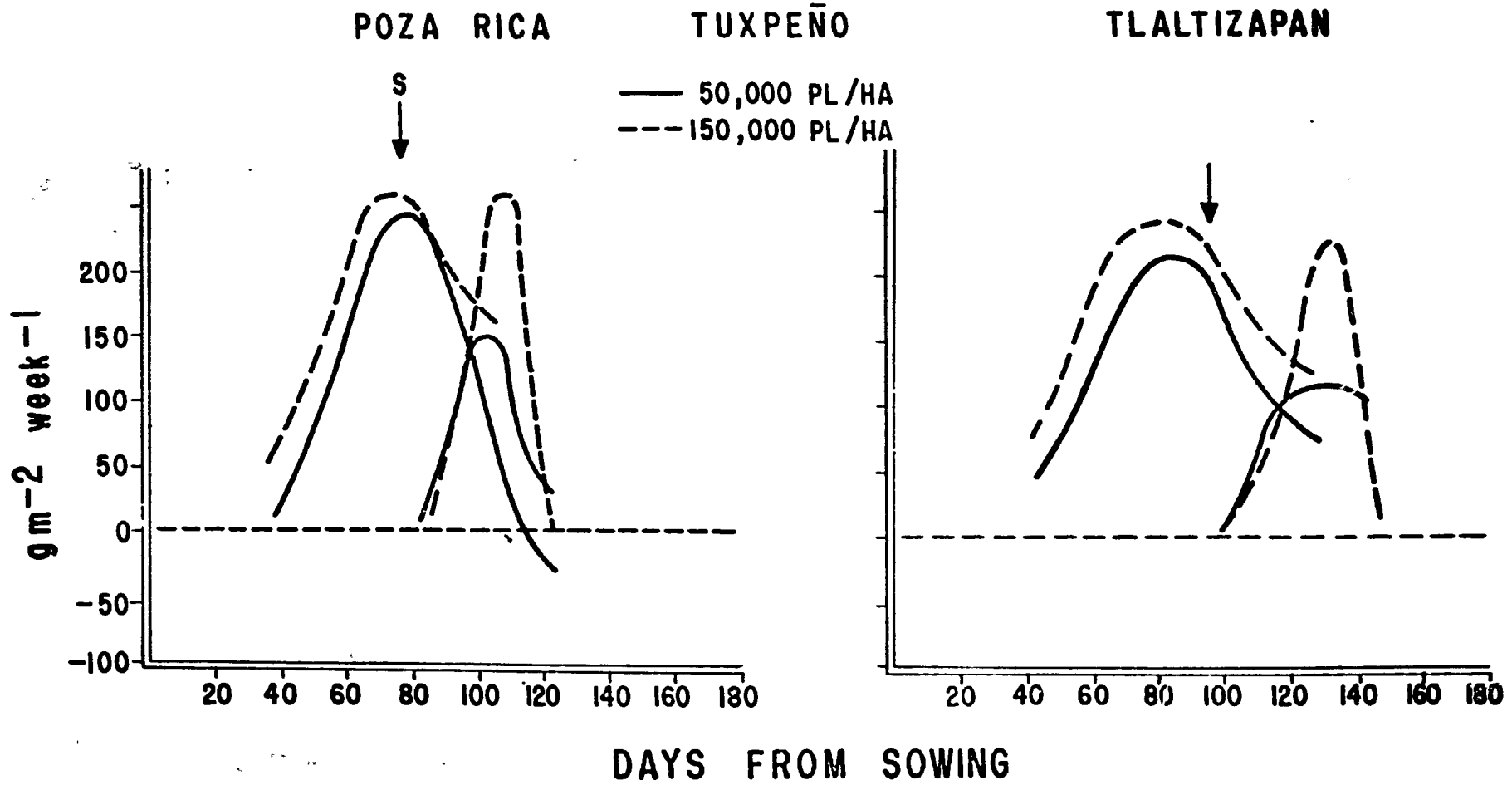


Fig. 9-8. **GROWTH RATES OF CROP AND GRAIN**

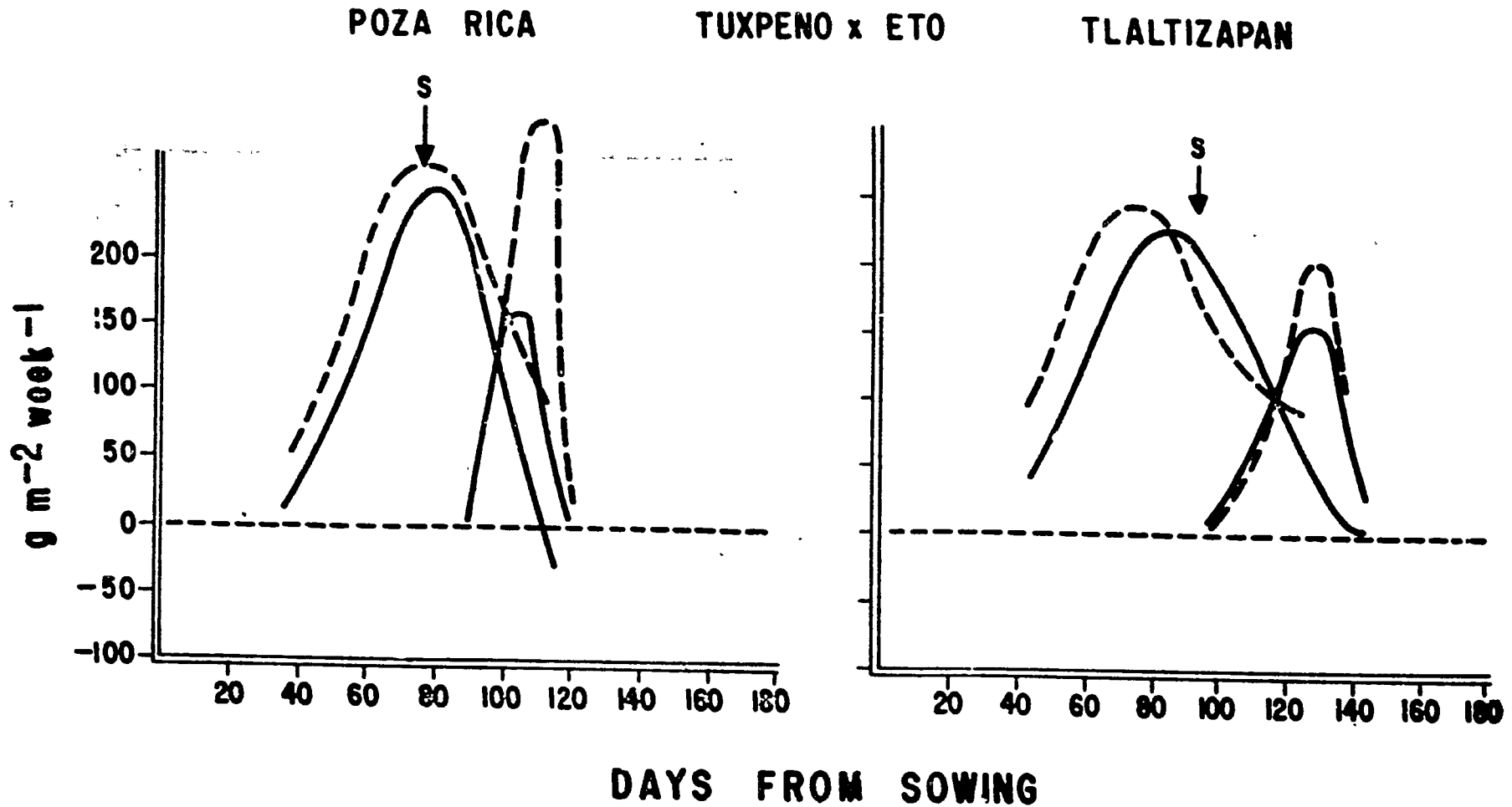


Fig. 9-9. DRY WEIGHT CHANGES IN MAIZE

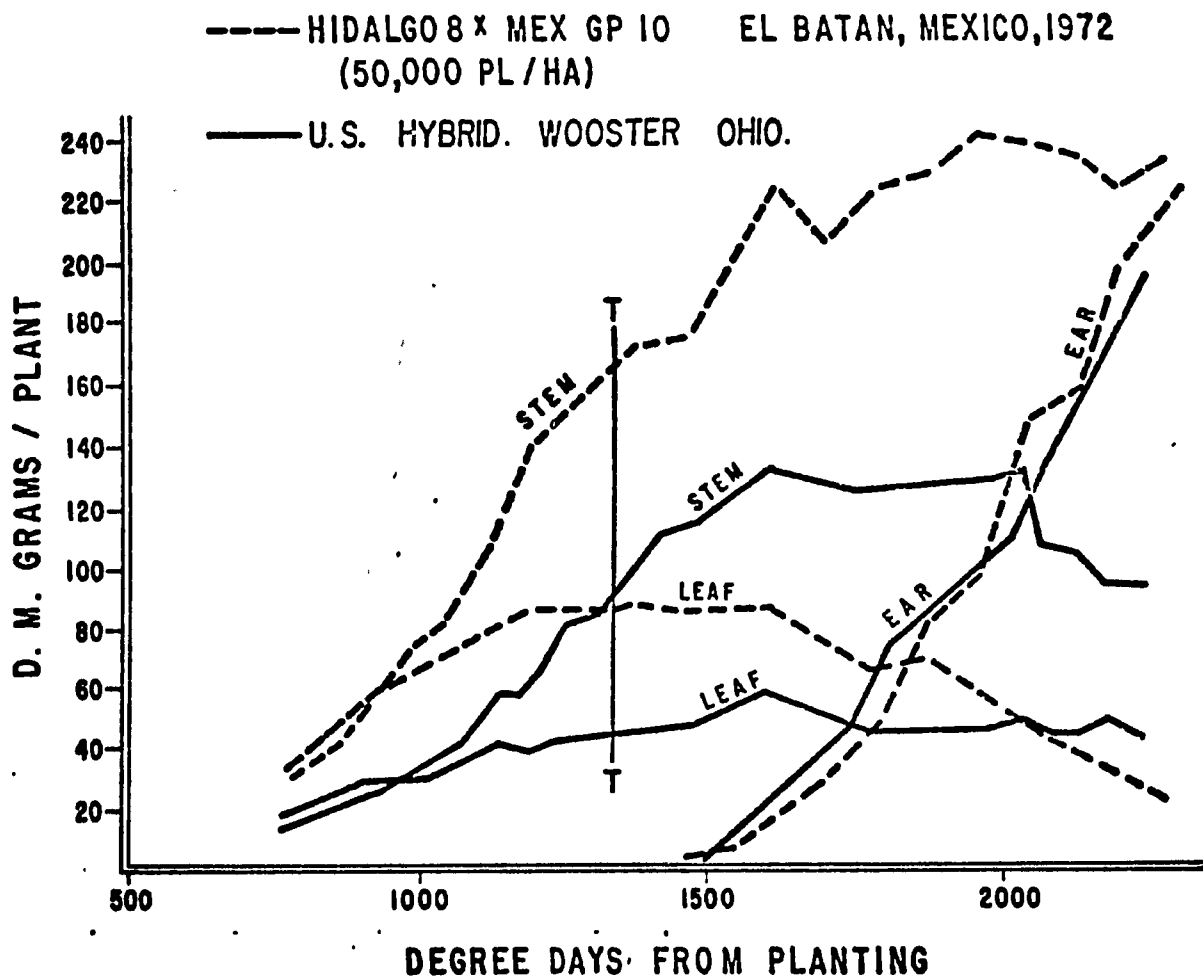


FIGURE 9-10.

DRY WEIGHT CHANGES IN MAIZE

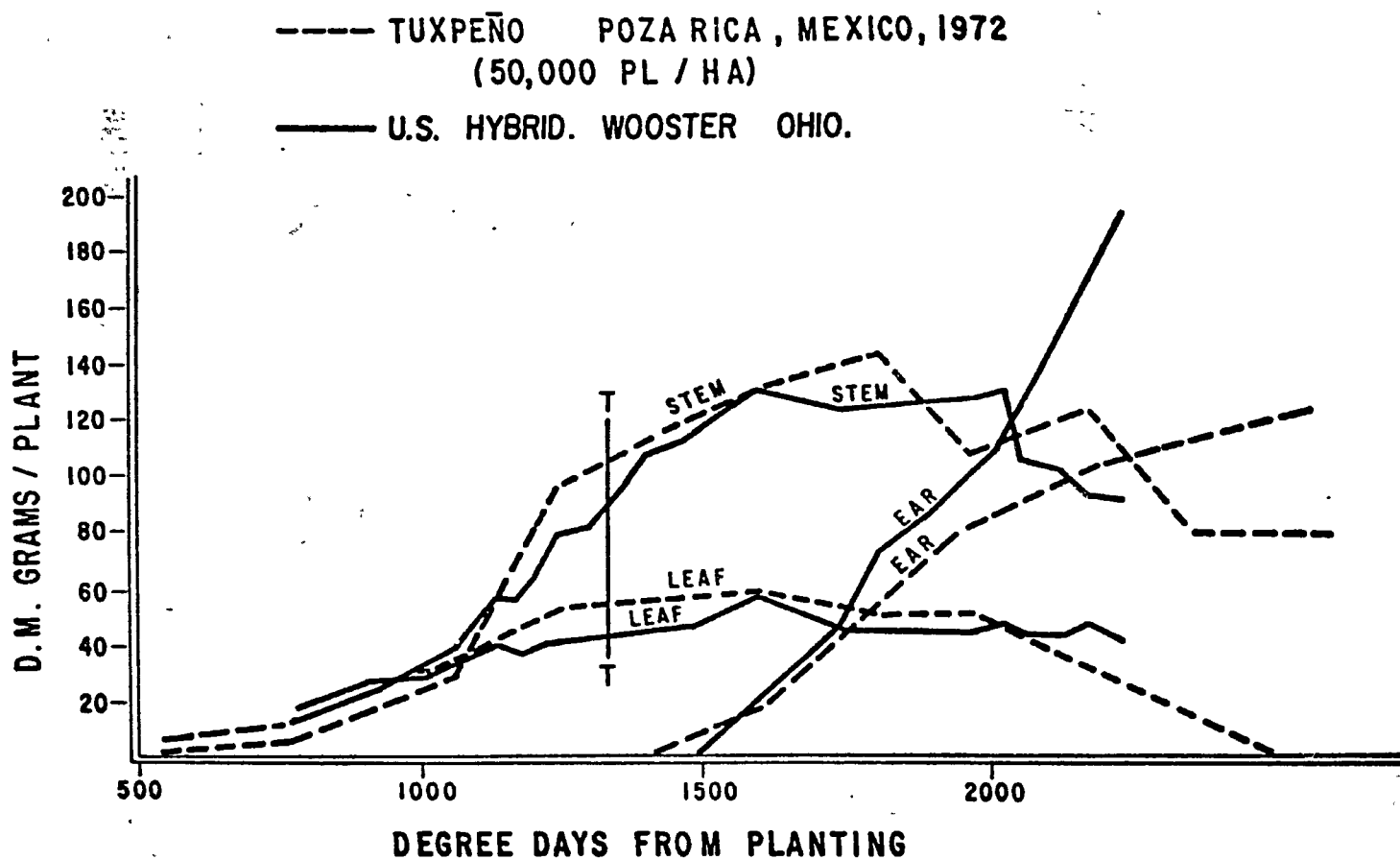


Fig. 9-11.

DRY WEIGHT CHANGES IN MAIZE

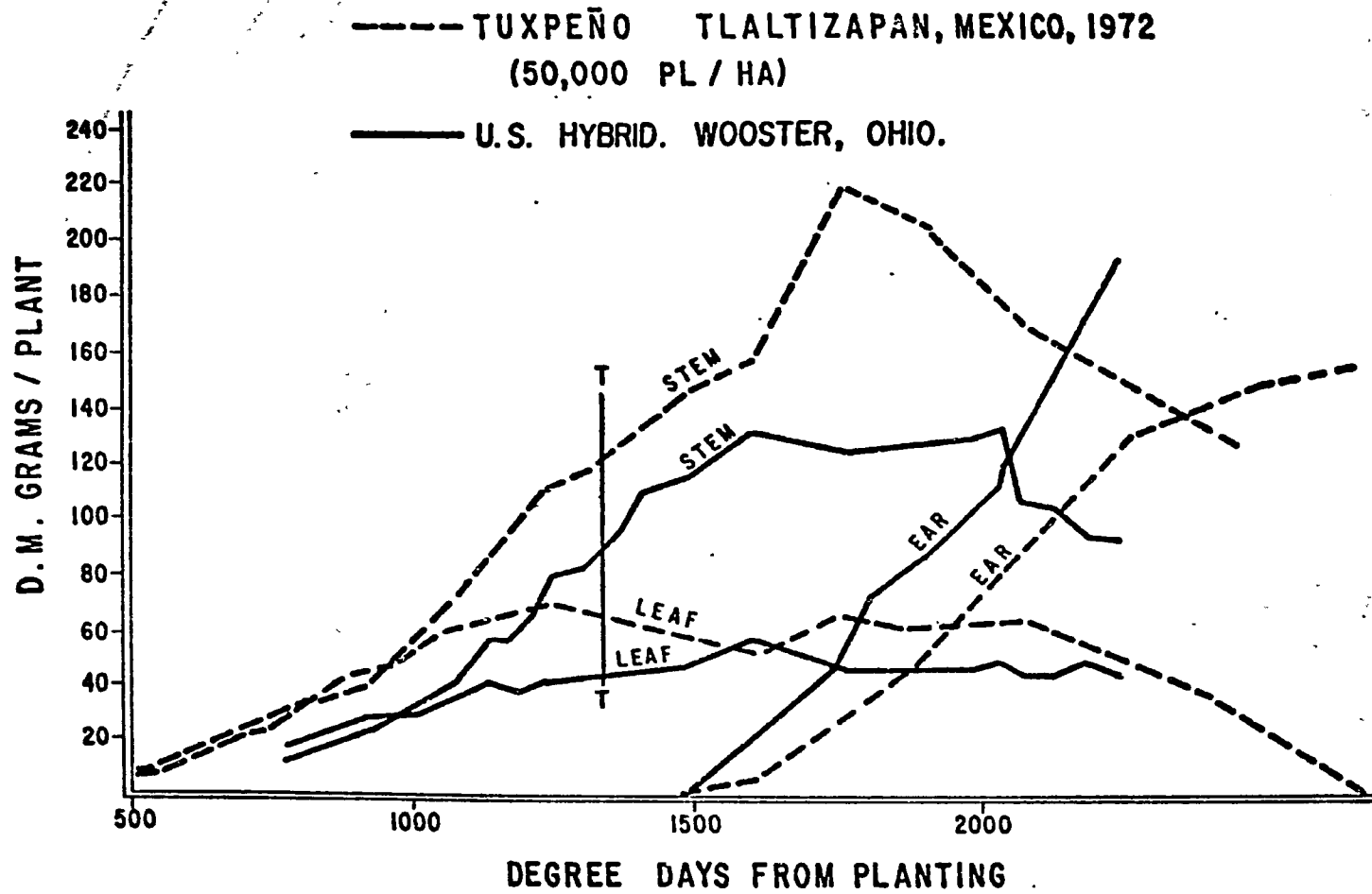
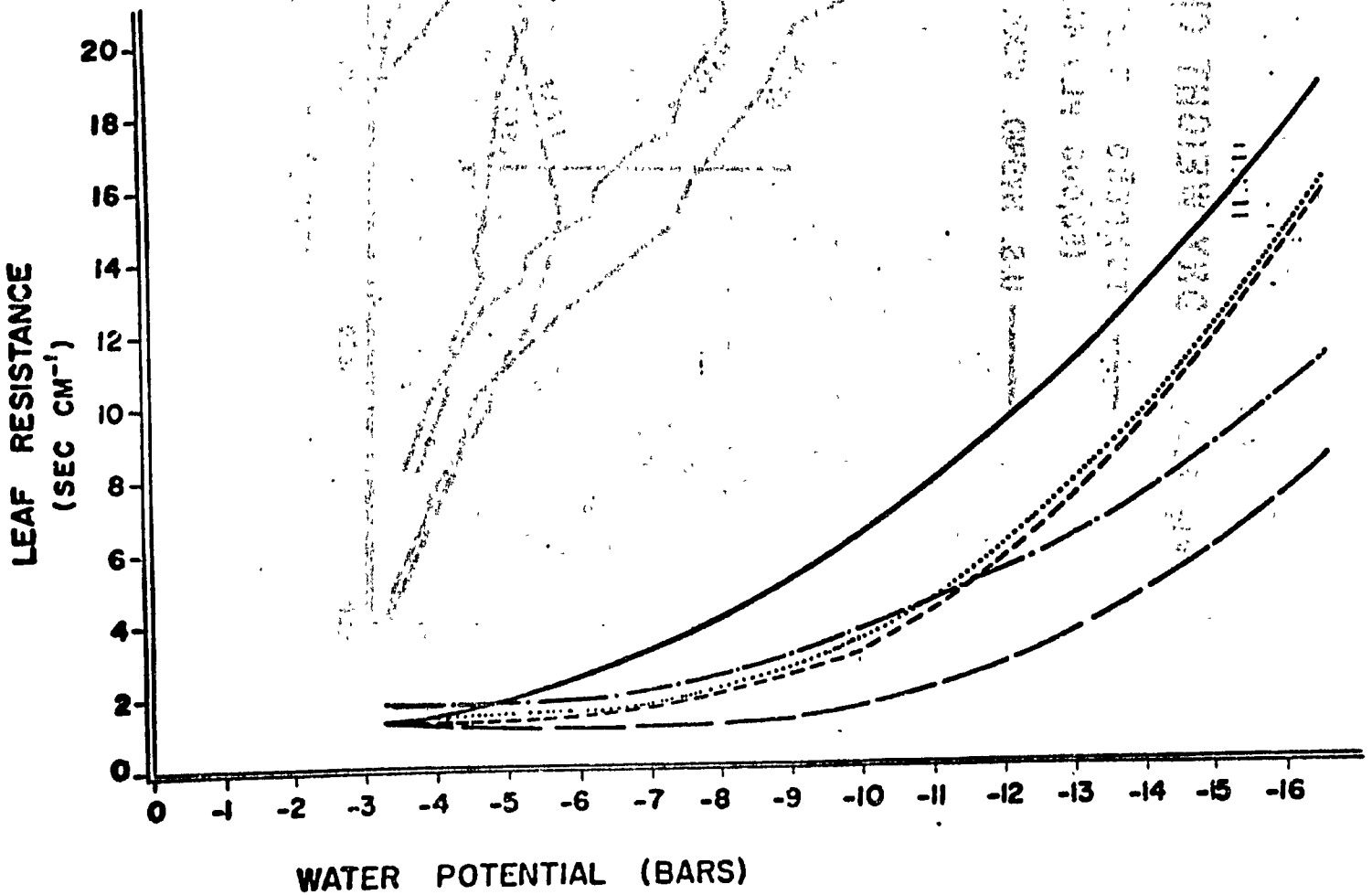
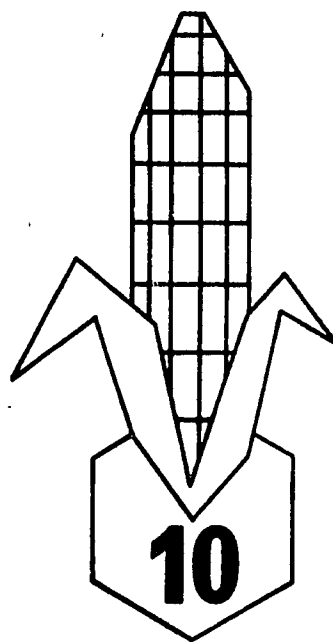


Fig. 9-12.

RELATIONSHIP BETWEEN LEAF WATER POTENTIAL AND STOMATAL RESISTANCE FOR FIVE MAIZE VARIETIES. EL BATAN, 1973

AMARILLO BAJIO,
ETO x ILLINOIS,
H 28,
ZACATECAS 58,
HYBRID, (U.S.)





NUTRITIONAL QUALITY IN MAIZE

by
S. K. Vasal, CIMMYT

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Asst. Professor
Faculty of Medicine
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Cali, Colombia

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10.0

NUTRITIONAL QUALITY IN MAIZE

by
S. K. Vasal

10.1 INTRODUCTION

Maize is a vital element of human diets in developing countries, accounting for 50 to 60% of the dietary protein. Of the total cereal protein production (approximately 106 million tons) in the world, maize ranks second in the order of production and accounts for roughly one-fourth of this total.

Protein in maize is of poor nutritional value, because of the limiting concentrations of two important amino acids: lysine and tryptophane. This imbalance in maize protein, coupled with insufficient caloric and protein intake, contributes to malnutrition problems among the low-income, maize-consuming families of the developing world. Though various approaches can be used to bridge this protein gap, the consensus among authorities is that the most feasible and economical solution will be to develop varieties and hybrids of maize that have higher protein content and elevated levels of essential amino acids. Thus, improvements gained through genetic manipulation can provide the consumer with more nearly adequate amounts of nutritionally balanced protein--without changing food habits of the people and without any additional food cost.

10.1.1 MALNUTRITION PROBLEMS IN DEVELOPING COUNTRIES

Protein-calorie malnutrition prevailing in many developing countries is a complex and challenging problem. It is roughly estimated that three out of every five people in the developing world do not receive balanced nutrition from the available food. Furthermore, the situation is more critical among vulnerable groups, especially preschool children, pregnant, and nursing mothers due to inadequate available food, priority

orderings in eating within the members of a family, and the lack of knowledge about the special food needs of these individuals. It is well known that for growing children there is not only greater nitrogen requirements in relation to calories, but proportionately also higher requirements of essential amino acids than older children and adults. It is also well documented that a child's brain reaches nearly 90% of its structural development during the period starting from the last three months of pregnancy and the first two years after birth. During this critical period, malnutrition causes a high mortality among young children, limits physical growth, impairs and retards mental development of hundreds of millions that survive and in turn reduces their productivity as adults.

There is no simple solution to overcome the protein crisis in the developing countries. Nevertheless, there is a strong need to implement all possible alternative approaches and measures that are thought practical in any given country or region so as to benefit as many individuals as possible. Fortification of cereals or staple foods with essential amino acids, the manufacture of protein-enriched processed foods, and the feasibility of single-cell protein production have been tried to a limited extent in certain countries, but the impact of these products has resulted in only limited success, restricted to the urban and suburban areas. In the first place, these products would encounter distribution and cost problems and would hardly reach the poor, needy, and the low-income farming families. Second, even if these products are available, the low purchasing power, the traditional food habits and the lack of understanding about the nutritious value of foods would prohibit access of such enriched protein foods to the low-income farming and non-farming groups. Furthermore, many low-income farming families often consume only the foodstuffs produced on their small land holdings. If these disadvantaged and underprivileged farming communities are to benefit, the only practical and feasible way of upgrading the nutrition level of these individuals will be to improve the nutritional status of the basic food staples which they normally consume.

Cereals are by far the most important staple foods in the developing countries. About 95% of the population in such countries depend on these for necessary calories and the protein needs. It is estimated that about 57% of the caloric requirements of the individuals in the developing world are met by cereals. It therefore seems obvious that if masses that are malnourished are to benefit, it would be necessary to consider the improvement of crop varieties of different cereals for protein content and for protein quality. This will be the most economical and feasible solution under the present circumstances, because this will not involve any change in food habits and any additional food cost.

To what extent high quality protein maize can play a role in alleviating malnutrition problems in the developing world can be judged from the fact that maize ranks second among cereals in terms of total protein supply on a world-wide basis. The introduction and the expansion of production of high quality protein maize to upgrade nutrition will therefore be limited to only maize-eating people in the world; nevertheless, it can affect as many as 200 million people. The use of high quality protein maize will continue to provide the calories that people derive from this cereal, but they will have the additional advantage of getting a modified protein profile that has twice as much biological value as the normal maize. It has been well demonstrated that protein quality of opaque-2 maize is about 90% of the skim milk when consumed by children (Bressani, 1) and that children suffering from various types of syndromes, such as Kwashiorkor, recovered on a diet in which high quality protein maize was the only source of protein (Pradilla and Harpstead, 5). This would mean that an ideal solution to eliminate protein deficiencies among low-income families that traditionally consume maize in large quantities would be to shift from ordinary maize to high quality protein maize. A daily intake of 250 to 350 g of high quality protein maize will satisfy the daily protein and essential amino acid requirements of young adults (Clark, 3).

It is therefore obvious that if nutritional status of low-income, maize-growing and maize-consuming families is to be upgraded, there is need to expand and accelerate research efforts to produce suitable high quality protein maize varieties that will be readily accepted.

The following sections list some of the specific barriers that are limiting production of these varieties.

10.2 FACTORS AFFECTING LARGE-SCALE CULTIVATION OF QUALITY PROTEIN MAIZE

The key discovery of the biochemical effects of the opaque-2 gene demonstrated that protein quality in endosperm of normal maize can be altered favorably by enhancing the levels of two limiting essential amino acids: lysine and tryptophane. This dramatic discovery in 1963 generated a world-wide interest among maize breeders, who sought to produce opaque-2 versions of normal flint and dent maize varieties with better balanced protein quality. Subsequent nutritional experiments have shown that the higher concentrations of essential amino acids in opaque-2 maize contribute to the biological superiority of this maize over normal maize. The increased nutritional value of opaque-2 maize was first demonstrated in studies of weanling rats, and later shown in studies on children and swine. More recent reports indicate that opaque-2 maize may also have some advantages for ruminant animals.

Although the above nutritional advantages seem to have been well demonstrated, opaque-2 materials have not made a far-reaching impact on world-wide production in the past decade. Breeding work with opaque-2 maize is being done in most countries, but the commercial use of opaque-2 maize has been limited to Brazil, Colombia, and the United States.

Brazil has shown a steady increase in production of opaque-2 maize hybrid seed: production figures for 1972 show that about 1,590 tons of opaque-2 hybrid seed were produced for distribution in 1973. Colombia produced and sold about 64 tons of seed of two opaque-2 hybrids (ICA-H208 and ICA-H255) in 1972, for planting of about 14,160 ha. No exact figures are available for the United States, but it is estimated that less than 1% of total area under hybrid seed production was devoted to opaque-2 maize hybrids in 1972. By 1975, opaque-2 hybrid seed production in the United States is expected to reach somewhere near 5,250 tons of seed for planting about 240,000 ha.

Opaque-2 maize varieties and composites also have been released in some other countries for commercial production. No exact figures are available for these countries, but production is estimated to be negligible.

The restricted use of present opaque-2 maize reflects a number of problems which severely limit commercial acceptance of these materials. These problems vary, however, in different parts of the world.

Major limitations of the opaque-2 materials include:

- (1) Reduced grain yield, about 10 to 15% less than normal maize. This decline in yield is attributed to loose packing of starch granules in the endosperm and to low kernel density.
- (2) Non-acceptability of the kernel phenotype of opaques having endosperms with soft, chalky, dull, and lusterless appearance. This acts as a major hurdle in those areas of the world where farmers are used to growing hard flint maize types with clean, shiny, and lustrous appearance. In certain regions of the Andean zone, however, where farmers are already growing floury types, the appearance of opaque-2 kernels does not seem to pose any problem so far as acceptance is concerned.
- (3) Greater vulnerability to ear rot organisms. This probably is due to slow drying of opaque-2 kernels after physiological maturity is complete.

awods(4) Greater infestation by weevils, both in the field and in
tills of storage. This may result from the soft, floury endo-
sperm of the opaque-2 maize.

- (5) Opaque-2 maize presents dry milling problems. The absence of vitreous endosperm in opaque-2 maize makes it almost impossible to obtain flaking grits and coarse brewer's grits. Also, the yield of regular grits is 10% less than that of normal maize. Difficulties also are experienced in separating bran and germ.

Some additional problems may be related to a specific area
or situation, such as germination problems under freezing tempera-
tures and losses due to cracking of grains during harvest by combines.

10.3 CIMMYT'S QUALITY PROTEIN PROGRAM

Opaque-2 versions of a very large number of normal varie-
ties and composites, with varying grain types, have been obtained from
the tropical, subtropical, temperate, and high altitude areas of differ-
ent countries. In addition, by pooling of opaque-2 materials, CIMMYT
has produced a number of opaque-2 composites for tropical and sub-
tropical areas (Composite K, CIMMYT opaque-2 Composite, Thai
Opaque-2 Composite); temperate areas (medium altitude and temperate
opaque-2 composite); and high altitude areas (Composite i). Also,
opaque-2 versions of short, agronomically desirable normal maize
populations are being obtained through a parallel breeding improve-
ment procedure, to be discussed later.

Various breeding approaches have achieved some success
in overcoming the barriers to the broader scale usages of opaque-2
maize.

10.3.1 OVERCOMING YIELD BARRIERS

Yield levels of opaque-2 materials have been raised by single
approaches, or by combinations, including:

- (1) Identifying superior genetic materials in which opaques
have comparable yield performance to their normal
counterparts (Table 10-1). It can be seen from the table
that there are some genetic materials in which opaque-2
segregants had 100 grain test weight very close to their
normal counterparts.
- (2) Intrapopulation selection schemes of full-sib and half-sib
family selection have raised the yield level of some

opaque-2 materials (Table 10-2). This table shows that there is considerable variation for yield in different families derived from different populations and that selection of superior families can lead to yield level increases of opaque-2 materials.

- (3) Changing soft endosperm texture of opaques to vitreous by capitalizing on genetic modifiers, followed by full-sib and half-sib family selection schemes of population improvement. Some of the hard endosperm opaque-2 materials are undergoing selection and the data from the last cycle of selection is shown in Table 10-3. Here again, the data suggest that there is variation in yield from family to family and that the yield levels of opaque-2 materials can be raised by identifying and recombining superior performing families in each cycle of selection.

10.3.2 IMPROVING PHENOTYPE OF OPAQUE-2 KERNELS FOR GREATER ACCEPTABILITY

Factors preventing general acceptance of opaque-2 maize stem directly or indirectly from the soft, floury endosperm of this type of maize. CIMMYT feels that changing the phenotypic characteristics of opaque-2 maize can resolve most of these problems speedily and effectively.

Recent findings have provided means of altering the soft floury endosperm texture of opaques to provide an appearance more like normal maize. Genetic manipulation of modifier genes produces vitreosity in opaque-type kernels, thus improving the appearance of opaque-2 kernels and leading to greater consumer acceptance.

Genetic manipulation of opaque-2 modifiers is complicated, because some modified opaque-2 kernels do not maintain protein quality as do completely opaque phenotype kernels. Thus, a back-up chemical laboratory is needed, together with efficient, reliable, and rapid screening techniques. Breeding efficiency can be increased with quicker analysis; thus, CIMMYT's protein laboratory is adequately equipped with facilities to provide the necessary service to meet present and future needs.

Opaque-2 materials with normal looking appearance and desired protein quality have been developed and are now available. They are being further improved for various agronomic characteristics, uniformity in vitreousness, and for stability of modified phenotype under different climatic conditions.

Biological evaluation of newly developed hard endosperm opaque-2 materials is necessary so that results of satisfactory chemical analysis are supported by superior biological performance. One of CIMMYT's hard endosperm opaque-2 materials (Ver. 181-Ant. Gpo. 2 x Ven. 1 opaco 2) that has been subjected to biological tests on rats, swine, and children shows results nearly comparable to completely soft opaque-type materials.

In tests on rats at Purdue University, using CIMMYT materials, normal and soft opaque-2 maize were compared with modified opaque-2 versions of Ver. 181-Ant. Gpo. 2 x Ven. 1 o₂. These tests indicated protein efficiency ratios of 1.59 for the normal, 2.83 for the soft opaque-2, and 2.93 for the modified opaque-2 versions. The soft opaque-2 maize did not differ significantly from the modified versions; however, both were significantly superior to the normal maize.

In tests conducted with children at the University of the Valley in Colombia, the hard endosperm opaque-2 version of Ver. 181-Ant. Gpo. 2 x Ven. 1 o₂ had a biological value (BV) ranging from 71.4 to 77.4. This compared with biological values for casein only of 75.3 to 84.3.

Experiments performed on rats and pigs at CIAT suggest that a hard endosperm opaque-2 version of Ver. 181-Ant. Gpo. 2 x Ven. 1 o₂ had a nutritive value very close to that of the soft opaque-2 type of maize.

10.3.3 BASIC INFORMATION ON MODIFIERS

Because CIMMYT strongly believes that genetic manipulation of modifiers will aid greatly in solving most of the problems associated with opaque-2 maize, basic information on modifiers has been accumulated that will accelerate the process of breeding for quality protein, hard endosperm opaque-2 materials. Some conclusions from CIMMYT's studies are:

- (1) Vitreousness in opaque-2 kernels is due to the action of modifying genes.
- (2) Vitreous kernels, in general, have a higher percent protein in endosperm. Percent tryptophane in protein declines somewhat; but exceptions to this occur in different genotypes (Table 10-4).
- (3) Hard and soft fractions of modified phenotype opaque-2 kernels differ in protein content and quality (Table 10-5). In some cases, however, negligible or no differences are observed.

- (4) Protein fractions of different materials vary in the way they are altered as a result of modifier selections (Table 10-6).
- (5) Selection for modifiers can help to increase vitreousness and kernel test weight (Table 10-7).
- (6) Germ size seems to be under the influence of modifiers and is affected differently in different genotypes (Table 10-8).
- (7) Modifiers are complexly inherited. Additive gene effects are more important than dominance in the expression of kernel vitreosity.
- (8) Reciprocal differences have been observed in crosses between opaques and modified materials, suggesting some degree of maternal influence in the expression of this character (Table 10-9).

10.4 BREEDING STRATEGY: 1974-1980

Although genetic improvement of protein content and quality in maize can only partially solve protein deficiency problems in the developing countries, many millions of malnourished families could be helped without radically changing their dietary habits. Research efforts during the next few years will be focused on the following breeding strategies to improve performance of opaque-2 maize materials.

10.4.1 DEVELOPING BETTER AGRONOMIC TYPES

Because of specific preferences for different maize types in different regions of the world, opaque-2 materials are needed that will meet the following objectives.

10.4.1.1 Soft, Big-seeded Quality Protein Materials

Development of opaque-2 versions of floury-1 materials will be of greatest benefit in the Andean region, where introduction of opaque-2 materials can make a strong and direct impact as soon as suitable materials become available. After opaque-2 versions are developed with big kernel type in floury-1 backgrounds, they can be directly introduced in this region with few problems (phenotypic characteristics of the kernels and yield recovery of these materials will be more like that of non-opaque-2 floury-1 materials).

Although a number of floury-1 populations are being converted to opaque-2 types, it is difficult to differentiate opaque-2 kernels from floury-1 types. The dosage effect of the floury-1 gene further complicates this conversion program. Genetic test-crossing, coupled with chemical screening, can speed the identification of opaque-2 kernels in a routine back-crossing program. Materials of this kind are now being developed.

10.4.1.2 High Yielding Soft Endosperm Type Opaque-2 Materials

Soft endosperm materials are useful either as animal feed or where the consumer prefers this kernel phenotype. Materials of this type are available and will be further improved for plant type; disease and insect resistance; for still higher levels of protein, tryptophane, and lysine.

10.4.1.3 Hard Endosperm Opaque-2 Populations

Development of hard endosperm opaque-2 populations with vitreous kernels will continue to be emphasized in the maize breeding program. Changing the phenotype of opaque-2 kernels will assist in the problems of higher yields, kernel acceptability, ear rotting, and other minor problems of varying importance. Information about the behavior of modifiers will contribute to the development and breeding of such populations.

Hard endosperm opaque-2 materials in the breeding program have been developed through the following approaches:

- (1) Recombination of hard endosperm opaque-2 lines and families into populations (yellow hard endosperm opaque-2 composite and white hard endosperm opaque-2 composite). After appropriate recombination, these materials will be handled by full-sib family selection.
- (2) Intrapopulation selection for hard endosperm in opaque-2 populations through full-sib family selection (Ver. 181-Ant. Gpo. 2 x Ven. 1 opaco 2; Composite K; and Thai opaque-2 Composite).
- (3) Screening hard endosperm opaque-2 segregates from crosses between normal and hard endosperm opaque-2 source.

In the materials handled by the first two approaches, much emphasis has been given to building up the frequency of favorable modifiers without altering or sacrificing protein quality. Since gene action controlling kernel vitreosity in modified kernels is additive, full-sib family selection was found to be effective. These materials are being improved for various agronomic characteristics, and for resistance to disease and insect complexes. Future work will involve improve-

ment of these materials through a systematic full-sib progeny test in different locations. These materials also will be used as source materials for converting normal maize varieties to vitreous opaque-2.

The third approach will be used more frequently in future work to obtain hard endosperm opaque-2 versions of normal materials in the Advanced and Back-up Units. Back-up materials, especially the pools that are being developed and handled in a half-sib family system, will be handled in the manner as shown in Fig. 10-1. The system, in essence, resembles closely the back-crossing program, except that the recurrent parent used in each back-cross is of superior performance, as compared to the original or the last cycle of selection. This system permits having an opaque-2 version with more or less parallel level of performance to the normal counterpart population.

Advanced Unit materials that have a family structure and are handled in a full-sib scheme are being converted to opaque-2, as shown in Fig. 10-4. Only selected families from the normal population based on multi-locational progeny testing will be used for crossing to opaque-2 donor every time. This system can be practiced with any given normal population undergoing population improvement through full-sib family selection.

With the above approach, it will be possible to obtain opaque-2 versions of all normal populations with less effort and with about the same level of improvement as the normal materials.

10.4.2 ADDITIONAL APPROACHES FOR THE DEVELOPMENT OF HARD ENDOSPERM OPAQUE-2 MATERIALS

Certain stocks of maize, with both opaque-2 and sugary-2 genes in a homozygous recessive condition, are characterized by a translucent endosperm of hard texture (Glover, 4). The kernel test weights reportedly compare favorably with normal stocks.

Though this data is preliminary, it does suggest that interaction of opaque-2 and sugary-2 genes in some genetic backgrounds might produce a translucent segregant of high kernel weight. Lysine content of this combination was as high or higher than opaque-2. Some work on these lines has begun.

10.4.3 INTERACTION OF MODIFIERS WITH ENVIRONMENT

Do hard endosperm opaque-2 materials interact with environment? The answer is yes. Results from CIMMYT's maize trials and reports received from other countries suggest that these hard endosperm opaque-2 materials tend to throw varying proportions of soft kernels. This effect is surely undesirable and suggests the need for bringing about stability for this character. The following approaches are being considered:

- (1) Systematic progeny testing in different locations and eventually recombining only those families that are relatively stable for this character into new populations.

- (2) Building up broad-based source populations for modifiers from as many diverse sources as possible, followed by systematic progeny testing.
- (3) Selecting translucent segregates from opaque-2 and sugary-2 combinations to test stability. If they prove more stable, this process may provide a new tool in developing vitreous opaque-2 materials with better stability.

10.4.4. FURTHER IMPROVEMENT IN PROTEIN, TRYPTOPHANE, AND LYSINE LEVELS

Excellent opportunities exist for further improvement in the protein, tryptophane, and lysine levels of opaque-2 materials. Considerable variation for these traits has been observed and can be exploited within certain limits because of negative correlation between protein content and quality. The following approaches will be used to enhance the levels of protein, lysine, and tryptophane in opaque-2 materials:

- (1) Exploiting variation within converted materials to upgrade the levels of protein and essential amino acids.
- (2) Increasing size of germ. Since germ has high protein content of superior quality, an increase in the size of germ will result in increased levels of protein, tryptophane, and lysine. This approach will be quite useful if whole grain is used for consumption.
- (3) Increasing the number of aleurone layer in seed. The seed aleurone is a protein-rich layer with good nutritional quality. This multiple aleurone character can be combined with opaque-2 to increase protein content. If encouraging reports are received from other institutions, some work on these lines will be initiated.
- (4) Opaque-2 and sugary-2 gene combinations in certain backgrounds have lysine values that exceed the value of opaque-2 alone, providing another approach to be used if such gene combinations are found to be superior.

10.4.5. INTERACTION OF PROTEIN CONTENT AND QUALITY WITH THE ENVIRONMENT

Environment influences quantity of protein, but there is little information as to its effect on the quality of protein in the maize grain. If further increases in the levels of both quantity and quality of protein in opaque-2 materials are to be realized, the interaction of these chemical traits with the environment should be taken into consideration. Genetic improvement in chemical composition obtained in this manner will survive interaction with the environment, thus providing nutritional and economic advantage to both the producer and consumer, no matter how the improved variety is produced or consumed.

CIMMYT is considering the following:

- (1) Seed samples of progenies from two or three locations in each of the populations will be analyzed for protein and tryptophane content.
- (2) Chemical data will be considered, together with yield and other attributes, to select families to be reconstituted into a new population to start the next cycle of selection.
- (3) The influence of genotype and of differential nitrogen nutrition on the total protein content and quality of grain will also be studied. Such studies can determine the genotype-fertilizer interaction to decide which particular variety or varieties are better at optimal or high levels of fertilization (so far as these chemical traits are concerned).

10.4.6 CONTAMINATION PROBLEMS AND THE NEED FOR MARKERS IN OPAQUES

The contamination problem and the need for markers to differentiate opaques from normals will vary greatly under different situations and may be considered from two different angles: (1) to maintain purity of seed, and (2) to determine how contamination might lower the quality of the product.

In regards to seed purity, the recessive nature of the opaque-2 gene and its associated phenotypic characteristics offer certain advantages only in areas where farmers generally grow hard flint type of normal maize varieties. In such regions, if farmers can be persuaded to grow opaque-2 maize, it is thought that they also can be taught to keep their varieties pure by planting only opaque kernels. Thus, in regions where farmers prefer soft opaque-2 kernels, maintaining the purity of seed will pose few problems. This should also be the case in regions where farmers may choose to plant modified phenotype opaque-2 materials due to their preference for hard flint, shiny maize. Here again, vitreous opaque-2 materials with a small opaque fraction in the kernel base will be more acceptable. An opaque fraction at the base of kernels assures the presence of the opaque-2 gene in homozygous condition, and at the same time, also acts as a marker for differentiating opaque-2 kernels from the contaminants.

In Andean regions where farmers may choose to grow opaque-2 versions of floury-1 materials, there is no way to detect contaminant

seeds because of similar phenotype associated with opaque-2 and floury-1 kernels. Here, if purity of seed is to be maintained, an intensive campaign should be made to introduce and expand the cultivation of opaque-2 materials over the entire village level. Under such circumstances, the farmers can save seed from their harvest to plant next season's crop.

The seriousness of the contamination problem in opaque-2 production plots for commercial use will vary greatly with the size of holdings, and with the proportion of farmers growing opaque-2 maize. If a farmer has a fairly big holding and plants the whole area with opaque-2 maize, the contamination will not be a serious factor, even if farmers in the neighboring areas grow normal maize. Although maize is a wind pollinated crop, the maize pollen is quite heavy; thus, contamination decreases very rapidly with distance from the source of contaminating pollen.

Contamination can be a consideration, however, when farmers have very small holdings and are growing opaque-2 and normal maize side by side. In this situation, the farmer growing opaque-2 maize would have varying amounts of contamination, depending upon wind direction at the time of flowering. Under these situations, all farmers in a given area might be persuaded to grow opaque-2 or to use time differentials in seeding.

10.5 SOME SUMMARY RECOMMENDATIONS

In previous discussions we have cited some of the more obvious problems which have hindered the commercial production of high quality protein maize varieties and hybrids, including: low grain yield, non-acceptability of soft floury kernel phenotype, storage problems, marketing problems, and unsuitability for milling and making certain preparations. These problems have been largely overcome, and there is every reason to believe that the commercial production of new hard endosperm high quality protein maize varieties will be speeded up considerably within the next few years.

If acceptable varieties of high quality protein maize become generally available, strategies will be needed to introduce and expand production of high quality protein maize in the developing countries.

In these countries, increased plantings of high quality protein maize will replace normal maize varieties or hybrids. This can be achieved only if there is a considerable stimulus and support from the national governments. Undoubtedly, this will not happen until and unless the national governments become aware of the widespread malnutrition problems on an urgent and priority basis. In other words, a

high order of priority must be given to food and nutrition as part of planned development in national agricultural policies. The protein advisory group of the United Nations system has made a significant contribution in alerting national governments to the protein problem and in suggesting measures to avert a protein crisis. It is vitally important that governments should initiate and implement special programs to expand the production of high quality protein maize. After the governments are committed, the success of the program will depend upon the following factors:

- (1) A suitable variety or varieties of high quality protein maize that can compete with normal maize varieties in yield, kernel acceptability, and in cooking characteristics; in a free market situation and without any price differential.
- (2) Massive demonstration trials in the farmer's field to evaluate the performance of high quality protein varieties in comparison with normal varieties or hybrids that are being grown locally.
- (3) Making the seed available to the farmers, with sufficient promotional campaign to obtain a rapid replacement of normal maize varieties. (All production and sale of seed of normal varieties or hybrids might be barred to speed the adoption of high quality protein maize.)
- (4) Intensive educational campaigns to promote the production of high quality protein maize among small farmers for home consumption. (Promotion of high quality protein maize using quality protein as the argument will probably not be successful unless preceded by an educational campaign through which consumers learn the importance of protein in the diet.)
- (5) Demonstration of the nutritional quality of high quality protein maize, using farm animals such as pigs fed normal versus high quality protein maize. Where farm animals cannot be used in promotional campaigns, the superior protein quality of opaque-2 maize should be promoted by equating it with other quality nutrition products such as meat and milk, etc.
- (6) Demonstration of cooking characteristics of high quality protein and ordinary maize, comparing and contrasting with local products using maize. Small samples of 1 kg

or more might be given to a number of families to find the acceptability of this type of maize for cooking different kinds of dishes. In certain preparations where high quality protein maize cannot be used successfully, necessary changes in cooking methods be tried and suggested to obtain satisfactory results.

- (7) Promotion among producers, consumers, and the marketing agencies. Governments must play a major role in this by providing mass media such as radio and television. Such campaigns may also be carried out by public agencies and private firms.
- (8) Initiation of school lunch programs for children, using high quality protein products.

Governments should also support private food industry in producing low-cost, processed baby foods and other products to help eliminate malnutrition problems among especially vulnerable younger children.

Mixtures of maize and grain legumes should be further developed to provide maximum efficiency of protein quality. Some current research suggests that maize gives highest protein quality when combined in a 50/50 protein ratio with beans and in a 60/40 protein ratio with soybeans (Bressani, 2).

It is hoped that suitable high quality protein varieties that are being developed will go a long way in alleviating serious malnutrition problems of maize-eating people in many developing countries of the world.

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Table 10-1. 100 grain weight comparison of normal and opaque-2 kernels

Pedigree	100 grain weight in gms.		Difference	Percent decrease in weight
	Normal	Opaques		
J ₁	23.0	21.0	2.0	8.70
Syn. 493	25.5	23.5	2.0	7.84
Sn. Luis Potosí Gpo. 1	31.0	29.0	2.0	6.50
Tamaulipas Gpo. 1	26.5	24.5	2.0	7.50
Cuba 11J	26.0	23.5	2.5	9.60
Columbia Cateto Compuesto	27.0	25.0	2.0	7.41
Perola Piracicaba	26.0	24.0	2.0	7.70
Comp. II (C ₃)	26.0	24.0	2.0	8.30
Comp. III (C ₃)	27.0	26.0	1.0	3.70 *
Comp. (IV)	29.0	28.0	1.0	3.40 *
Mex. 5	25.0	23.0	2.0	8.00
Samaru Comp. III	25.0	24.0	1.0	4.00 *
Comp. Grano duro	26.0	26.0	0.0	0.00 *
Mix. 1-Col. Gpo. 1 x Eto Blanco	24.0	22.0	2.0	8.33
Tuxp. PD(MS) ₆ -Sel. Amar.	27.0	25.0	2.0	7.41

TABLE 10-2. Summary of grain yield data in kg/ha at 15% moisture of full-sib families of different opaque-2 populations during the year 1973.

Population / Location	No. of families		Tested families		Selected families		C H E C K			V A R I E T I E S				C.V. %	L.S.D. (.05)
	Tested	Selected	Range	Mean	Mean	Selection Differential %	Comp. K H.E.	Ver. 181-Ant. Gpo. 2xVen. 10 ₂	Yellow H.E. 0 ₂	White H.E. 0 ₂	La Posta x Tuxpeño 0 ₂	Tuxpeño-1			
Tuxpeño x La Posta 0₂															
Poza Rica	250	85	2360-6401	4258	4685	10.0	3277(143)*	3084(119)	3865(121)	3464(135)	4189(112)	4083(94)	14.8	1232.6	
Tlaltizapan	250	85	1632-8860	5246	6152	17.3	6539(94)	6174(100)	6188(99)	5523(111)	5574(110)	6423(96)	23.1	2386.8	
Combined	250	85	---	4752	5418	14.0	4908(110)	5061(107)	5026(108)	4493(121)	4881(111)	5703(95)	--	---	
Cimmyt opaque-2 Composite															
Poza Rica	250	76	1960-5220	3710	4140	11.6	4300(96)*	4223(98)	3212(125)	3577(116)	3945(105)	4271(97)	14.9	1086.7	
Tlaltizapan	250	76	1001-8544	5409	6187	14.4	5748(108)	5176(120)	6286(98)	4584(135)	3737(166)	5725(108)	18.3	1941.7	
Combined	250	76	---	4559	5163	13.2	5024(103)	4699(110)	4799(108)	4080(127)	3841(134)	4998(103)	--	---	
Composite K															
Poza Rica	250	78	2802-5523	3904	4624	9.2	4058(105)*	4128(103)	3954(108)	4142(103)	3887(110)	4523(94)	13.2	1014.2	
Tlaltizapan	250	78	1984-6517	4400	5128	16.5	5093(101)	3663(140)	4214(122)	3687(139)	4377(117)	3550(144)	22.2	1909.7	
Combined	250	78	---	4152	4696	13.1	4575(103)	3895(121)	4084(115)	3914(120)	4132(114)	4041(116)	--	---	

* Selected family mean as % of check in the respective locations.

TABLE 10-3. Summary of grain yield data in kg/ha at 15% moisture of full-sib families of different hard endosperm opaque-2 populations during the year 1973.

Population/Location	No. of families		Tested families		Selected families		C H E C K			V A R I E T I E S					
	Tested	Selected	Range	Mean	Mean	Selection Differential %	Comp. K H. E.	Ver. 181 Gpo. 2xVen. 102	Ant. H. E. o ₂	Yellow H. E. o ₂	White H. E. o ₂	La Posta Tuxp. o ₂	Tuxp. P. B. Normal	C. V. %	L. S. D. .05
Ver. 181-Ant. Gpo. 2xVen. 1 o₂															
Poza Rica	250	79	1983-5106	3461	3918	13.2	3355(117)*	3874(101)	2952(133)	3192(123)	3953(99)	4750(83)	12.8	435.9	
Tlaltizapan	250	79	3025-11356	6471	7316	13.1	8017(92)	6975(105)	7690(95)	7704(95)	6748(108)	8266(89)	14.8	1887.3	
Combined	---	--	---	4866	5617	13.11	5686(99)	5424(104)	5321(106)	5448(103)	5353(105)	6508(86)	--	1161.6	
Composite K (H. E. o₂)															
Poza Rica	250	90	1562-4965	3401	3774	11.0	3256(116)	3278(115)	3900(97)	3598(105)	4028(94)	6229(61)	20.6	688.7	
Tlaltizapan	250	90	1963-9715	5715	6524	14.2	5641(116)	4436(147)	6639(98)	5181(126)	5339(122)	7200(91)	16.7	1871.1	
Combined	250	90	---	4558	5149	13.0	4448(116)	3861(133)	5269(98)	4398(117)	4683(110)	6714(77)	--	1279.7	
White H. E. o₂															
Poza Rica	250	79	1851-4748	3477	3867	11.2	4021(96)	3200(121)	3329(116)	3482(111)	3453(112)	4864(80)	19.8	1352.4	
Tlaltizapan	250	79	2436-10503	6534	7346	12.4	6223(118)	6070(121)	7159(103)	8043(91)	6434(114)	8417(87)	13.9	1730.2	
Combined	250	79	---	5005	5606	12.0	5122(109)	4635(121)	5244(107)	5762(97)	4943(113)	6543(84)	--	1566.3	
Yellow H. E. o₂															
Poza Rica	250	120	1891-5409	3702	3973	7.3	3345(119)	2942(135)	4398(90)	4260(93)	3194(124)	4240(94)	15.7	1136.6	
Tlaltizapan	250	120	2681-9266	6138	6510	6.1	5941(110)	6610(99)	7224(90)	5471(119)	5967(109)	6692(97)	14.4	1736.3	
Combined	250	120	---	4290	5241	6.5	4643(113)	4776(110)	5811(90)	4865(108)	4580(114)	5466(96)	--	--	

* Selected family mean as % of check in the respective locations.

Table 10-4. COMPARISON OF % PROTEIN AND % TRYPTOPHANE IN PROTEIN OF COMPLETELY OPAQUE AND MODIFIED PHENOTYPE OPAQUE-2 KERNELS SELECTED FROM DIFFERENT HALF SIB FAMILIES OF TROPICAL OPAQUE-2 COMPOSITE

Family No.	% Protein in Endosperm			% Tryptophane in Protein		
	Opaque	Modified	Difference (%)	Opaque	Modified	Difference (%)
Half sib-63	9.88	9.75	+ 1.33	0.89	0.86	3.49
67	9.13	8.94	+ 2.13	0.82	0.80	2.50
69	9.00	9.75	- 8.33	0.84	0.66	27.27
79	9.19	10.63	-15.67	0.89	0.66	34.85
125	7.63	10.19	-33.55	1.05	0.74	41.89
144	7.00	7.56	- 8.00	0.96	0.99	- 3.12
147	8.25	9.00	- 9.09	1.09	0.91	19.78
151	7.75	8.13	- 4.90	0.90	0.87	3.45
159	6.44	7.25	-12.58	0.98	0.87	12.64
162	9.19	9.75	- 6.09	0.97	0.82	18.29
164	8.88	9.38	- 5.63	0.72	0.69	4.35
175	8.38	8.25	+ 1.58	0.80	0.79	1.26
196	8.50	9.25	- 8.82	1.01	0.90	12.22
250	9.13	12.88	-41.07	0.72	0.53	35.84
278	8.50	8.31	+ 2.28	0.88	0.84	4.76
279	8.38	11.38	-35.80	0.93	0.73	27.40
292	11.25	11.50	- 2.22	0.63	0.60	5.00
297	9.13	9.38	- 2.74	0.78	0.70	11.43
118	10.38	11.13	- 7.22	0.84	0.74	13.51
101	9.75	10.50	- 7.69	1.07	0.78	37.18

TABLE 10-5 PROTEIN LYSINE AND TRYPTOPHANE CONTENT IN WHOLE ENDOSPERM AND IN HARD AND SOFT FRACTIONS OF THE ENDOSPERM SEPARATELY - MODIFIED PHENOTYPE

OPAQUE - 2 LINES

.N.	L i n e	% P R O T E I N			% T R Y P T O P H A N E I N P R O T E I N			% L Y S I N E I N P R O T E I N					
		Whole Endosp.	Fraction Hard	Differ- Opacue ence (%)	Whole Endosp.	Fraction Opacue Hard.	Differ- ence (%)	Whole Endosp.	Fraction Opacue Hard.	Differ- ence (%)			
1	PD(MS)6Eto-Cuba 11J - Pob. Cirst. #1(A)-1-#-#	9.88	9.99	7.69	29.90	0.70	0.83	0.63	31.75	2.67	2.88	2.22	29.73
2	PD(MS)6-Eto-Cuba 11J - Pob. Crist. #1-#1-#-#	8.75	8.49	9.13	7.54	0.87	0.87	0.77	12.98	2.81	3.30	2.60	26.92
3	Pob. Crist. -#1-#-#-#	9.42	10.21	8.43	21.11	0.73	0.72	0.55	30.91	2.73	3.36	2.43	38.27
4	(Tropical opaque-2 Comp. 163-6-1-#1) x PD(MS)6-# -#-#-#	10.92	11.57	11.25	2.84	0.76	0.85	0.63	34.92	2.87	3.65	2.98	22.48

**TABLE 10-6. % PROTEIN FRACTIONS IN NORMAL, OPAQUE, AND MODIFIED PHENOTYPE OPAQUE-2
SAMPLES OF TWO POPULATIONS**

P o p u l a t i o n	T y p e o f S a m p l e	% Protein fractions in endosperm					
		A c i d S o l u b l e		Z e i n		G l u t e l i n s	
		A c t u a l	% o f n o r m a l	A c t u a l	% o f n o r m a l	A c t u a l	% o f n o r m a l
1. Ver. 181-Ant.gpo. 2 x Venezuela 1	Normal	27.0	100.0	42.3	100.0	19.8	100.0
	Opaque	39.7	147.0	24.2	57.2	31.3	158.1
	Modif.	35.0	129.6	26.3	62.2	29.3	148.0
2. White Composite	Normal	32.5	100.0	45.2	100.0	19.0	100.0
	Opaque	35.0	107.7	25.4	56.2	31.4	165.3
	Modif.	33.5	103.1	26.7	59.1	28.5	150.0

Table 10-7.

100 GRAIN TEST WEIGHT OF OPAQUE AND MODIFIED PHENOTYPE OPAQUE-2 KERNELS SELECTED FROM
DIFFERENT OPAQUE-2 CONVERTED MATERIALS

S.No.	Material	family or Ear #	100		
			Grain test weight in Gms.	Modified Opaque	% Increase
1	PD(MS)6-Eto-Cuball J-Pob. Cirst.	3	23.10	22.73	1.62
2	"	4	30.30	30.00	1.00
3	164-3 Cat. 1(ii)-2-1	2	29.00	27.83	4.20
4	La Pcsta-#6-#1	1	20.00	18.92	5.70
5	Flint Comp. Amarillo-#6	1	28.11	25.42	10.58
6	Nicarillo-#-#	1	28.70	26.49	8.34
7	Composite K	514	25.71	25.45	1.02
8	"	515	28.46	27.08	5.09
9	"	517	23.04	22.07	4.39
10	"	518	27.30	26.59	2.67
11	CIMMYT O ₂ Composite	-	28.89	28.68	0.73

TABLE 10-8. EFFECT OF SELECTION FOR HARD ENDOSPERM ON THE CONTRIBUTION OF GERM TO THE WHOLE KERNEL PROTEIN IN OPAQUE-2 CONVERTED MATERIALS

S. No.	M a t e r i a l	Ear No. or Family No.	% Contribution of germ to the whole grain protein		
			O p a q u e	Modified	Difference
1	Composite K	118	22.01	17.92	+ 4.09
2	Composite K	4	20.55	14.41	+ 6.14
3	Ver. 181-Ant. gpo. 2 x Venezuela 1 opaco-2	8	33.37	26.13	+ 7.24
4	PD(MS)6-Gr. Amar. -2#-1.	1	22.00	14.67	+ 7.33
5	Thai Opaque-2 Composite-#16	1	17.56	13.38	+ 4.18
6	Nicarillo	Self I	24.75	18.01	+ 6.74
7	Flint Compuesto Amarillo	1	28.08	24.38	+ 3.70
8	Eto Blanco	1	24.17	18.37	+ 5.80
9	Composite K	1	13.59	15.07	- 1.48
10	Composite K	101	28.21	32.10	- 3.89
11	Ver. 181-Ant. gpo. 2 x Venezuela 1 opaco-2	3	11.87	18.73	- 6.86
12	Nicarillo	1	25.99	33.55	- 7.56
13	Antigua gpo. 2	2	24.31	25.78	- 1.47
14	Ver. 181-Ant. gpo. 2 x Venezuela 1 opaco-2	4	15.54	17.85	- 2.31
15	Thai Opaque-2 Composite	4	17.07	18.03	- 0.96
16	Thai Opaque-2 Composite	2	16.41	17.31	- 0.90

TABLE 10-9. FREQUENCY OF EARS WITH DIFFERENT PHENOTYPES IN
 RECIPROCAL CROSSES BETWEEN OPAQUE AND MODIFIED
 PHENOTYPE OPAQUE-2 MATERIALS

S. No.	Material	% Frequency of ears with different phenotypes		
		Opaque	Segregating	Modified
1	P ₁ x P ₂	56	40	1
	P ₂ x P ₁	-	70	30
2	P ₁ x P ₃	94.4	5.6	-
	P ₃ x P ₁	-	63.2	36.8
3	P ₁ x P ₄	8.3	58.3	33.3
	P ₄ x P ₁	-	11.8	88.2
4	P ₁ x P ₅	9.1	63.6	27.3
	P ₅ x P ₁	-	21.4	78.6
5	P ₆ x P ₂	75.0	16.7	8.3
	P ₂ x P ₆	-	75.0	25.0
6	P ₆ x P ₃	69.4	30.6	-
	P ₃ x P ₆	38.5	46.2	15.4
7	P ₆ x P ₄	42.1	57.89	-
	P ₄ x P ₆	10.0	55.0	35.0
8	P ₆ x P ₅	78.6	21.4	-
	P ₅ x P ₆	9.1	63.6	27.3

P₁ - Ver. 181-Ant. gpo. 2 x Venezuela 1 opaco-2 (opaque phenotype)
 P₂ - Ver. 181-Ant. gpo. 2 x Venezuela 1 opaco-2 (Modified phenotype)
 P₃ - Thai Opaque-2 (Modified phenotype)
 P₄ - Composite K (Modified phenotype)
 P₅ - PD(MS)6 - Gr. Amar. - #6-# (Modified phenotype)
 P₆ - Thai Opaque-2 (opaque phenotype)

Fig. 10-1 Scheme for Making Parallel Improvement in Opaque-2 and "Normal" Backup Pool Undergoing Half Sib Family Selection.

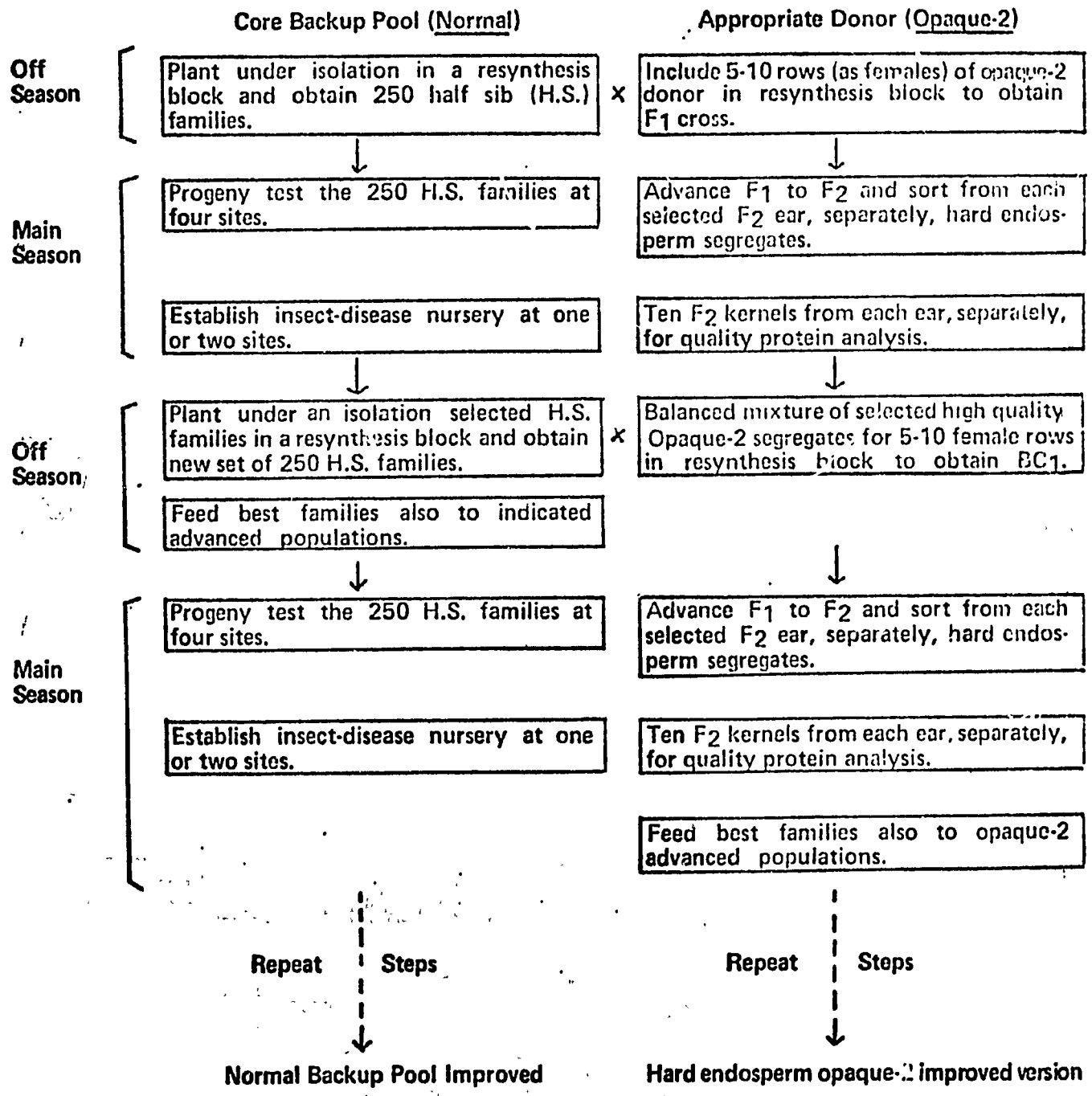
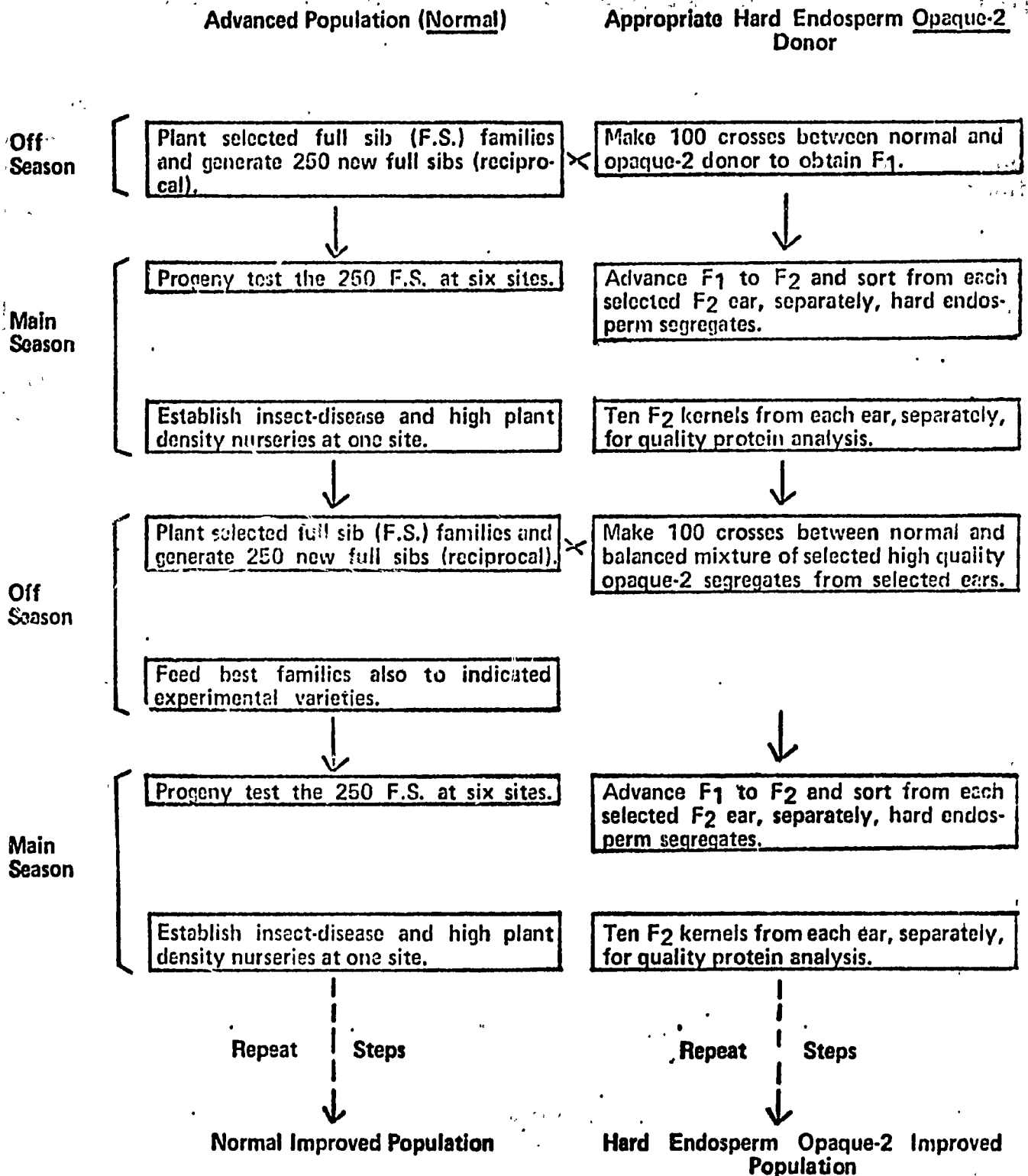
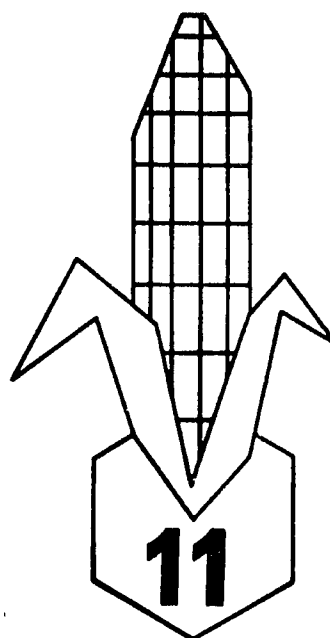


Fig.10-2 Scheme for Making Parallel Improvement in Opaque-2 and "Normal" Advanced Population Undergoing Full Sib Family Section.





TRAINING

by
Alejandro Violić, CIMMYT

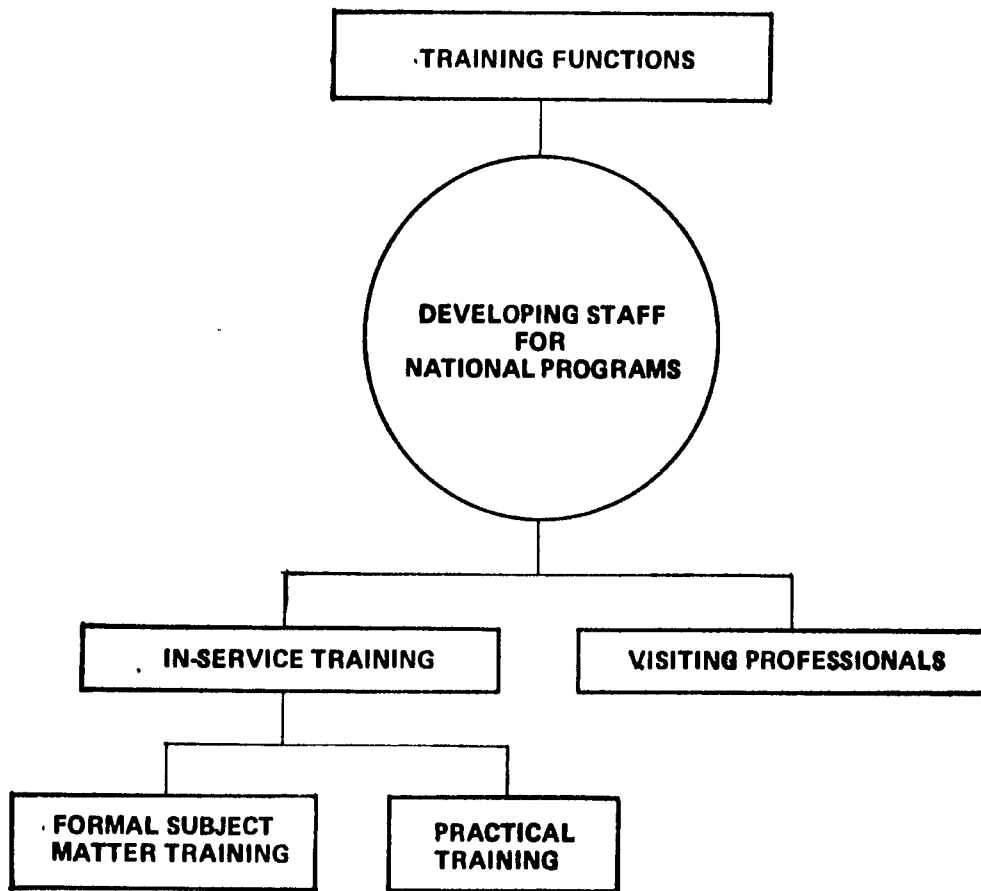
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11.0

**CIMMYT MAIZE IMPROVEMENT ROLE
WORLD-WIDE CONTEXT**



FARM PRODUCTION

11.0

CIMMYT'S MAIZE PROGRAM TRAINING

by
Alejandro D. Viočić

11.1 INTRODUCTION

CIMMYT's training activities provide an orientation and specialization for agricultural scientists and technicians with a professional interest in maize research or extension. A basic aim is to provide the necessary technology for boosting maize production in their home countries. In most developing countries, research and production programs have severe limitations, including (1) few qualified research and production workers and (2) a lack of modern organization structures for generating technology and extending it rapidly to the farm production level.

The program is designed to expand the experiences and activities of the trainees within the framework of Production, Breeding, Plant Protection, and Protein Evaluation; the four fields of specialization offered. Within this training concept, specialized and technical personnel can achieve an ample and profound knowledge of their specialty, while learning enough about other specialties to confront and solve many problems that would normally be outside the realm of their specialized knowledge.

11.2 TRAINING CATEGORIES

Since 1966, training of scientists in several educational categories has included: In-service Trainees, Master of Science Degree Candidates, Doctoral Candidates, Post-Doctoral Fellows, Visiting Senior Scientists, and Short-term Visitors. Several national and international agencies grant scholarships for this training, and CIMMYT also offers a limited number. (Fig. 11-1 is a flow chart of the interrelations among training activities.) The training categories are defined as follows:

In-service Trainees: Young researchers and extension personnel, mainly from national programs of developing countries, who spend six to eight months of direct participation in the program. Their goals are development of practical skill and knowledge in maize breeding, production, protection, and protein evaluation. Emphasis is on team work, research enthusiasm, technical knowledge, and an understanding of agricultural development. Trainees are expected to work as trainers when they return to their programs.

Master's Degree Candidates: Fellowships are granted to professional individuals, mainly from national programs closely associated with the outreach activities. These trainees have normally completed a period of practical training with CIMMYT. Support is provided for further academic training if it is felt that such study will better equip the candidate to serve national accelerated production programs of his own country.

Doctoral Candidates: Post-graduate Students who have completed their course work and passed their preliminary examinations for the Ph.D. degree are accepted to conduct their thesis research under joint university and CIMMYT supervision. They are selected on the basis of their outstanding scientific promise for aiding national programs or for participation in international activities.

Post-Doctoral Fellowships: Selected scientists who have recently completed their Ph.D. degree come to our program for one or two years to carry out applied research in collaboration with scientists from this Center. Most of them are engaged in national programs from Asia, Africa, or Latin America; however, a few are from advanced countries, preparing for careers in international work.

Visiting Senior Scientists: These scientists participate in joint research in the program, generally for 4 to 12 months; sometimes as a sabbatical for the individual. Those from developing countries aid us in keeping its research oriented toward the needs of Asia, Africa, and Latin America. Scientists visiting from developed countries are generally employed by universities that hold joint research contracts with CIMMYT, and their visit is expected to contribute to the program goals.

Short-term Visitors: New outreach staff, recent graduates, or policy-making officials from developing countries come for periods of one week to three months to observe our research and production methods. New outreach staff may spend one full cropping season at CIMMYT for briefing.

Of these categories, In-service Training involves more trainees, staff, and budget. It was initiated as a program category in July 1971, and in previous years (1966 to 1970), there was a total of only 27 In-service Trainees. However, in the last three years, a total of 124 trainees entered the program: 25 in 1971, 43 in 1972, and 56 in 1973 (Table 11-1).

Of the 151 individuals who have entered training in the Maize Program since 1966, 82 are citizens of Latin American countries, 27 are from Asia, and 42 are from Africa. Table 11-1 shows the 39 countries involved and the trainees per country per year. The donors supporting this training from 1969 to 1973 are shown in Table 11-2.

CIMMYT's capacity for In-service Training is probably about 50 trainees per year; in two groups of not more than 25 each, for seven-month training periods. The dates for the Breeding, Production, and Plant Protection phases are May 15 to November 30 and November 15 to May 30 each year. There is an overlap of two weeks at the beginning and at the end of the training period for each group. Trainees in Protein Evaluation start their training in accord with the physical capacity of the laboratories, and the training period depends upon each individual's background and capabilities.

Some innovations have been introduced to the Program in order to make it more efficient and, at the same time, more attractive for the trainees. Upon their arrival, the trainees spend a full three-day period in an Orientation Period. Staff members explain the overall CIMMYT approach and philosophy for the four areas of specialized training, and for operation and management of experiment stations. The trainees then become involved in the planting of different experiments at our Experiment Stations and with the farmers in their fields. For this purpose, trainees interested in Breeding are assigned in groups of two or three to each member of the Breeding Staff. Similarly, those interested in Plant Protection are assigned to work with Pathologists and Entomologists.

The largest trainee group is Maize Production. These trainees also are assigned responsibilities at the experiment stations and in the field. Some of the results of these experiments are shown in the Production Agronomy Section of this report.

After the initial experiments are planted, the trainees' activities are concentrated for three weeks at El Batán. Staff members provide a program of Academic Training consisting of 24 hours of lectures in Statistics and Experimental Design and eight hours each in Maize Pathology, Maize Entomology, Genetics and Breeding, and Maize Production. This basic training is complemented later with

seminars and special topics presented by trainees and staff (including Agricultural Economics and Communications topics).

Before completion of his training period in Mexico, each trainee is asked to write in detail what he expects to do upon returning to his country to help solve the most important problems facing maize production in the area where he works. Maize staff helps each trainee with ideas in developing the best approach to this task.

The above training emphasizes the need to redefine research objectives, and perhaps more importantly, the need to redefine the relationship between research and extension. A central idea is to develop an approach that will take new practices and varieties to the farmer as quickly and efficiently as possible. The trainees learn that the researcher's responsibility begins with the generation of new technology and follows through with demonstrations of how this technology can be used by the farmers. Thus, the researcher's work includes farm tests in large plots to establish the reliability of recommendations from research. If a variety, or recommended practice, is to be released, it should be approved by the user: the farmer.

11.3 TRAINEES AND TRAINING PLANS

CIMMYT's training assumes that there is a strong need for developing human resources at the national program level; that lack of qualified people is a major limitation on maize production of developing countries. Thus, a logical question becomes: How many well-trained people are needed at the national level? This question is made more difficult by several factors. In one African country, for example, with about 700,000 ha. of cultivated maize and few differences in environment throughout the country, has about 60 breeders. Other countries have no breeders, although technology in maize production is at its lowest level--or perhaps only one breeder, as in the case of another African country which plants about 500,000 ha. of maize.

This question has been discussed with staff members, visiting scientists, and trainees from different countries and has arrived at the following estimates (see Table 11-4): (1) Countries cultivating more than 30,000 and less than 100,000 ha. will need a team of 11 trained technicians, including Breeders, Entomologists, Pathologists, Research Production Agronomists, Maize Extension Agronomists, and Protein Evaluation Specialist. (2) Countries cultivating more than 100,000 and less than 500,000 ha. will need 26 trained personnel. (3) Countries with more than 500,000 and less than 1,000,000 ha. need 55 such people. (4) And, for each additional increase of

1,000,000 ha., 20 additional Maize Extension Agronomists would be needed. This latter group of Extension Agronomists would work directly at the farmer level along with the general extension agents of the country to determine the most suitable treatments (varieties, fertilizers, insecticides, etc.), using field days and other media for demonstration purposes.

Table 11-5 was prepared on the basis of maize acreages and a minimum of skilled personnel. It was assumed that 20 countries from America, 17 from Asia, 34 from Africa, and probably one European country would have a total need for 2,235 specialists. Countries with less than 30,000 ha. of maize were omitted due to small acreages, but they also deserve training aid. How many such specialists exist at present? How many need training? Only a very extensive survey could provide an adequate answer.

If the overall totals from Table 11-5 are grouped according to specialty, it is seen that the most needed trained maize specialists are: Extension Maize Agronomists (59.82%), followed by Breeders (15.70%), Research Production Agronomists (9.53%), Plant Pathologists and Entomologists (5.86% each), and finally, Protein Evaluation Specialists (3.22%).

Thus, given a training capacity of 50 trainees per year, and considering that the figure of 2,235 specialists needed is very conservative, maize training would become an endless task. Obviously, more effort is needed, particularly at the national level.

11.3.1 FUTURE APPROACHES

Perhaps one solution might be to train "trainers" among the most promising and outstanding trainees who come to our program. As soon as these superior individuals are recognized, they should be given special training emphasis to accomplish the tasks listed above. These "trainers" could perform well in their national programs, especially if supported periodically by visits from our staff.

Some well-qualified professionals have recently been selected for this purpose and will work along with the Training Officer as a Training Assistant. They observe the procedures used in Maize Training, selecting and adapting for use in their National Training Programs upon return to their home countries.

Before the end of the 1970's, Maize Production Training will probably be devoted exclusively to training "trainers." Regular training will then be continued only for Breeders, Entomologists, Pathologists,

and Protein Evaluation Specialists. In many cases, this training will be done in association with universities.

In the long run, National Production Training promises to be more effective and less expensive. The effectiveness should come from the fact that the production specialists will be trained under the same environment in which they will use their knowledge and skill. The reduced cost would stem from a somewhat different system in training: the trainees would meet periodically at a training headquarters (i. e., experiment station) in their own country during the maize growing cycle, but would spend the rest of their time performing their production activities in their own localities.

As an example, at the beginning of a training period, trainees might be gathered at a training headquarters for three or four weeks of academic activities and discussion of different systems and approaches that could be used to increase productivity. Design and conduct of in-station experiments and off-station demonstration plots could be analyzed thoroughly, since information obtained from such activities would be the basis for forming production packages. CIMMYT staff could assist local trainers during this period.

After establishing in-station and off-station plots as part of the training activities, trainees would return to their posts and do the same experiments in their own regions. All trainees could meet at the training headquarters every two to three weeks for two or three days to observe progress of the experiments and demonstration plots. Maintenance and observation of various treatments would be done under the supervision of the trainer.

At the proper stage of maize development, field days would be organized to show the trainees how to use the off-station plots to reach local farmers.

Results obtained from the training experiments and demonstration plots, plus those derived from experiments conducted by trainees in their own areas, would be analyzed, interpreted, and used to show how to design production packages for different areas of the country. Our staff would participate in these training courses through well-coordinated visits to the countries involved in National Training Programs, and would assist in work with local farmers.

Another approach might be for CIMMYT to expand its present capacity in Mexico. However, 25 trainees in two periods a year seems to represent a near-optimal condition, at present. Significant expansion of this number would entail less personal attention to the trainee's specific problems and desires; fewer opportunities for them

to carry out personal projects; a substantial increase in equipment, housing facilities, staff, transportation, etc. Perhaps most importantly, the trainees might find less professional pride and sense of accomplishment in a larger scale operation.

It seems unlikely that university education alone can replace the practical and applied aspects of training. Thus, we must provide the minimum academic training needed by the individuals, if academic work is necessary to complete a solid preparation. It seems likely that college graduates should be trained only after having spent one or two years detecting and analyzing the restrictions on maize production in their own countries.

11.3.1.1 Some Priorities

Present priorities in training are: In-service Trainees first, followed by Post-Doctorals, Visiting Senior Scientists, Master's Degree Candidates, and finally, Pre-Doctoral Fellows. Short-term Visitors are considered on the basis of specific need.

We emphasize teamwork; thus, it seems more efficient to train groups of three or four persons from a given national program, rather than single individuals from several different countries. The advantages of the team approach can be stressed by practical application of this principle in training.

Training plans are to be based on projected needs of the developing countries, rather than on an arbitrary yearly basis. Present projections assume that the major limiting factors in production faced today are not likely to differ in these countries over the next six years. Thus, training stress will be upon topics such as grain quality, insect and disease resistance, and agronomic practices that lead to higher yields.

Population pressures on food resources will probably call for additional accelerated grain production programs in developing countries. And it can be anticipated that additional land, although marginal in some countries, will have to be used in order to increase overall production; thus, training plans should consider production practices under such adverse conditions.

Similarly, off-station research at CIMMYT should be stressed in order to face trainees with the raw realities of farm-level production. Each country has its own environment and presents different conditions; these facts cannot be overemphasized. The farmer, and his production conditions, must remain the primary target for all research and production packages.

11.3.2 SELECTION OF TRAINEES

In selecting trainees, special attention is given to countries where production can be greatly improved by aggressive and reliable systems of breeding and use of adequate production practices. Priority in selection and training is given to tropical and semitropical countries where maize is considered a vital staple food and thus central to the nation's interests.

Priorities for training should be given to countries in which there is a clear necessity to fill slots in the different areas of maize breeding and production, and also to countries in which maize production is not increasing fast enough due to lack of maize professional teams.

Criteria for participants are that they be professional persons from 24 to 35 years of age for In-service Training, and perhaps ranging higher for the other categories. They should (1) be well motivated, enthusiastic, and play a useful role in their home countries' maize production program; (2) demonstrate a thirst for more knowledge, leadership capabilities, and a willingness for teamwork, maturity, good physical and mental health; and (3) be fluent in the English or Spanish language.

English and Spanish are the working languages and trainees are taught in either language, using simultaneous-translation equipment when necessary. Recently, large numbers of French-speaking trainees have arrived from African countries; however, experience has shown that it takes only two months, without any special language aid, for French-speaking trainees to obtain a good working knowledge of Spanish. Officials from French-speaking countries also have indicated the necessity for their trainees to learn English. Undoubtedly, an English language laboratory for these trainees would help a great deal.

Trainees arriving from different countries show varying academic backgrounds a factor which is clearly identified when they submit a general written examination upon arriving. This examination is given (1) to determine the general level of the group and the particular background of each trainee, and (2) to evaluate the progress during and at the end of the training course.

Before arrival, the trainees are exposed to the detailed contents of the maize training program, which includes both practical and theoretical subjects. It is expected that all trainees should arrive on the appropriate beginning dates; however, consideration is given to the needs of national programs. Some countries, for example, cannot

afford to permit the absence of maize staff for more than one full growing season. Thus, some trainees have been allowed to arrive weeks or months after the initiation of the courses. This type of flexibility should be maintained in order to perform a better service to the different countries.

CIMMYT's training allows some flexibility for special programs such as Plant Pathology, Experiment Station Operation, Breeding for Quality, Maintenance of Germplasm Banks, etc. This variation from the normal program causes few problems.

11.3.3 OTHER TRAINING CATEGORIES

A total of 83 M.S. Candidates, Ph.D. Candidates, Post-Doctoral Fellows, Visiting Senior Scientists, and Short-term Visitors participated in the maize program during 1973. This total includes 21 degree candidates, 8 Post-Doctoral Fellows, 14 Visiting Scientists, and 40 Short-term Visitors.

Table 11-7 shows the number of individuals and countries involved in each category.

Deserving trainees should be given opportunities to obtain advanced academic degrees, and there are many institutions that are able to cover the costs involved. Nevertheless, the selection of candidates for advanced degrees from developing countries merits careful consideration. During CIMMYT's External Program Review Panel in 1972, serious doubts were expressed about the utility of Ph.D. training for research staff in developing countries--until such time as unusually well-motivated and scientifically talented young scientists are identified. Ph.D. training for scientists who are poorly motivated and lacking in vision can only contribute to mediocrity. According to Review Panel members, some of these less-qualified people have been trained in the past, then appointed as heads of programs where they can stifle progress for years. Advanced academic training can sometimes contribute to neglect of field work; or alternately, the transfer of the individual out of the research field for which he was trained. For the above reasons, we do not encourage Pre-Doctoral Fellows training, except for individuals who develop capabilities needed to participate in international activities. The present plan is to train no more than two Pre-Doctoral Fellows per year.

Post-Doctoral fellowships, however, will be given priority. Their participation in our activities in Mexico for a period of one or two years will enable them to become acquainted with the teamwork philosophy and with the advances and fulfillments of the different pro-

grams. After spending several years of academic study at the university, Post-Doctoral Fellows can become directly involved in the farmer's production problems and the research related to solving such problems. Thus, training plans call for six Post-Doctoral Maize Fellows to be participating as CIMMYT staff members during each year. Aside from the practical and theoretical knowledge gained by the participants, their work ideas and scientific contributions reinforces our overall program.

Visiting Scientists and Short-term Visitors also are important categories of training for professionals who may be in charge of breeding and production work in their own countries, and for maize program directors.

11.4 GRADUATE STUDENT EDUCATION

CIMMYT's philosophy toward graduate-level education follows the same pattern as that for previously mentioned categories of training and education: education should have a functional-service purpose and not be merely a social elevator for the student. Thus, in our view, a student's education should contribute to the improvement of maize production in his country. This structured approach to education seems necessary if national programs are to succeed; developing countries cannot afford to have their scientists pursuing research lines of purely individual interest. We view advanced education as simply another step in the development of human resources to meet production needs, by no means representing an endpoint in the scientist's development.

In making advanced education meaningful, we are concerned with the interaction of several components: the farmers, national programs, academic institutions, the student, and CIMMYT. Central focus is on the student.

The farmer and national program components are seen as pace setters, determining the principal educational needs of the student. The student, and other components, play a role in determining educational needs, but must function within the basic framework of needs set by the farmers and national programs.

It must be emphasized that education is viewed in its broadest form, with both formal and informal experiences seen as essential. The academic institutions, of course, play a major role in providing the formal education, but work with farmers and national programs is vital to the student's educational process.

The national programs assume a primary responsibility for understanding and interpreting the farmers' needs in maize production, and these needs must be translated into trained manpower. Graduate-level education should be aimed at meeting these staffing needs. Students at this level should be very energetic and intelligent. They should be teamworkers dedicated to serving their national program and local farmers. These characteristics should be given careful consideration, or advanced education may simply perpetuate national program problems.

CIMMYT attempts to serve as a link between national programs and academic institutions, since it has close relationships with both. In traditional academic programs, the student becomes accustomed to the concept of specialization and individual research. He often fails to see the larger picture, much less contemplate where he fits into it. Academic and thesis programs often do not equip students with the necessary tools to identify and solve relevant problems back home. In general, a strong feeling of "clear education purpose" is often missing.

CIMMYT's strategy in collaboration with national programs and academic institutions is to expand upon the training of traditional academic programs and develop scientists capable of interdisciplinary teamwork.

Working very closely with Kansas State University and Cornell University, CIMMYT is helping develop interdisciplinary graduate student teams to solve maize production problems.

The KSU team, for example, consists of four students representing three countries (i. e., Pakistan, Zaire, and Cameroon), and four disciplines (i. e., Agronomy, Physiology, Breeding, and Plant Pathology). The students spent several months as trainees at CIMMYT, where the team was being formed and KSU approached regarding the project. The academic program and research was planned during a series of meetings at both CIMMYT and KSU--involving KSU faculty, the students, and our staff.

As a key step, KSU assembled a team of professors to work with the student team. The thesis research is being done at selected sites in Mexico and Kansas and an ad-hoc committee has been formed to meet the students' needs while in Mexico. When possible, KSU professors accompany the students for their work in Mexico.

At KSU, regular planning sessions are held once per week. During these meetings the advisor and students continue to map their research course. A given graduate committee for one student includes

all three of the advisors for the other students, thus aiding the interdisciplinary planning process. For such a project to function well, students must participate actively and academic institutions must be well aware of their needs. For this reason, the students have spent several months with us, and all professors have visited CIMMYT for preliminary discussions.

We are convinced that team efforts similar to the KSU project can provide a worthwhile approach to graduate education. However, more effort is required of both professors and students than would be the case if a non-team approach were followed. The thesis planning, plot layouts, sequence of data gathering, etc. require group participation. This forces all individuals to have firm ideas of what the others are doing. Modifications and compromises are the rule.

Although national programs have participated to some extent in planning the KSU and Cornell projects; national programs should play a greater role in helping plan the student's program in future projects.

Means are being explored whereby academic institutions and national programs can be more directly involved in a student's education. For example, thesis research could be done in the home country. In any event, our resident program does not have the capacity to bring all graduate students from national programs to Mexico for their thesis work.

We feel that it will be necessary to develop close working relationships with six to ten universities to meet the kinds of needs outlined above. Contacts have been made with U.S. universities and Graduate School of the National School of Agriculture (Mexico), and other possibilities are being explored. A diversity of universities would permit a given national program to have personnel trained at several institutions.

We believe there are many opportunities for injecting imagination and ingenuity into graduate programs at all levels and plans to continue its explorations and encouragement of new and different approaches for the academic and practical experience that young scientists need to become leaders in their home countries and in world agricultural production.

CIMMYT will also work with government policy makers in an effort to obtain more structured staffing patterns in phased staff development programs.

11.5 RELATED STAFF AND FOLLOW-UP ACTIVITIES

Quality of training depends on the number of staff members involved and the time that each can allow for training. On the average, it is expected that staff members, other than training officers, will spend 8 to 10% of their time in training activities, and make an effort to visit former trainees whenever they visit their countries.

Obviously, training is greatly improved when individual trainees have the opportunity to work directly with a specialist. The Training Officer plans joint efforts with the staff and, if possible, designs a specific program for each trainee. This process is used as a model for all categories of training. The Training Officer also must select the potential trainees and evaluate their progress during the course of the program; organize lectures and seminars; and assist other staff members with training techniques.

Our maize training has now produced sufficient material to produce a maize training manual for use by trainees in Mexico and former trainees who are currently working in their own countries.

The staff also plans follow-up activities for the trainees in their own countries. This is important in reorienting former trainees and provides a means for evaluating CIMMYT's training in Mexico.

Follow-up work also assures the former trainee of CIMMYT's continued interest in their performance and post-training guidance.

Upon the completion of training, an In-service Trainee is scheduled to return to his home country for one or two years before being considered for advanced studies. This period provides both incentive and background for future study.

Former trainees keep in touch with the program activities through correspondence, or a newsletter planned soon, and by personal visits of staff members who are able to provide on-the-spot advice.

Periodic invitations to visit CIMMYT can provide motivation for former trainees to keep up with new developments. However, transportation costs may be a serious obstacle if this procedure is to be used with former trainees from distant continents. This problem can be overcome by inviting the most active former trainees to attend special meetings to be held in a country of their own continent every three or four years. Our staff seeks to build a bond or fraternal membership among the trainees. Hopefully, this common link can be extended across distance and time.

11.6 OUTLOOK TO 1980

Previously, we have made a very conservative estimate of 2,200 persons who should be trained for placement in 72 developing countries. With this additional training, such staffs would be well prepared to undertake dynamic and well-oriented programs to rapidly increase maize production.

Our overall estimates are intended as working guides, not exact blueprints or perfect fits for every country. We did not consider those countries with less than 100,000 ha. in maize cultivation in making this estimate of more than 2,200 potential trainees. Even so, considering a capacity of 50 participants per year, CIMMYT could only train a total of approximately 300 professionals by 1980. Thus, emphasis in training must be given to carefully selected program areas.

Training of Breeders and specialists in Plant Protection will require the support of a well-organized program of maize improvement, with sufficient personnel to conduct a solid training program. Such training could best be done in Mexico, taking advantage of CIMMYT's excellent physical and human resources available for the task.

CIMMYT should train annually 25 Breeders, Pathologists, and Entomologists selected from the countries that most urgently need well-qualified personnel. Since the number of Breeders, Pathologists, and Entomologists that should receive training is relatively less--in comparison with the number of Production Research and Extension Agronomists--and considering that national programs should centralize their programs of maize breeding, substantial contributions could be made to national maize improvement programs.

The 25 remaining positions available each year for CIMMYT training should be filled by production specialists who could act as trainers on return to their respective countries. Thus, these trainers could multiply the work of CIMMYT, with the aim of training about 1,500 Production Research and Extension Agronomists that are urgently needed in the developing countries. These trainers could count on technical aid from CIMMYT in creating national programs (those that would not require a special infrastructure, as is the case in facilities needed for training Breeders). In this way, CIMMYT could make a significant contribution to the development of maize production in the countries that most need it.

In the case of training that includes M.Sc. degree candidates, Pre-Doctorals, Post-Doctorals, Senior Visiting Scientists, and Short-term Residents, we do not foresee significant changes in the policies that CIMMYT has now underway.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Dr. Wayne Haag for his contribution to this paper in the discussion of graduate student training.

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TABLE 11.1 CIMMYT IN-SERVICE TRAINEES PER COUNTRY:

1966 - 1973 *

Country	1966	1967	1968	1969	1970	1971	1972	1973	Totals/ Country
Afghanistan		2	1						3
Algeria								1	1
Argentina			1	1		3		8	13
Bolivia								2	2
Brazil								2	2
Cameroon								1	1
Colombia							3		3
Costa Rica								1	1
Chile							1	1	2
Dominican Rep.		2				1	2		5
Ecuador						1	1	1	3
Egypt				5		1		2	8
Ethiopia				1					1
El Salvador		1		2		1	5	3	12
Ghana		1							1
Guatemala		2	1		1		4	3	11
Guyana							1		1
Haiti							3		3
Honduras						1	1	5	7
India	1					1			2
Ivory Coast			1			1			2
Japan						3			3
Mexico								2	2
Nepal						2		1	3
Nicaragua				1		1	1	1	4
Nigeria							3	1	4
Panama		2					1	2	5
Peru								2	2
Philippines						4	3		7
Portugal (C. Verde)								1	1
Tanzania							5	6	11
Thailand							1	2	3
Tunisia						1			1
Turkey								2	2
Uganda								1	1
Uruguay					1				1
Venezuela						3			3
West Pakistan						1	2	1	4
Zaire							6	4	10
Totals per year	1	10	4	10	2	25	43	56	151

* Arrived up to December 31, 1973.

**TABLE 11.2 SUMMARY OF IN-SERVICE TRAINEES PER
CONTINENT ***

AMERICA	82
ASIA	27
AFRICA	42
<hr/>	
TOTAL :	151

* As of December 31, 1973.

TABLE 11.3 INSTITUTIONS SPONSORING IN-SERVICE TRAINEES: 1969 - 1973 *

INSTITUTIONS	YEARS					TOTAL
	1969	1970	1971	1972	1973	
FORD FOUNDATION	6		3	8	7	24
AID	2	2	8	14	9	35
CIMMYT	2		1	5	15	23
BID			10	14	13	37
CONACYT			3			3
DIRECT				2	8	10
UNDP					4	4
T O T A L	10	2	25	43	56	136

* Arrived up to December 31, 1973.

TABLE 11.4 AVERAGE MINIMUM RESEARCH & PRODUCTION STAFFING REQUIRED BY COUNTRY, ACCORDING WITH THE CORN ACREAGE.

Number Of Ha. Planted To Corn	Maize Breeders	Plant Pathologists	Entomologists	Research Production Agronomists	Extension Agronomists	Protein Evaluation Specialists	Total/Country
30,000-100,000 Ha.	3	1	1	2	3	1	11
100,001-500,000 Ha.	5	2	2	3	10	1	26
500,001-1,000,000 Ha.	8	3	3	5	20	1	55
Each additional 1,000,000 Ha.	0	0	0	0	20	0	

TABLE 11.5 CALCULATED REQUIREMENTS FOR TRAINED PERSONNEL (B.Sc. & Up) IN DEVELOPING COUNTRIES WITH CORN PLANTED AREAS OF ABOVE 30,000 HA.

02-11

America (20 Countries)
Asia (17 Countries)
Africa (34 Countries)
Others (1 Country)

Staff	No. of Ha. Planted to Maize				Totals/ Specialty/ Continent
	30,000 - 100,000 Ha.	100,001 - 500,000 Ha.	500,001 - 1,000,000 Ha.	Over 1,000,000 Ha.	
Maize Breeders	15	50	24	16 ⁽¹⁾	106
Plant Pathologists	5	20	9	6	40
Entomologists	5	20	9	6	40
Res.Prod.Agronomists	10	30	15	10	65
Ext. Agronomists (maize)	15	100	60	460	635
Protein Evaluation Sp.	5	10	3	2	20
Maize Breeders	18	10	18	24 ⁽²⁾	70
Plant Pathologists	6	4	6	9	25
Entomologists	6	4	6	9	25
Res.Prod.Agronomists	12	6	6	15	39
Ext. Agronomists (maize)	18	20	18	200	256
Protein Evaluation Sp.	6	2	6	3	17
Maize Breeders	33	75	56	8 ⁽³⁾	172
Plant Pathologists	11	30	21	3	65
Entomologists	11	30	21	3	65
Res.Prod.Agronomists	22	45	35	5	107
Ext. Agronomists (maize)	33	150	140	120	443
Protein Evaluation Sp.	11	15	7	1	34
Maize Breeders	3				3
Plant Pathologists	1				1
Entomologists	1				1
Res.Prod.Agronomists	2				2
Ext. Agronomists (maize)	3				3
Protein Evaluation Sp.	1				1

TOTAL STAFF 2,235

- (1) Includes: Argentina & Brazil.
 (2) Includes: India, Indonesia & Philippines.
 (3) Includes: South Africa.

TABLE 11.6 OVERALL TOTALS FOR SPECIALTY

<u>Specialty</u>	<u>No.</u>	<u>Percentage</u>
Corn Breeders	351	15.70
Plant Pathologists	131	5.86
Corn Entomologists	131	5.86
Research Production Agronomists	213	9.53
Extension Maize Agronomists	1,337	59.82
Protein Evaluation Specialists	<u>72</u>	3.22
	2,235	

TABLE 11.7 PLACE OF STUDY, COUNTRY OF ORIGIN AND NUMBER OF DEGREE CANDIDATES, PREDOCTORALS, POSTDOCTORALS, SENIOR VISITING SCIENTISTS AND SHORT TERM RESIDENTS DURING 1973.

	Country of Origin	Number
<u>Degree Candidates</u>		
Chapingo	Argentina	3
	Bolivia	1
	Colombia	4
	México	1
	Uruguay	1
		<u>10</u>
Kansas State University	Cameroon	1
	Pakistan	2
	Zaire	1
		<u>4</u>
Cornell University	Colombia	1
	Honduras	1
	Malaysia	1
	Uganda	1
	U. S. A.	1
		<u>5</u>
<u>Predoctorals</u>		
CIMMYT	Egypt	1
	Ivory Coast	1
		<u>2</u>
<u>Postdoctorals</u>		
CIMMYT	Australia	1
	Barbados	1
	Chile	1
	India	2
	Thailand	1
	U. S. A.	2
		<u>8</u>
<u>Senior Visiting Scientists</u>		
CIMMYT	Colombia	1
	Egypt	1
	Guatemala	1
	India	2
	Pakistan	1
	Philippines	3
	Taiwan	1
	Yugoslavia	4
		<u>14</u>
<u>Short-Term Residents</u>		
CIMMYT	Argentina	1
	Cameroon	1
	Colombia	4
	Costa Rica	1
	Dominican Rep.	1
	El Salvador	1
	Guatemala	1
	Haiti	1
	Honduras	1
	India	1
	Indonesia	1
	México	2
	Nepal	1
	Nicaragua	1
	Nigeria	2
	Pakistan	2
	Panama	1
	Peru	3
	Spain	1
	Thailand	1
	U. S. A.	11
Zaire	2	
	<u>40</u>	

TABLE 11.7 PLACE OF STUDY, COUNTRY OF ORIGIN AND NUMBER OF DEGREE CANDIDATES, PREDOCTORALS, POSTDOCTORALS, SENIOR VISITING SCIENTISTS AND SHORT TERM RESIDENTS DURING 1973.

	Country of Origin	Number
<u>Degree Candidates</u>		
Chapingo	Argentina	3
	Bolivia	1
	Colombia	4
	México	1
	Uruguay	1
		<hr/> 10
Kansas State University	Cameroon	1
	Pakistan	2
	Zaire	1
		<hr/> 4
Cornell University	Colombia	1
	Honduras	1
	Malaysia	1
	Uganda	1
	U. S. A.	1
		<hr/> 5
<u>Predotorals</u>		
CIMMYT	Egypt	1
	Ivory Coast	1
		<hr/> 2
<u>Postdoctorals</u>		
CIMMYT	Australia	1
	Barbados	1
	Chile	1
	India	2
	Thailand	1
	U. S. A.	2
<u>Senior Visiting Scientists</u>		
CIMMYT	Colombia	1
	Egypt	1
	Guatemala	1
	India	2
	Pakistan	1
	Philippines	3
	Taiwan	1
	Yugoslavia	4
		<hr/> 14
<u>Short-Term Residents</u>		
CIMMYT	Argentina	1
	Cameroon	1
	Colombia	4
	Costa Rica	1
	Dominican Rep.	1
	El Salvador	1
	Guatemala	1
	Haiti	1
	Honduras	1
	India	1
	Indonesia	1
	México	2
	Nepal	1
	Nicaragua	1
	Nigeria	2
	Pakistan	2
	Panama	1
	Peru	2
	Spain	1
	Thailand	1
U. S. A.	11	
Zaire	2	
		<hr/> 40

CIMMYT'S MAIZE TRAINING UNIT

MAIZE TRAINING

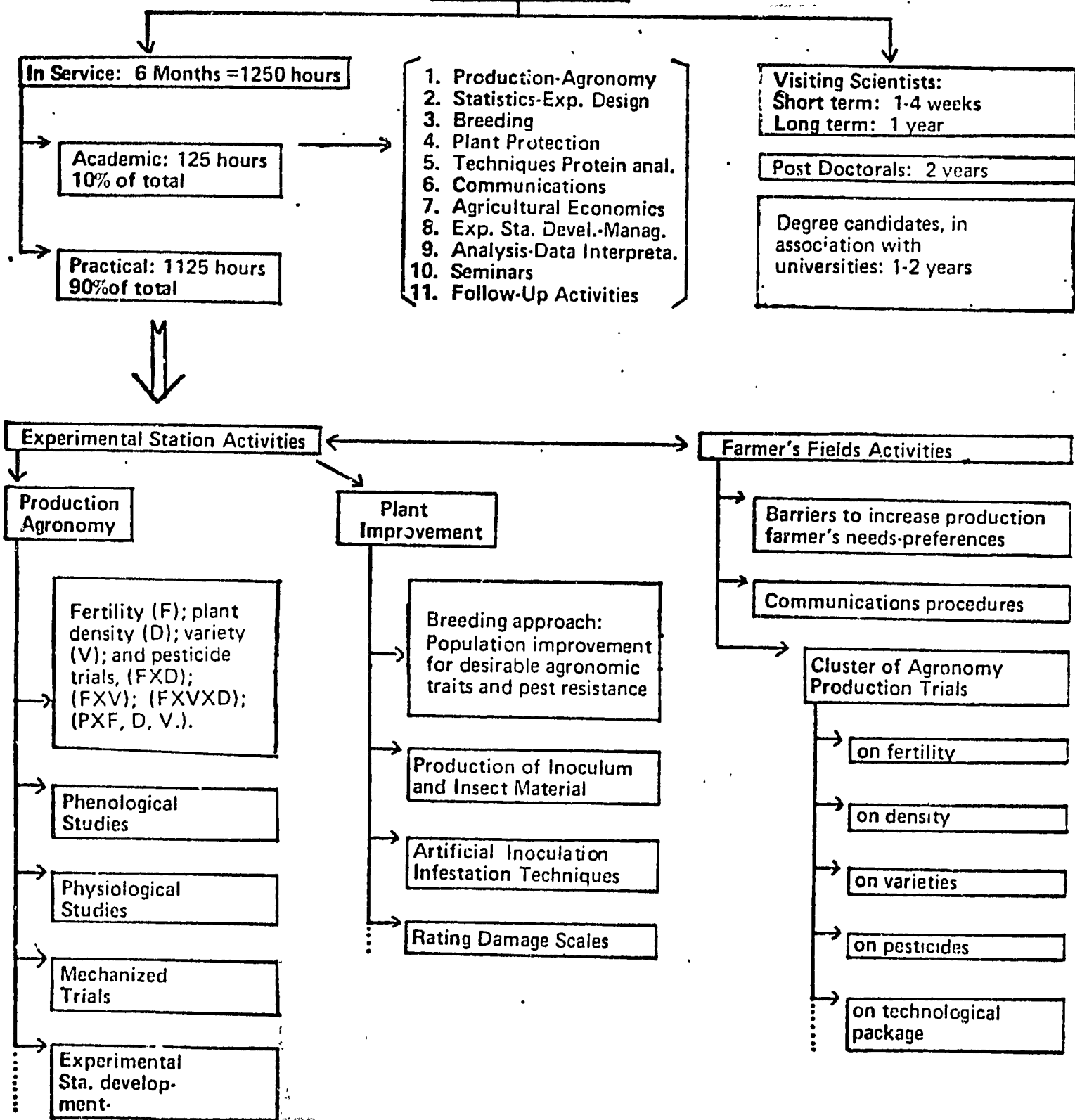
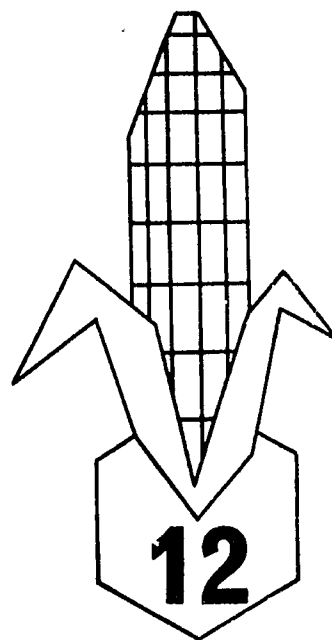


Fig. 11.1



**ROLE OF THE ECONOMIST IN
MAIZE IMPROVEMENT**

by
Don Winkelmann, CIMMYT,

Lead Discussant:
Dr. Vernon Ruttan
President
Agricultural Development Council
New York

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THE ROLE OF ECONOMICS IN INCREASING
MAIZE PRODUCTION

by
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12.1 INTRODUCTION

In a conference dedicated to maize improvement, one might well ask how economics fits in, what functions it fulfills. Agronomists or breeders or entomologists and maize improvement--these combinations conjure up ready images of purpose and function. But, economists? They're not quite standard fare.

The title of this paper hints at the orientation to be taken. The emphasis is on how economists can best collaborate with other maize improvement workers to boost maize production. Collaboration of this kind--where agricultural scientists and economists each contribute their special knowledge and points of view--is not at all common. We do have some examples; e. g. , the joint ventures into the formulation of profit maximizing recommendations, but not many.

In such cooperation, we can say that the special contribution of the agricultural scientist is his knowledge of plants, their needs, and how they interact with the environment. The economist contributes procedures for identifying and organizing the elements impinging on a decision-maker who seeks to maximize something while subject to constraints. Even so, such questions remain as to how these contributions should be integrated and what problems can be treated fruitfully. Answers are not readily available.

In the two years since CIMMYT began its collaborative ventures between biological scientists and economists, several problem areas have emerged. Their identification is a joint product of CIMMYT efforts and of soundings from national programs, from policy makers, researchers, and from farmers.

In the earliest days of CIMMYT's program in economics, work aimed at formulating profit maximizing recommendations was considered. It was quickly apparent, however, that the Center's agricultural scientists were fully aware of what has to be done to identify profit maximizing levels of inputs. With this fact established, attention was turned to the consideration of other problem areas. A description of the work now underway at CIMMYT is presented next. We don't claim to have identified all of the areas which warrant joint undertakings. Indeed, CIMMYT's list differs even from that of its sister institutions. Our selection of activities is, we think, consistent with CIMMYT's mandate and with the Center's experiences. We look forward to your observations on how such collaboration could be made more useful to CIMMYT and to national programs.

The following sections emphasize CIMMYT's experiences in fostering collaborative work among agro-scientists and economists. The first section sets the scene by juxtaposing the world grain situation and the guidelines which orient CIMMYT's activities. The next section identifies critical points for collaboration among agricultural scientists and economists. In the third section, specific cooperative activities are discussed and exemplified. The final section is a summary giving emphasis to the point of view which motivates CIMMYT's work in economics.

12.2 CEREALS PRODUCTION AND CIMMYT'S OPPORTUNITIES

12.2.1 WORLD PROJECTIONS

Before looking at CIMMYT's work in maize and economics, we can consider the argument for increasing production. Cereals are in short supply around the world at the moment. Prices started rising in late 1972, continued high through 1973, and promise to remain intermediate between the highs of 1973 and the levels of the early 1970's (see Table 12-1). The marked increase in the price of cereals (as compared with the price of production inputs and with the general price level), along with the notable reduction in stocks, offer testimony that grains are relatively scarce and seem destined to remain scarce.

What about the rest of this decade, the period from 1975 to 1984? Forecasts made by FAO and USAID indicate that on a worldwide basis, cereals, in general--coarse grains in particular--will not be in short supply. They show world production increases keeping pace with the world's increases in consumption through the 1980's and on to 1985. (see Table 12-2).

These projections were made at a time when grain and energy prices were lower, when fertilizer was readily available. What do the recent changes imply for these world-wide projections? If grain prices stay higher relative to the general price level than they were in the 1960's and early 1970's, this will tend to shrink the use of grains, especially for animal products. At the same time, policies aimed at restricting production in certain countries will be relaxed, leading to increased output. Both reactions would reinforce the long-run projections.

On the other hand, if energy remains relatively expensive, costs of production will be higher, yields will be reduced, and production increases will be below those forecasted. If fertilizer stays in short supply, production will obviously be limited. This latter, however, seems unlikely. Industry forecasts indicate that adequate fertilizers will be available to resume past trends in fertilizer use within the next three to four years. Fertilizer prices will be higher, of course, but it is not clear what will happen to the critical ratio relating grain prices to fertilizer prices.

We have, then, higher prices for grain reinforcing the USDA and FAO projections of world-wide abundance, while higher costs-- especially for energy and fertilizer--would tend to counter the projections.

On balance, what can be forecast? It appears that the best guess remains that found in the FAO and USDA projections--that world production of coarse grains will meet world needs at relative prices not much above those of the late 1960's.

But is this enough? It might be, if the world had a system for freely transferring grain from those who have an excess to those who suffer deficits. The impressions of Dr. Pangloss' aside (a character in Voltaire's Candide who insisted, even when immersed in evidence to the contrary, that "All is for the best in this the best of all possible worlds.") such a system does not now exist, nor is it in the offing. This makes it important to alter the focus of the discussion.

12.2.2 REGIONAL PROJECTIONS

Look, now, at the world by regions and consider only coarse grains (see Table 12-2). Here we see that the projected increases in production originate in the developed countries. For developing countries, on the other hand, production does not keep pace with consumption. They will import to supply their needs. Refining our view even more, USDA projection shows only four developing subregions exporting coarse grains by 1980. These are Argentina, East South America,

East Africa, and Southeast Asia (see Table 12-3). The seven remaining developing subregions will be importing significant quantities of coarse grains.

12.2.3 COUNTRIES WITH APPARENT SHORTAGES

Seen differently and in the terms of the Symposium's introductory papers, for 45 of the 55 developing countries with at least 100,000 ha. of maize, population increases exceeded increases in maize yields in the 1960's. (see Table 12-4). Unless production is increased, this finding implies that net imports must be increased or that domestic use must be reduced for those 45 countries.

The forecasted world sufficiencies, then, mask critical shortages of coarse grains--largely maize--in the developing countries. Barring an apparatus for freely transferring grain to deficit areas, these projected shortages offer a stimulus for substantially increasing local production and, more importantly, human well-being. CIMMYT's work should focus precisely on means for overcoming these critical shortages.

12.2.4 CIMMYT'S CONTRIBUTIONS

CIMMYT's mandate calls for it to work with the national programs of developing countries to promote the production of maize and wheat. Thus, CIMMYT staff engage in research aimed at identifying critical problems in cereals production. (Many such problems related to maize were reviewed in earlier papers.) Beyond its research, CIMMYT engages in training staff members for national programs. Center staff also consult with national policy makers on ways in which national programs can be made more effective. Each of these activities is aimed at increasing the production of maize and wheat in developing countries. Each, then, is aimed squarely at the kinds of contributions referred to above.

And what do these contributions entail? In brief, the requirements are: (1) national programs capable of formulating and promoting new technologies which farmers will adopt and (2) policies which facilitate the diffusion of these technologies among farmers. This statement identifies the decision makers important to increasing maize production. It also marks the points at which collaboration among agricultural scientists and economists can be critical. Both Dr. Sprague's introductory comments and Dr. Finlay's discussion to follow are elaborations of these requirements.

DECISION MAKERS: FARMERS, RESEARCHERS, POLICY MAKERS

12.3.1 DECISION MAKERS INTRODUCED

There are three important groups of decision makers who are instrumental in shaping the production of maize. These are farmers, researchers, and policy makers. Each group has a set of questions which deal with issues of special concern to economists. These issues orient the discussion which follows.

Before going into the questions affecting these groups, consider the way in which these decision makers are related. If production is to be increased, then farmers must do something differently. Clearly, then, the central figure on the scene, the major protagonist of the drama, is the farmer. It is through him that the efforts of the researcher and the policy maker are manifested. Researchers can offer new technologies and policy makers can ensure that inputs are properly available, but the farmer is the vital link in the chain that binds the desire for more foodstuffs to its fruition in greater production.

12.3.2 THE FARMER: GOALS AND CONSTRAINTS

Look now at the farmer. In times past, it was argued that the farmers of developing countries resisted change because custom, tradition, superstition, or ignorance played dominant roles in orienting their behavior. Now it is widely held that the farmer's behavior is purposive, that he is sensitive to the nuances of his environment, and that he uses his limited resources efficiently. He is seen as motivated by certain goals, but constrained from achieving these goals by the existing technology and by the availability of inputs. To a lesser degree, it is held that he is restricted by ignorance of what is available to him.

With respect to goals, it is usually assumed that the dominant force motivating farmer behavior is the drive to achieve higher profits. Evidence is accumulating, however, that other factors also affect his behavior in a significant way. In particular, the farmer's aversion to risk is now regarded as a very important concern in decision making. A risk-averse, income-seeking farmer requires more income if he is to expose himself to situations in which he perceives more risk.

Formally, risk-averse behavior follows from three assumptions, each of which is intuitively appealing. First, it must be assumed

that the decision maker prefers more income to less income. Second, it must be assumed that the extra satisfaction derived from extra income decreases as income increases--e.g., the change in satisfaction is greater from an extra dollar of income when total income is \$1,000 than when total income is \$100,000. Finally, given that farmers operate in an uncertain environment, it must be assumed that they take decisions in terms of expected returns. (This last assumption can be deduced from certain antecedent assumptions, each of which is intuitively appealing.) Informally, we seem quite ready to acknowledge that humans are inclined to avoid situations which are risky.

The more the farmer is averse to risk and the more unstable his natural environment, the less likely he is to adopt new technology, even when the new technology promises greater average profits than the old technology.

But is it really true that risk influences farmer decisions? After all, agriculture is always a risky business. Just so, but clearly some strategies open to a farmer are more risky than others. There are several ways to define risk. One way is in terms of the probability of ruin--that strategy which has a higher probability of ruin for a given farmer is said to have a greater risk for that farmer. A second way is in terms of the premium, in the form of additional average income he must be given in order to expose himself to a given uncertain situation. No farmer eliminates risk; rather, he seeks to keep it at what he perceives to be acceptable levels. Some direct evidence of risk aversion is available from small-scale surveys conducted in the Plan Puebla area. Indirect evidence is available from data on the adoption of new technology.

Consider, for example, the data in Table 12-5. These show yields of the new wheat technology in Pakistan and yields for the new maize technology in Puebla. (The sources of the data are fully described in the footnotes of the table.) Notice that traditional yields are much the same for the two programs, that farmer yields with the new technology are much the same, and that experimental yields favor Plan Puebla, but undoubtedly understate average performance in Pakistan. The increases in profit promised by the new technologies also compare favorably.

For the Pakistan case, the adoption of the recommended wheats was rapid and pervasive. In Puebla, the rate of diffusion of new technology--featuring more fertilizer and greater planting densities--has been appreciably slower (see Table 12-6 for more on this point). One major difference between the two environments is that Pakistan's Punjab is irrigated, while the Puebla area is rainfed. In

Pakistan, new wheats are a dominant strategy, almost certainly better than the old wheats when both are irrigated. In Puebla, however, with inadequate rainfall, new technology can produce incomes below those of the traditional strategy. (Efforts to demonstrate that risk-averting farmers might prefer the traditional to the recommended strategy have not been notably successful. These efforts, however, are based on data from 1971 and 1972, years of good rainfall for the area.)

This example does not prove that risk is dampening the response of Puebla farmers. Other possible explanations for their apparently anomalous behavior come to mind. The example is, however, consistent with risk-averting behavior and, hence, suggestive. The data in Table 12-6 that show a continuing increase in planting densities, could be the result of changes in farmers' perceptions of risk as experience accumulates. With this change in perception, adoption of recommended practices increases.

Turning now from farmers' goals to the constraints which impede their achievement, the farmers' access to inputs--which inputs are relatively abundant and which are relatively scarce--must be analyzed. Constraints can arise from shortages in inputs owned by the farmer (e. g. , labor, or power for land preparation), as well as from shortages of these inputs which must be purchased (e. g. , fertilizers or insecticides).

12.3.3 COLLABORATION ON COMMON THEMES

What does the above imply for the role of the economist as he collaborates with agricultural scientists?

The most important contribution of the economist is in organizing research which will identify the farmers' objectives and characteristics of his constraints. This assertion is based on the belief that research aimed at developing new technologies is most effective when it considers what motivates and what constrains farmer behavior.

In a similar way, the economist can provide information about the farmer to the policy maker. Again, the idea is that policy is most effective when it is based squarely on knowledge of the primary forces shaping farmer behavior, coupled with knowledge of the potential change in technology available from agricultural research.

In brief, then, the role of the economist is (1) to collaborate with agricultural scientists and policy makers by providing information and analysis on the critical elements that shape farmer behavior, so that (2) new technology will be consistent with farmer needs and poli-

cies will be helpful in its diffusion. It must be emphasized that this does not exhaust the set of activities engaged in by economists concerned with agriculture; many other themes could be treated under a broader rubric. This role is, however, a critical one in shaping and diffusing the new technologies which will lead to greater production.

Against this background, the next section will describe related lines of work which CIMMYT is now pursuing.

12.4 PROBLEM AREAS AND EXAMPLES OF CIMMYT'S WORK

The discussion of this section concentrates on problems that emerge after it has been decided to increase production among specific sets of farmers (e.g., among all farmers, among irrigated farmers, among subsistence farmers, among farmers of a particular region, etc.). It assumes that a substantial number of important questions have already been answered. In a rough way, these questions can be subsumed under an assertion like the following: that introducing new maize technology to these farmers is an efficient way to achieve the broader goals of the government.

12.4.1 TECHNOLOGY AND THE FARMER'S CIRCUMSTANCES

The first issue of concern is the technology itself. It must be useful to farmers, which is to say that it must be consistent with their goals. The technology must also be consistent with farmer constraints, or policy makers must agree that a program for ameliorating constraints be launched with the program introducing the new technology. There is ample evidence that farmers will not accept technologies that do not fit their circumstances; no matter how these technologies are promoted, nor how many inputs are made available.

These are certainly obvious conditions, but what might they imply for the recommendations and for their promotion? Consider first the objectives of farmers. Imagine a homogeneous area populated by farmers and assume an agronomist who seeks to formulate a set of recommendations for the area's farmers. Suppose, to start, that agro-climatic conditions and prices show little variability from year to year and that farmers' circumstances are such that profits dominate decision making, with risk having little influence.

In such a situation, recommendations can be framed in terms of profits and well-known procedures for their formulation can be followed. (This assertion is a bit strong in that we know that the response surface analysis necessary to finding maximum average profits can be a tricky business. It often occurs that there is little difference in statis-

tical measures, e.g., coefficients of correlation, between alternative models applied to the same data. At the same time, profit maximizing recommendations from each model can be quite different from one another. This suggests that the researcher should be armed with a certain amount of skepticism as he goes from data to recommendations via response surfaces.) Because the environment is stable, it is likely that recommendations can be based on relatively few experimental results. Finally, the recommendations -- variety, fertilizer, planting rates, etc. -- can be made with substantial specificity.

Now, let's turn to a second situation, one in which farmers' decisions are sensitive to risk--better, to the farmer's perception of risk--as well as to income. Further, assume that agro-climatic conditions and prices can vary substantially from year to year. These two new elements--risk averting behavior and an unstable environment--can lead to significant changes in the way recommendations are made, in the way technology is diffused, and, as will be seen in subsequent paragraphs, even how experimental work aimed at formulating recommendations is organized.

Because both risk aversion and income are important goals, research and recommendations must somehow incorporate the two if they are to be consistent with the farmer's purposes. For example, a breeding program focused exclusively on raising yield potential to the exclusion of yield stability will not be consistent with the farmers' purposes. Because farmers are concerned about yield stability as well as about yield potential, breeders must have the same concern. To focus on the latter and ignore stability is to jeopardize farmer acceptance of the new lines.

So, too, for recommendations, those aimed only at profits will probably not be consistent with farmer circumstances, hence are likely to be rejected. Well and good, but each farmer can (probably will) have a different way of looking at profit and risk and it's just not feasible to tailor separate recommendations for each farmer. What can be done? The researcher must be content with a rather untidy situation. The information he'd like to have can't be obtained. He knows only that he must present recommendations which are acceptable to risk averting profit seekers. What he will often discover, not always but often, is that he can only recommend ranges -- e.g. from 37,000 to 47,000 plants per hectare. He can know that potential strategies outside the range are inferior to those inside but he cannot know which of those within the range is preferred by a given farmer.

What is needed, then, are data which permit characterization of the unstable environment and a way to relate these characteristics to the production arising from alternative strategies. This might mean several years of experimental data or it might mean good data on the environment, a few years of experimental data, and a sound knowledge of the interaction among weather, production strategies, and maize yields. The researcher also needs access to a mechanism for identifying acceptable strategies.

One of the first attempts to move from the theoretical issues surrounding risk-averse behavior to a set of operational procedures for identifying agricultural strategies acceptable to risk averters is found in a manuscript by Dr. Jock Anderson, now under review for publication by CIMMYT.

As for promoting new technologies, farmers must not only become convinced of their profitability, but must learn about their variability as well. This requires that demonstration plots be maintained long enough so that farmers' perceptions of risk will approximate real risk. Moreover, unless one strategy is always more profitable (i. e., always gives more profit than competing strategies independent of how the weather or plant disease or prices behave), it will not be sufficient to demonstrate only the profit maximizing strategy. Other strategies must be demonstrated.

And now what of the constraints, how might these influence the orientation of research on which recommendations are to be based? First, it must be recognized that, where farmers have access to credit and to markets, some constraints can be relaxed. If the farmer runs out of seed or fertilizer, he can acquire more. When family labor is exhausted, he can hire labor. When the hoe or mules cannot satisfy tillage requirements, he can turn to custom services.

The question of the economist then becomes which of the constraints are only apparent; which are real? Which constraints can be relaxed through policy (e. g., by making credit and fertilizer available?) Which constraints arise because of high opportunity costs (e. g., a longer season maize is not feasible because of double cropping)? Which constraints emanate from natural circumstances and cannot be evaded by the farmer (e. g., rainfall or the amounts and timing of canal water)?

The researcher is obviously not working in a vacuum, isolated from knowledge of what happens in the surrounding countryside. There are, however, a wide variety of circumstances which might influence farmer reception of a new technology. Some are not obvious. They can be identified and their importance assessed through farm and market level research.

12.4.2 CIRCUMSTANCES AND TECHNOLOGY: SOME EXAMPLES

Three examples come to mind. In Zaire, field trials show a marked response to nitrogen. Nitrogen, however, is little used by farmers who grow maize, is not readily available in the markets frequented by farmers, and, where available, sells at relatively high

prices. This might suggest that the first version of a new maize technology should feature low levels of nitrogen and/or a cropping system with maize and a legume interplanted. Subsequent versions could go on to higher levels of inputs. How quickly and by what route high yielding strategies can be introduced depends upon (among other things) farmer willingness to accept the perceived risks implied by using ever more nitrogen, on the capacity of the distribution system to deliver nitrogen, and on the price in terms of maize at which nitrogen can be delivered to the farmer.

A second example comes from northern Turkey. There it is not uncommon for the same farmer to have excellent tobacco side by side with low yielding maize. What underlies this apparent anomaly? Is it that the maize technology currently being recommended is flawed and, if so, how? Does the recommended technology require substantial inputs of labor at a time when family labor is fully committed to tobacco (or vegetables)? And, if so, what of the market for hired labor? Are the risks associated with tobacco production all that the farmer is willing to accept?

Or, consider a third example from Kenya, west of the Rift Valley. According to a survey on which CIMMYT collaborated with Kenya-based agencies, the hybrids developed at Kitale Station have been widely accepted (see Table 12-7). At the same time, the data indicate that several other dimensions of the recommendations are not as well received (see Table 12-8).

Notice, in particular, that roughly 40% of the interviewed farmers with less than 50 acres of land interplant maize with other crops, contrary to the recommendations. Information on interplanting-- what crops, in what subregions, by what classes of farmers-- can be useful in orienting the research work of agronomists, possibly even leading to recommendations involving intercropping.

12.4.3 CIRCUMSTANCES AND RESEARCH

Intercropping is a common practice for the maize farmers of Latin America and Africa. Several factors, separately or jointly, seem to motivate it. While one of these might be risk, it seems more likely that other considerations contribute, such as: weed control (with the consequent reduction in the need for labor); complementarities with respect to plant nutrients, as exemplified in the joint production of pole beans with maize; or the potential for immediate utilization of available moisture where moisture is scarce and soils have little moisture carrying capacity. It seems likely that in much of Latin America, where maize is commonly grown with pole beans, that complementarities with

respect to plant nutrients motivates intercropping. In much of Africa, many crops are grown with maize. Here it is more likely that labor and moisture utilization motivate intercropping.

In any case, researchers will do well to remember that while intercropping is not the best strategy for the Ohio farmer-- with high labor costs, ready access to fertilizers, and deep soils-- it might well be the best strategy for large numbers of farmers in Africa and Latin America. Careful examination of the farmers' circumstances can discover whether it is the best strategy or not. If farm level investigation shows intercropping to be potentially advantageous to farmers, then agricultural scientists will do well to include it in their research.

There is another, closely related, dimension of the development of new technology which warrants consideration. This has to do with the conservation of the Government's scarce research resources, especially trained manpower.

In assessing such resources, we ought first to convince ourselves that the research problem at hand is an important one, that its resolution has a high priority. On this issue, both the agricultural scientist and the economist can cooperate in providing information to policy makers. They will then decide if a problem warrants attention, given the budget and the other problems which are competing for solution.

Once the decision is made to proceed, the work should be done quickly and efficiently. Suppose that the problem is to formulate recommendations useful to farmers. One element of the preceding discussion--viz. that farmers are risk averse--can have important consequences for how the research effort is organized. If risk aversion plays an important role in decision making, then it is not possible to make recommendations that have a precise level of each input (specific recommendations) and that are exactly consistent with each farmer's preferences. Recommendations based on ranges (e. g., 60 to 110 kilos of nitrogen per hectare) might require less experimentation than would specific recommendations based on profit maximization (e. g., 110 kilos of nitrogen per hectare). It might be possible to develop range recommendations based on two or three years of experiments in conjunction with a simulation model and time series data on weather. If simulation models are used, the classes of data collected might be influenced (e. g., soil moisture at seeding, critical to simulation models, is not commonly recorded in agronomic experiments).

In brief, the introduction of risk aversion can have implications for the way recommendations are formulated that could result in

the need for different experimental data. When less data is required to make useful recommendations, less research resources need be committed.

The preference for intercropping should also influence the orientation of research. Where farmers follow this practice--sometimes even when they do not--intercropping should be considered by researchers. This seems especially appropriate when the crop planted with maize is a legume. Fertilizer prices have increased over recent lows and, because of the higher cost of energy, it seems likely that they will stay above those lows. With higher prices of chemical fertilizer, higher values must be attributed to the nitrogen fixed by plants, making maize/legume combinations relatively more profitable than before.

One further aspect of the design of research aimed at formulating recommendations offers opportunities for collaboration among agricultural scientists and economists. This arises from recognizing that experiments, whether on station or on farmers' fields, offer far more scope for control over the crop's environment than farmers exercise over their own fields. For example, experiments on response to nitrogen are kept weed-free, while farmers' fields are not. To the extent that these controlled dimensions interact in an important way with the variables under study, recommendations should reflect this interaction.

The range of recommendations emerging from the discussion on risk might be sufficient to compensate for these interactions. In any case, one would want to be conscious of the phenomenon in formulating recommendations. To ascertain its importance, farm-level research involving agricultural scientists and economists could be useful.

12.4.4 CIRCUMSTANCES AND COLLABORATION

Up to this point, the discussion has focused on collaboration among agricultural scientists and economists aimed at formulating recommendations. Emphasis was given to the need to orient research toward developing strategies which are consistent with farmers' goals and with the constraints of their attainment; which recognize that certain inputs are relatively scarce or relatively expensive, while others are relatively abundant or relatively inexpensive.

The economist's special role in formulating such recommendations is to contribute data analysis aimed at identifying goals and the relative scarcity of resources. Although such research--from questions to questionnaire to sampling strategies to interviews with farmers

to data analysis--will be executed by the economist, the agricultural scientist must assist in identifying the elements to which production and marketing are sensitive. The agricultural scientist will then shape his own research in terms of what is discovered about farmers and markets. Omission of these considerations reduces the relevance of the research.

Sometimes, an apparently perfectly adequate technology meets with less success than expected by researchers. El Salvador's experience with improved maize technology--hybrids, insecticides, and fertilizers-- is a case in point. Data taken from a CIMMYT-sponsored survey in El Salvador shows that, after some years of promotion, roughly 35% of the country's farmers are using hybrids (see Table 12-8). A second dimension of the recommended package is insecticides. Less than 20% of the sampled farmers reported using insecticides. (El Salvador is a lowland tropical country. Heavy infestations of fall army worms do severe damage to the maize crop virtually every year.) Interestingly, there is little correlation between use of hybrids and use of insecticides. There is a strong relation between use of the inputs on the one hand, and agro-climatic zone and farm size on the other.

If the potential of the new technology is to be realized, new avenues must be explored. The package is profitable, promising easily twice the income per hectare of the traditional technology. Obviously something is not working right. Identifying the problems and rectifying them will require the combined talents of agro-biologists, economists, and policy makers.

12.4.5 POLICY MAKERS AND MARKETS

Economists can also contribute to increasing maize production by providing information and analysis to policy makers concerned with the rapid diffusion of new technology. These policy makers will want to facilitate the spread of new technology and to avoid surprises which can arise from unforeseen disruptions of the systems which link farmers to those who provide inputs and to those who utilize farm products.

The preceding discussion emphasized farm-level research, and the following discussion will accent market-level research. The two are obviously related; moreover, both must be of concern to the policy maker. Nevertheless, the points at which policy makers can most influence the adoption of new technology is off the farm in the markets which serve farmers.

Two classes of markets must be considered. The first is the market for those inputs that the farmers will utilize in following new technologies (e.g., improved seeds, fertilizers, and insecticides). Obviously, if the new technology calls for these inputs, they must be available to the farmer. Availability, of course, is only a necessary condition to farmer use of the inputs and the technology which they form. Whether or not farmers will even want to use them will depend on (among other things) whether they suit their purposes--the theme of the preceding discussion.

With respect to inputs, the policy maker must be apprised of ways in which distribution can be made less costly and more timely. This requires analysis of transport, storage, financing, credit, and prices. When the process of diffusion implies increasing use of inputs, the system's capacity to accommodate ever larger flows must be examined. Constraints on expanded deliveries must be identified. These become the points at which investment should be encouraged.

The tone of the previous paragraph is an optimistic one, that is, constraints on the availability will be identified and they can be alleviated. Suppose that there is some reluctance on the part of the policy maker, or other decision makers, to make necessary investments. Some would argue that the agricultural scientist should tailor new technologies to fit the constraints. For example, if fertilizers are not likely to be available without a substantial investment in infrastructure, and if this will not occur in the ordinary course of events, then research on technologies should reflect this. Others argue that the technologies should be developed independently of such considerations and that the technology itself will create a demand for inputs which public or private decision makers will be compelled to satisfy. An intermediate position (like that described earlier as a possibility for Zaire) can also be argued. It relies on a commitment to deliver increasing flows of inputs as the recommended technology changes to ever higher rates of utilization of these inputs.

The extent to which the availability of inputs shapes the evolution of new technologies can be related to literally dozens of considerations. Identification and resolution of the issues should involve the combined efforts of policy makers, agro-biologists, and economists.

Among the input-related strategies often mentioned for hastening the spread of new technology are offering credit at subsidized interest rates and subsidizing the price of inputs.

The former strategy has played a prominent role in the efforts of development assistance agencies to promote agricultural development. There is growing evidence, however, that subsidized credit often leads to results different from those being sought.

First, it is evident from experience in India and Pakistan that, if the technology being promoted is consistent with farmers' interests, then farmers will obtain inputs, either from internal financing or from a variety of non-official sources of credit.

Second, when the technology is not consistent with farmer interests, then subsidized credit will make little difference in the technology's diffusion. The credit will be used, to be sure, but not in the manner that justified the subsidy. Rather (and this is documented in many places) rationing of the limited supplies of subsidized credit will tend to be done in terms of the power structure. Those who occupy positions of power and importance will get the credit. This is a wind-fall gain for them, a transfer of wealth from other parts of the society. Moreover, those who receive the subsidy usually have access to credit through normal channels.

Some have tried a variant involving credit given in kind rather than in cash. This often leads to a transfer of inputs to others at low prices, and these users are usually among those who would have employed the inputs without the subsidy.

When the technology is right and sufficient credit is available for all potential users, then subsidized credit can be helpful. The latter condition is a stringent one.

So, with respect to subsidized credit, it is apparently neither necessary nor sufficient to the diffusion of new technology. Moreover, it is fully helpful only under quite stringent conditions.

Turning now to subsidized inputs, it should first be recognized that there are several ways in which inputs can be subsidized. All involve offering inputs to farmers at prices lower than the full cost of making them available. These strategies also suffer from certain disadvantages. What must be ascertained is: who will finally use the inputs, who will finally benefit from increases in production, and who will finally pay the costs of the subsidy?

In general, the argument seems to favor unsubsidized inputs. Each case, however, should be considered on its merits. For example, a case for subsidizing inputs can be made when it is thought that risks perceived by farmers exceed real risks. The effect of the subsidy is to reduce perceived risks, thereby encouraging use of the input. Experience with the input can, in turn, bring perceived risks in line with real risks. This can lead to more use of the input even when its price is no longer subsidized.

The market for the final product is also important for policy makers and those promoting the diffusion of new technology. Few in developing countries have clear impressions of the characteristics of their product markets--amounts marketed through various channels, marketing margins, or demands by final users. Beyond this, especially when increases in production are contemplated, knowledge of the systems' capacity to absorb output increases is critical. Failure to plan for adequate storage, transport, financing, and perhaps drying facilities, could well spell sharp price declines and substantial waste. These consequences can, in turn, lead to undesirable low levels of farm income and can restrain the spread of new technology.

These are the elements which require that an examination of the marketing system must be undertaken while new technologies are being developed. Emphasis must be given to identifying constrictions on the system's capacity to accommodate increased flows of product.

One strategy often mentioned as an essential ingredient in introducing new technology is that of guaranteeing prices at levels acceptable to farmers. These programs can facilitate the diffusion process. They are not costless, however, and might resolve today's problems only to create new, and perhaps more formidable, problems for tomorrow. Whether or not price supports are to be employed in an issue to be faced for each national program. The preceding discussion on risk and subsidized inputs might apply here. A decision on the issue will rest on the answers to a number of questions: What are acceptable prices for farmers? What do these imply for other crops? What do they imply for utilization of the product? Is there an apparatus for implementing price supports? Can the supports be made effective in the countryside? Can the guarantees be changed as circumstances change? Etc.

For the policy maker promoting rapid and pervasive adoption of new technology, then, the economist should provide analysis of the markets for inputs and production. These investigations will accent the characteristics of the distribution system--transport, treatment, storage, and financing--and its capacity to accommodate new demands. They will identify constrictions in that system which are amenable to policy (e. g., the allocation of public investment). They will look to identifying new domestic or international markets for the product.

Once the decision is made to increase production among a given set of farmers (all farmers from a given region) so as to achieve a given set of ends (increased farm income, lower real food prices in urban areas, safe foreign balances), then policies designed to achieve

these ends can be implemented. Literally dozens of levers are available to the policy maker. Which of these, if any, should be employed depends on how the ends of the policy maker combine with the circumstances of the farmer, the characteristics of the markets, and the potential strategies offered by the agro-biologists. Relating these elements, associating them with alternative policies, and making a convincing presentation to the policy maker will require the combined skills of the agricultural scientist and the economist.

12.4.6 CIRCUMSTANCES AND QUALITY PROTEIN MAIZE

Finally, what of analysis for quality protein maize? Under what circumstances will a policy maker opt for a program featuring such maize?

While quality protein maize has the obvious advantage of offering more lysine and more tryptophane to its consumers, these gains are not achieved without cost. There are some costs in managing such a program, but these are insignificant as compared with potential advantages. The predominant cost is in the delay in releasing new quality protein maize materials as compared with releasing new ordinary materials. This delay occurs because it will take two to three cycles to incorporate the quality maize with desirable kernel characteristics into the otherwise ready materials. This implies that a quality protein maize program is always some years behind a program based on ordinary maize. How many depends on how many cycles the breeder can supply in a year.

We have, then, marked advantages from quality protein maize. Against the advantages, we must set the cost of the lag in potential yields--a lag of from one to three years, depending on circumstances--when compared with ordinary maize. Here, again, the agricultural scientist, the economist, and the policy maker have an opportunity to collaborate.

The critical issue in choosing which strategy to follow--ordinary maize or quality protein maize--is the cost of protein foods (e.g., chick peas, beans, etc.) as compared with the cost of maize. (It seems quite unlikely that differentiation between the two will be possible in the market, hence both will sell for the same price.) The relative cost will, in turn, be influenced by agro-climatic factors, by access to markets, by marketing margins, etc. In general, when protein foods are scarce or expensive, policy makers will opt for quality protein maize programs.

12.4.7 ACHIEVING COLLABORATION

The preceding sections have described collaboration among biological scientists and economists. The aim, of course, is to facilitate the development and diffusion of new technology by national programs. Given this aim, it should be apparent that collaboration must occur in national programs as well.

CIMMYT seeks to promote this kind of collaboration through its maize and wheat programs by cooperating with economists from developing countries. Our adoption studies, involving economists and agricultural scientists from more than eight different countries, are an example. In the future, as national programs undertake to develop and introduce new technologies, CIMMYT will cooperate with local economists in studies like those described above.

While the modus operandi and the broad themes will be similar, the specific questions and the sources of data will be determined by each country's circumstances. These will be worked out in conjunction with the agro-scientists, policy makers, merchants, farmers, and economists of each national program.

12.5 SUMMARY

The preceding discussion has developed a perspective on collaboration among agricultural scientists, economists and policy makers aimed at increasing maize production. Emphasis was given to the need to make the actions of each consistent with the goals and relative access to inputs of the farmer, the critical decision maker in the production process.

In particular, technologies must be made consistent with the circumstances of the farmer. These circumstances are not only characterized by natural factors, but by other considerations as well. Here the discussion accented farmer goals -- increasing income while keeping risk within tolerable levels -- and access to inputs -- from on the farm and through the market.

Failure to identify the relative importance of goals and to assess the relative importance of constraints can jeopardize the technology's relevance to farmers' interests. Farmers will not adopt technologies which run counter to their goals and constraints. It was argued that collaborative research on farms and markets can help to make technologies more consistent with the interests of farmers. This will stimulate adoption and lead to greater production.

Subsequent discussion focused on markets for inputs and for products. Here, again, collaborative research, incorporating the special perceptions of agro-scientists and economists, can play an important role. The purpose of such research is to help policy makers to avoid surprises arising from unforeseen disruptions in marketing systems by identifying constraints on these systems as demands on them increase. A second important purpose is to offer to policy makers alternative strategies for eliminating constraints on the capacity to accommodate increased demands.

The overriding theme of the discussion is easily summarized. We are all participants in a drama of immense importance. The protagonist of that drama is the farmer; we -- scientists, economists, and policy makers and administrators -- are playing supporting roles. The forces impinging on the farmer's behavior as he chooses among technologies are multi-faceted and complex. Understanding and harnessing these forces will require the combined skills of all of us. Not to understand them or to understand only a few facets is almost certain to make us less effective than we might otherwise be. The opportunities open to us are too important to run this risk.

One final point. Developing and diffusing new maize technology adds to the welfare of consumers of maize and can add to the incomes of farmers. But, this undertaking can have another important consequence. As farmers become more effective managers of complex production strategies and as their willingness to accept risk increases, they will become more disposed to shift to other, higher valued crops. In this way, new maize technology can be the vehicle for introducing a catalytic element into traditional agriculture, an element which can lead to self sustaining change and improvement for farmers and the consumers of their products.

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TABLE 12-1

**Recent Maize Prices -- No. 3 Yellow, FOB Gulf Ports -- Dollars U. S.
per Metric Ton (rounded to nearest dollar).**

	<u>Annually^{i/}</u>	<u>1972</u>	<u>Monthly^{ii/}</u>		<u>1974</u>
			<u>1973</u>		
1964/65	\$ 56	Jul. 54	Jan. 77	Jul. 111	Jan. 123
1965/66	55	Aug. 55	Feb. 79	Aug. 124	Feb. 129
1966/67	59	Sep. 58	Mar. 80	Sep. 107	
1967/68	50	Oct. 57	Apr. 77	Oct. 105	
1968/69	49	Nov. 60	May 89	Nov. 110	
1969/70	54	Dec. 68	Jun. 101	Dec. 112	
1970/71	63				
1971/72	52				

i/ Annual figures are computed from World Grain and Rice Situation and Outlook, IBRD, Sec. M73-395, June 28, 1973, Table 2, taken from Commodities and Export Projections Division, Economic Analysis and Projections Department. The IBRD data report on No. 2 yellow maize at Gulf Ports. USDA publication available present No. 3 yellow maize at Gulf Ports. For six comparable months in 1972, the average difference (Price No. 2 less Price No. 3) was \$.18 per ton. The annual data reported by IBRD for No. 2 maize were diminished by \$.18 per ton to estimate the price of No. 3 yellow maize.

ii/ From "Guide to U.S. Commercial Sales". U.S. Department of Agricultural Services, Washington, D. C. 20250.

TABLE 12-2

FAO and USDA Projections to 1980 and to 1985 on World Production, Consumption, and Trade of Coarse Grains (millions of metric tons).

FAO ^{i/}	1980 <u>Implied Exports</u>
Class I (Developed Countries)	25.4
Class II (Developing Countries)	13.9
Class III (Centrally Planned Countries)	1.8
World	41.1

^{i/} From FAO Agricultural Commodity Projections 1970, 80, Vol. I, Rome, 1971, p. 97. Assumes constant prices and continuing trends. No effort to balance trade.

	USDA			1985 ^{iii/}		
	1980 ^{ii/}					
	Produc- tion	Consump- tion	Net Exports	Produc- tion	Consump- tion	Net Exports
Developed Countries	340.6	335.7	4.2	395.8	386.9	8.9
Centrally Planned Countries	199.9	198.4	1.5	267.3	269.3	-2.0
Developing Countries	163.3	169.0	-5.8	178.6	185.5	-6.9

^{ii/} 1980- From World Demand Prospects for Grain in 1980, Foreign Agricultural Economics Report No. 75, USDA, ERS, Washington 1971, p. 69, Set I.

^{iii/} 1985- From Anthony Rojko, "Future Prospects for Agricultural Exports", USDA, ERS, Aug. 1973. Data is from Table II, page 33.

Detail in 1985 projections is not sufficient to permit judging whether all categories are comparable with 1980 data.

TABLE 12-3

**USDA Projections to 1980 by Region for Developing Regions on Net Imports
of Coarse Grains (millions of metric tons)**

	Projections <u>ii/</u>				
	<u>Set I</u>	<u>Set II</u>	<u>Set IIA</u>	<u>Set IIB</u>	<u>Set III</u>
Central America/Mexico	2.2	.7	1.2	1.0	3.1
West South America	1.2	1.2	1.3	1.2	1.3
West Africa	2.8	2.2	2.4	2.3	3.3
North Africa	1.0	.4	.6	.5	1.6
West Asia	2.8	2.6	3.0	2.8	3.0
South Asia	2.8	2.4	2.6	2.5	3.2
East Asia/ Pac. Is.	3.7	1.3	1.8	1.6	5.2
Argentina	-7.0 ^{iii/}	-8.4	-7.8	-8.2	-6.0
East South America	-1.0	-3.0	-.8	-1.8	-
East Africa	-1.2	-3.3	-2.7	-3.0	-
Southeast Asia	-1.6	-2.9	-2.7	-2.8	-.9

i/ From World Demand Prospects for Grain in 1980, Foreign Agricultural Economic Report No. 75, USDA, ERS, Washington, 1971, p. 69, 74.

ii/ Set I assumes a continuation of late 1960 food and fiber policies, allowing for moderate gains in productivity in developing countries.

Set II allows for higher growth in productivity and in the economic activity in developing countries.

Set IIA has developed exporters maintaining earlier shares of the market.

Set IIB has developed exporters following world prices for grain.

Set III projects lower rates of growth in productivity and economic activity in developing countries.

iii/ Minus sign indicates net exports.

TABLE 12-4

55 Developing countries^{i/} with Annual Rates of Population Change^{ii/} in the 1960's and Annual Rate of Change in Maize Yields, 1962-4 vs 1967-9^{iii/}

Central America and Caribbean

	<u>Yields</u>	<u>Pop.</u>		<u>Yields</u>	<u>Pop.</u>
Costa Rica*	- .1	3.3	Honduras	2.6	3.1
Cuba	- .3	2.1	Mexico	2.0	3.5
El Salvador	5.3	3.7	Nicaragua	.8	3.3
Guatemala	1.6	3.1	Panama	.2	3.3
Haiti	.4	2.0			

South America

	<u>Yields</u>	<u>Pop.</u>		<u>Yields</u>	<u>Pop.</u>
Argentina	4.0	1.5	Paraguay	- .3	3.1
Bolivia	1.7	2.6	Peru	2.2	3.1
Brazil	1.3	2.9	Uruguay	.8	1.3
Colombia	.4	3.2	Venezuela	.5	3.5
Ecuador	.5	3.4			

Asia

	<u>Yields</u>	<u>Pop.</u>		<u>Yields</u>	<u>Pop.</u>
Afghanistan	- .1	2.0	Nepal	-1.4	1.8
Burma	-1.0	2.1	Pakistan	.9	2.7
India	1.9	2.9	Philippines	3.3	3.0
Indonesia	- .3	2.0	Thailand	3.2	3.1
Khmer Rep.	-2.0	3.2	Vietnam	.6	2.6

Africa

	<u>Yields</u>	<u>Pop.</u>		<u>Yields</u>	<u>Pop.</u>
Angola	1.4	1.3	Morocco	- .9	2.9
Burundi	1.1	2.0	Mozambique	2.5	1.9
Cameroon	1.6	2.1	Nigeria	2.4	2.9
Dahomey	.9	2.9	Rhodesia	1.7	3.2
Ethiopia	2.0	2.2	Somalia*	8.5	2.4
Ghana	1.0	2.6	South Africa	.4	3.0
Guinea*	.3	2.6	Tanzania	- .8	2.5
Ivory Coast	1.4	3.0	Togo	-1.3	2.9
Kenya	3.7	3.1	Uganda	.3	2.7
Lesotho	-2.1	2.8	U.A.R.	4.8	2.5
Madagascar	-1.7	1.5	Upper Volta	- .6	2.1
Malaur	1.3	2.6	Zaire	1.8	2.8
Mali	-4.3	2.1	Zambia	5.1	2.5

Near East

	<u>Yields</u>	<u>Population</u>
Turkey	1.7	2.5

^{i/} Countries included are all those developing countries with more than 100,000 hectares of land in maize or more than 10% of total calories in average diet from direct consumption of maize. Production data are from FAO Production Yearbooks average area 1967-71. Dietary data are from FAO Agricultural Commodity Projections, 1970-1980, Vol. II, Table A, pp. 85-128 and apply to the years 1964-65-66.

^{ii/} The rate for yields is from the equation $Y_9^* = (1+r)^6 Y_3^*$ where Y_3^* is a three year average centered on 1963 and Y_9^* is the three year average centered on 1969. Yield data are from FAO Production Yearbooks. Solving such an equation for 'r' for each country estimates the annual average rate of change in yield for the period 1962 through 1970.

^{iii/} Rate of change in population is the annual compound rate implied by data on population in FAO Production Yearbooks for 1960 to 1969. For each country, the rate is the solution for 'r' in the equation $P_{69} = (1+r)^9 P_{60}$

TABLE 12-5

Yields Puebla and Pakistan: For Traditional Farmers, for Farmers Using New Technology, and for Experimenters.

	<u>Plan Puebla</u>	<u>Punjab</u>
Experimental Yields ^{i/}	6.64	4.50
Adopters Yields ^{ii/}	2.80	2.50
Traditional Yields ^{iii/}	1.89	1.48

i/ The Puebla yield is the average for 1968 and 1969 calculated from estimated response surfaces based on experimental data using profit maximizing levels of fertilizer. 1 The Pakistan yield is the average of nine experiments seeded in November, 1968, at Lyallpur Station. 2 All were in Mexipak, the then dominant variety of dwarf wheats. (It should be noted that wheat yields for this seeding were reduced somewhat by hot winds during the growing season).

ii/ The Puebla yield is from 3, Discussion Paper No. 8, Table IV for 1969 (1968 is not representative as it involves only 103 farmers, all carefully monitored by Puebla staff). Pakistan is for all wheat seedings, 1968, as reported in 4, p. 11.

iii/ The Puebla yield is the average for 1968 and 1969 as reported in 3, Discussion Paper No. 8, Table IV. While Pakistan is for fall seedings, 1968 as reported in 4, p. 11.

* From Winkelmann, "Plan Puebla After Six Years", (Forthcoming).

1 Antonio Turrent, "Value of Agronomic Research in a Project to Rapidly Increase Crop Production," in Delbert Myren (Ed.) Strategies for Increasing Agricultural Production on Small Holdings, Centro Internacional de Mejoramiento de Maíz y Trigo, Mexico, D. F., 1970 pp. 40-41.

2 Fourth Annual Technical Report, Accelerated Wheat Improvement Program, West Pakistan, 1968-69, Lahore, September 1969, pp. 28-29.

3 CIMMYT Program Review, 1971, CIMMYT, Mexico. (Mimeo).

4 Jerry B. Eckert, "The Economics of Fertilizing Dwarf Wheats in Pakistan's Punjab, (Mimeo), July 1971.

TABLE 12-6^{i/}

Percent of Sampled Puebla Farmers Planting Different Densities of Maize by Year 1968-1972

	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>
0 - 20,000	12.4	10.7	5.2	16.1	3.7
20,001 - 30,000	38.4	39.5	38.8	29.2	23.5
30,001 - 40,000	35.2	34.0	30.8	28.8	33.6
Over - 40,000	14.0	15.8	24.9	25.9	39.2

^{i/} Data are from "Reporte del Programa de Evaluación" Plan Puebla 1972, p. 15.

TABLE 12-7

Percent of Sample Farmers Adopting Hybrids and Percent With Maize Intercropped by Region and Farm Size - Kenya 1972

	<u>Hybrid Maize</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
Smallest ^{ii/}	80	77	6
Largest ^{ii/}	86	79	23
Special		94	
	<u>Maize Intercropped</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
Smallest ^{ii/}	30	37	62
Largest ^{ii/}	46	22	75
Special		15	

^{i/} Data are from a joint CIMMYT/Kitale Station survey in 1973. This is a part of a larger study now underway in collaboration with John Gerhart.

^{ii/} Farmers were arrayed by size for each agro-climatic region. For each region, except Region 2, the 50% (roughly) with least area are in "Smallest". Special in Region 2 includes all farmers with more than 50 acres, usually former European farms.

TABLE 12-8^{i/}

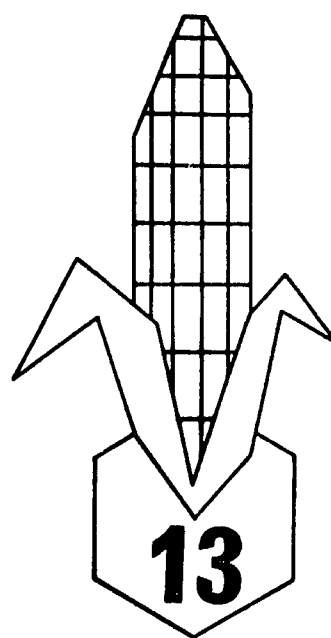
Percents of Sample Farmers Adopting Hybrids and Percents using Insecticide by Region and Farm Size in El Salvador in 1972

	<u>Hybrids</u>	
	<u>Hillside</u>	<u>Valley</u>
Smallest ^{ii/}	17	36
Largest ^{ii/}	33	51

	<u>Insecticide</u>	
	<u>Hillside</u>	<u>Valley</u>
Smallest ^{ii/}	6	19
Largest ^{ii/}	31	50

i/ Data are from a CIMMYT sponsored survey in 1973. They will form part of a more detailed study now underway by Jesus Cutié.

ii/ Farms were arrayed by size for each agro-climatic region. For each region the half (roughly) having the smallest area are in 'Smallest'.



OUTREACH PROGRAM

by
Keith W. Finlay, CIMMYT

Lead Discussant:
Dr. Gordon McLean
The Ford Foundation
Cairo, Egypt

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13.0

OUTREACH PROGRAM

by
Keith W. Finlay

13.1 INTRODUCTION

CIMMYT coined the term "Outreach" to encompass activities outside its program in Mexico; particularly those activities which assist and strengthen national maize and wheat programs in developing countries. This paper seeks (1) to describe CIMMYT's philosophy, and the complex networks of men, genetic materials, and institutions that make up the total Outreach program; and (2) to consolidate staff member ideas concerning the future trend in Outreach efforts.

The Outreach concept has developed within two major divisions. Most of the present maize Outreach activities have been initiated since 1970, when Dr. Ernest W. Sprague was appointed as Director of the International Maize Program. In sharp contrast, the International Wheat Program's Outreach program has been developing since the 1950's, under the continuous direction of Dr. Norman E. Borlaug (first, as part of the Mexican Government-Rockefeller Foundation program, and since 1966, as part of CIMMYT's program). Occasional reference is made to the total CIMMYT Outreach program, or to the Outreach activities of the Wheat Program, when they provide a useful example. Central focus, however, is on the Maize Program.

Although the various aspects of the Outreach and Resident Research activities are fully integrated to form the International Maize Program, they are discussed here separately as: (1) national maize programs, (2) network of genetic materials, (3) network of institutions, and (4) network of men.

13.2 MAIZE OUTREACH ACTIVITIES

CIMMYT believes that it should apply its limited resources of facilities and manpower to help strengthen national maize and wheat programs of developing countries so that they can exploit more of their production potential.

With the rapidly increasing world population, periods of food grain shortages can be expected more frequently and of greater severity. As has been seen during the past 12 to 18 months, the developing countries with deficit food production tend to suffer most in these periods of stress, largely because of the lack of sufficient foreign currency to pay the greatly inflated world prices.

Of the 55 developing countries in the Americas, Africa, and Asia that plant more than 100,000 ha. of maize, only six countries produce more than two tons per hectare and 17 countries produce less than one ton per hectare.

13.2.1 NATIONAL MAIZE PROGRAMS

13.2.1.1 The Approach

Requests for CIMMYT's assistance are (1) received directly from a government official, or (2) more commonly, channeled through or stimulated by an agency already cooperating with that government, for example, the United States Agency for International Development (USAID), the Ford Foundation, or other such organizations.

The requests usually ask for "assistance to increase maize production" or "help to make our country self-sufficient in maize production." A few requests seek increase of maize production for export.

13.2.1.2 The Response

The CIMMYT staff tries to respond quickly to all requests. A small team of CIMMYT maize scientists visits the country to survey the government's agricultural structure and the extent and level of production, and to discuss the problems of production with government scientists, university staff, farmers, seed producers, and relevant industry groups.

This survey provides a basis for discussion with the Director of Agriculture and the Minister of Agriculture. At this meeting, the team gains an impression of the degree of government commitment to

increasing crop production. Without such commitment, it seems unlikely that a sound and effective national program can be developed. If the government has a strong desire to move ahead and can furnish the necessary funds and people, a plan of action is proposed.

13.2.1.3 The Plan

The requirements of each country are different, but CIMMYT staff have found it useful to approach the planning as follows.

Few developing countries have an adequate number of trained scientists to staff a national crop program. For this reason, a staffing pattern is drawn up based on the size and ecological diversity of the country and the size of its production area.

A headquarters research staff of breeders, agronomists, crop protection specialists, and quality technicians probably will be needed in most countries, with their number and level of training varying from country to country.

This headquarters group will be supplemented by smaller regional research and production groups. Each of the main ecological areas of production will have one such group based on a strategically located experiment station. Crop selection and production with vigorous on-farm testing will be emphasized heavily by the groups.

The staffing plan can be used as the focal point of a total phased national program development plan, and as such, has a number of advantages:

- (1) It can be laid out in a simple diagram that lists the names of existing staff along with future positions needed and the level of training desired for each position. This diagram can be easily understood by both scientific and policy-making staff.
- (2) Each position has a job description which helps the staff understand exactly what their roles will be.
- (3) The staffing plan is also a training plan. A time scale can be fitted to indicate (a) when particular staff will be away for training, (b) for how long, (c) function of training, and (d) very importantly, which position they will occupy when they return to the national program.

For most developing countries, it seems likely that the initial training plan will require 12 to 15 years (especially if it is necessary to allow for staff who will be promoted up to fill the voids that may exist in administration, or who are transferred to other parts of the service. This type of manpower use does not really constitute wastage in terms of the total agricultural effort of the country.

Training plans require an extensive budget. Thus, outside support often is sought for this important part of the program, especially if most of the training has to be undertaken outside the country.

- (4) Job descriptions within the plan serve as a focal point in developing logical work plans with a time scale projection. When projections are coupled with the training schedule, a total dynamic development plan is created. Often this planning is the first such experience for many research directors and policy makers in the logical development of a national program.
- (5) A monetary budget can be built around the plan at this point to indicate what financial support will be required for both present and future operations. Foreign currency support requirements can be anticipated and kept small to stress the point that the planned program is a national effort, which can only be sustained by national resources of finance and manpower.
- (6) A dynamic plan will show in the long run that a national program can be initiated immediately on a small scale, then gradually built to an optimum level for a particular country's needs.
- (7) Although the plan deals with only a single crop, it provides invaluable experience in planning, initiating, and operating a national crop commodity research and production program. The experience can be applied to other crop programs by the national staff, serving as a model for training the local administrators and policy makers.
- (8) The plan also can be used to highlight some of the peripheral infrastructure needs that may be basic to improving national production (for example, fertilizer supply and cost, floor price for the product, adequate seed supplies and markets, etc.).

CIMMYT's experience has been that this type of planning is very well received and readily understood when discussed at the time of the first survey of the national needs.

13.2.1.4 CIMMYT's Role

Depending on the degree to which the government is willing to commit itself, the size and complexity of the proposed program, the size and sophistication of the existing research effort, etc., CIMMYT may offer some or all of the following services:

- (1) Staff to assist the local staff to establish and operate a national maize program.
- (2) Training opportunities at CIMMYT or at graduate schools for scientists, and observation tours for administrators and policy makers.
- (3) Breeding or advanced populations of maize from which suitable varieties may be selected.
- (4) Consulting visits of CIMMYT headquarters or regional staff to assist with planning or particular research or production problems as they arise

(Some of these services, particularly (1) and (2), would be subject to the availability of CIMMYT support funds.)

After a program has reached an appropriate stage of development, a laboratory technician could be trained to assist the breeders in identifying quality protein maize selections. The necessary equipment for a small quality-protein laboratory also could be provided as part of the UNDP/CIMMYT quality protein maize global research and training program.

During the past two years, the CIMMYT maize staff (sometimes in collaboration with other agencies) has surveyed the national maize research and production needs of the following countries:

Latin America and the Caribbean: Argentina, Belice, Colombia, Ecuador, Guatemala, Jamaica, and Venezuela.

Africa: Ethiopia, Ghana, Ivory Coast, Kenya, Malawi, Nigeria, Tanzania, Zaire, and Zambia.

Middle East: Egypt, Iran, and Turkey.

Asia and Southeast Asia: India, Indonesia, Malasia, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand.

CIMMYT has assigned staff to assist the governments of Egypt, Nepal, Paksitan, Tanzania, and Zaire (Tanzania and Zaire in collaboration with the International Institute of Tropical Agriculture-- IITA). The maize programs of IITA in Nigeria and CIAT (International Center for Tropical Agriculture) in Colombia collaborate with the CIMMYT international program.

All CIMMYT Outreach country assistance programs are presently funded by special grants in both the maize and wheat programs. This type of funding has proved satisfactory.

13.2.1.5 Features of National Program Assistance

CIMMYT staff members believe that some features of the assistance plans are especially important as guiding principles:

- (1) Governments of developing countries recognize that CIMMYT does not represent a particular government, nor does it represent a formal regional or international agency. As such; it is providing advice with "no axe to grind." Honest, straightforward advice is given and accepted. Any funding arrangement that links, or appears to link CIMMYT to a donor nation or donor organization and to act as an agent of the sponsor, tends to weaken the neutral role of CIMMYT in the eyes of the government being assisted.
- (2) Assistance should aim specifically at strengthening the national maize or wheat program. A strong national program can provide direct technical support to local rural development projects and other projects of an agricultural nature. However, outside sponsorship to a localized project could lead to an undesirable congregation of limited resources of trained manpower, finance, and equipment, often to the detriment of the national effort as a whole.
- (3) National programs should be assisted to develop strong and functional linkage between research and extension; this linkage would extend from the central research station, through adaptive research on regional experiment stations, and out to farmers' fields.

It is vitally important that research does not stop at the experiment station gate.

- (4) Strategically placed experiment stations should be fully developed with proper land management and technical supervision. Their research results should be accurate enough for making recommendations for on-farm trials. Poor experiment station development and administration is almost universal in developing countries. There is little value in training agricultural researchers if their experimental sites are so poor that no meaningful information can be obtained. To date, this is a feature of assistance that has not received sufficient emphasis.
- (5) Too much emphasis has been given to breeding hybrids of maize with very high yield potential on the research station, but which do not fit the local farmers' requirements for grain type or his farming system, or his access to reliable seed. Greater effort should be made to test the types suited to local needs on local farms and let the farmer make the final selections.
- (7) On-farm testing and selection of open pollinated varieties can provide an adequate supply of seed to distribute to farmers in the region. Because on-farm testing is part of the total research effort, all of the latest advanced populations will be available for selection by farmers who can make their own choices. Desirable selections will quickly be sold and distributed to neighbors, ensuring rapid upgrading of the production potential.
- (8) The complete reevaluation of the types of maize required in developing countries, as well as the methods of producing them, has led to the development of the breeding and germplasm handling procedures described earlier in the Symposium.

CIMMYT scientists do not view the continued improvement of maize and wheat research in developing countries as an isolated phenomenon, but as a process that benefits immeasurably by the interchange of materials, technology, and experiences on a regional and interna-

tional scale. The networks of genetic materials, institutions, and men to support this concept are now in operation. These operations are discussed in more detail in the following sections.

13.2.2 NETWORK OF GENETIC MATERIALS

Previous speakers have provided accounts of how CIMMYT is distributing germplasm from the maize germplasm bank; the new varieties being bred in collaboration with scientists in every continent; the testing, selecting, and utilizing of these materials on a global basis.

In 1973, approximately 1,500 sets of breeding materials representing various stages of development of maize and wheat were distributed by CIMMYT to collaborators in more than 85 different countries. CIMMYT's efforts are greatly augmented by the interchanges of breeding materials from nation to nation and within and between regions in collaboration with FAO, the Arid Land Agricultural Development Program in Beirut, the Inter-Asian Corn Program headquartered in Thailand, the Central American Corn Program, IITA and the West African Maize Program, the corn program of tropical East Africa headquartered in Kenya, CIAT, and the Andean Corn Cooperative programs--thus accounting for a further large quantity of germplasm.

As never before in history, the varieties of maize or wheat in almost every cereal-growing area of the world have been influenced by this immense interchange of genetic material. The process is self-stimulating, with new cycles of data and elite selections returning from various parts of the world for re-introduction within the breeding gene pools.

This elite genetic material is selected under every conceivable growing condition--hot, cold, wet, dry, good soil, poor soil, at sea level, on mountain tops, at the Equator, at high latitude, short days, long days, and under attack from diseases and insect pests.

All cooperation is voluntary and differences of political views, religions, and ethnic backgrounds--even wars--have not stopped the flow of improved germplasm between countries.

Each national program cooperating within the network has access to all of the material and information from the entire network program--a breeding program that could never be duplicated in any one place in the world.

Because of the availability of these breeding materials, CIMMYT advises that many national programs limit their improvement work to selection from within that distributed, and not under-

take a direct breeding program. As competent staff become available, some programs will be encouraged to initiate a modest breeding program to incorporate valuable characters from local varieties.

13.2.3 NETWORK OF INSTITUTIONS

CIMMYT has been building an increasingly diverse network of collaborative links with institutions throughout the world. Mention has been made of the cooperation with agricultural research organizations in more than 85 countries through the international breeding program. However, there are a number of other avenues for linkage-- financing, research cooperation, and training.

13.2.3.1 Financing

CIMMYT initially was financed solely by the Rockefeller Foundation, with assistance from the Mexican Government. Then the Ford Foundation and the United States Agency for International Development contributed.

With the formation in 1970 of the Consultative Group for the Support of International Agricultural Research, the level of support to CIMMYT and the other International Centers improved significantly. CIMMYT received financial contributions from additional organizations: the Inter-American Development Bank; the United Nations Development Program; the Canadian International Development Agency; the International Development Research Center of Canada; the World Bank; and the governments of the Federal Republic of Germany, Denmark, the United Kingdom, and Zaire.

Apart from the contribution of funds, many of the above organizations or governments have encouraged cooperation between CIMMYT and other organizations supported by them. This approach has led to cooperation between CIMMYT and other institutions in areas of research, production, and training.

13.2.3.2 Research and Production

Agencies, such as UNDP, the Rockefeller Foundation (RF), the Ford Foundation (FF), USAID, and IDRC, that assist the development of national, regional, or global programs of research and production have contracted with CIMMYT to assist with maize and wheat programs at:

National Level in: Nepal (USAID), Pakistan (FF), Turkey (RF), Egypt (FF), Tunisia (FF), Algeria (FF and IDRC), and Tanzania (FF and USAID).

Regional Level: The Inter-Asian Corn Program (RF) and the Arid Land Agricultural Development Program (ALAD-FF).

Global Level: (UNDP).

Since 1966, the research program in Mexico for both maize and wheat has grown in both extent and complexity. The Outreach program also has grown considerably. The expansion and increasing complexity of these programs has created a need for more research of a basic nature to ensure rapid and continued progress.

CIMMYT scientists believe that their own research should continue to be "production oriented," and that more basic research to support their work should be conducted in collaboration with scientists in universities and national research institutions that are specifically equipped for this work.

During the past few years, CIMMYT has entered into a number of formal cooperative research programs with research organizations in the United States and Canada; including, Oregon State University (bread wheat), University of California (bread wheat), Purdue University (maize), Cornell University (maize and Doctoral training), Kansas State University (wide crosses and Master's training), and Manitoba University (Triticale). Funds are being provided to these cooperating research groups by agencies who also support CIMMYT, such as USAID, the Rockefeller Foundation, CIDA, and IDRC.

Apart from these formal arrangements, CIMMYT scientists have formed a considerable number of informal cooperative links with research institutions in many different countries, including: Australia, Canada, Colombia, Egypt, West Germany, East Germany, Hungary, Mexico, the Netherlands, Rumania, Sweden, the United Kingdom, the United States, and Yugoslavia. This cooperation is in the fields of genetics, cytology, breeding, physiology, pathology, entomology, biochemistry, and nutrition.

These research links provide a valuable contribution to CIMMYT's resident and Outreach programs. More importantly, they offer a means of linking basic research into the network of national programs via CIMMYT--thus benefitting developing countries more rapidly and efficiently.

The training component is extensive and diverse and will be dealt with as part of the network of men.

13.2.4 NETWORK OF MEN

CIMMYT has always emphasized that competent men are the key to vigorous, effective action and change. Money and equipment will have little effect on improving agricultural production without dedicated, vigorous, innovative men to use them effectively. For this reason, training in various forms is a key part of the CIMMYT approach to strengthening national programs.

Another speaker has discussed the CIMMYT maize training program. Thus, this paper considers only one or two aspects of training associated with the Outreach program, and those aspects will deal with the network of men, rather than training per se.

CIMMYT staff believe that one of the greatest strengths in international work is a network of alumni from the training program that now numbers approximately 740 alumni from 60 countries. Grouped under the title of "CIMMYT alumni" are the following, In-service Trainees, Pre-Doctoral students, Post-Doctoral Fellows, Visiting Scientists, and Visiting Policy Makers.

When coupled with the 1,200 to 1,500 cooperators (including some of the alumni) who have a kinship with CIMMYT through the cooperative nursery programs, there are few countries in the world where CIMMYT does not have direct personal contacts at a policy or operational level in government. These contacts have helped build recognition and credibility for CIMMYT which is of inestimable value.

The contact between CIMMYT staff and the staff of funding and research organizations provides a further expansion of the network of men. These contacts increase the flow of new knowledge, ideas, and critical comments necessary for continuously improving planning, administration, and research at CIMMYT, and thus its service to the network as a whole.

13.3 A LOOK TO THE FUTURE--OUTREACH IN THE BALANCE OF THE 1970'S

If this expanding international network of men dedicated to improving the world food supply is going to be fully effective, it will need to have: (1) adequate financial support; (2) genetic materials with a large potential for improving yield and quality of grain; (3) the technology to economically exploit the potential of the improved varieties; (4) an efficient communication system for the multi-directional flow of materials and information between needy national programs, collaborating institutions, and CIMMYT; (5) most importantly, a means of increasing the number of trained national scientists; and (6) a means of creating

and maintaining an atmosphere of urgency, excitement, and accomplishment among cooperators throughout the entire network.

What are CIMMYT's plans to improve the existing maize Outreach and supporting networks to provide a more effective service to the national programs of developing countries during the balance of the 1970's?

During the past few months, CIMMYT maize staff have organized their resident research program in Mexico as described in the previous discussions. This organization is designed to provide (1) the improved maize populations suitable for use in the various climatic regions of the world; (2) the basic technology necessary to exploit the varietal potential; and (3) increased consultation time for senior experienced maize staff in client countries.

Drs. Elmer Johnson (maize breeding), Alejandro Ortega (plant protection), and Peter Goldsworthy (agronomy-production) will assist Dr. Ernest Sprague in this consulting work. This change in role of senior staff stems from the needs of many national programs for help in the design of their research programs, identification of pests and diseases, selection of material and methods for on-farm testing and seed increase, etc.

During the two years 1972 and 1973, 22 maize staff made 160 visits to 38 countries for a total of 1,375 days. That means about four man-years of travel. Even with this amount of travel and the recent changes to step up senior staff consulting, CIMMYT believes that it is not possible to service the present and future client programs wholly from Mexico.

With these facts as background, the maize staff have been planning collaborative research and a network of regional services for each of the major maize growing regions of the world.

13.3.1 COLLABORATIVE RESEARCH

There are some aspects of the CIMMYT research programs which cannot be performed in Mexico, generally because the necessary climate or diseases or insects do not occur in Mexico; for example, the breeding of maize populations resistant to maize stunt in Central America, maize streak in Africa, and downy mildew of maize in Southeast Asia

CIMMYT staff believe that in future years this type of research should be considered part of its basic research program but carried out in collaboration with selected national programs.

This approach would ensure that the collaborative research projects could be initiated at the most opportune time to be integrated into the total international research effort.

CIMMYT proposes to initiate several of these collaborative research projects during the next three to four years, particularly the disease resistance breeding projects mentioned above.

13.3.2 REGIONAL SERVICES

Each region is seen as unique; therefore, the actual format for the regional services will vary to some extent from region to region. However, certain principles in planning that seem to apply to all regions include:

- (1) It is now proposed that CIMMYT assign staff to maize-producing and wheat-producing regions outside Mexico, to perform supplemental services for regional groupings of national programs. These regional staffs would find their administrative "home" with a national or regional organization or would be employed by the regional organization, but with close technical links to CIMMYT.
- (2) The regional service staff should devote most of their time to development of national programs.
- (3) To service national programs in the region, CIMMYT favors stationing at least two full-time specialists in the region to increase the consulting services. These specialists could be:
 - (a) Production agronomist: He would review each season's maize production program of each client government; consult on national research, on-farm trials, seed multiplication; advise on targets, inputs required, and policies; attend the annual extension and research meetings, etc.
 - (b) Agronomist-trainer: He would help national programs plan and carry out training programs for production agronomists. (This training proposal assumes that international centers like CIMMYT will be able to provide adequate training for national researchers, and for national trainers, but not for the large number of extension workers.)

(4) Other services provided to national programs with the assistance of the above two specialists would be:

(a) Distribution of advanced germplasm in the form of nurseries, with the nursery entries originating from the national breeding programs or from CIMMYT international breeding program.

In order to assemble nurseries, the regional staff would require about 15 ha. of land for seed increase, followed by assembling of populations and distribution to national programs.

(b) Provide regular contact with former trainees in national programs.

(c) Assist national scientists to organize annual maize workshops.

(d) Assist in selecting new trainees for training outside the region, either in academic institutions or in international centers like CIMMYT.

(e) Keep national scientific staff up to date with new developments anywhere within the region by circulating a newsletter and arranging for occasional visits among programs by relevant staff, especially when interesting or innovative features can be interchanged.

13.3.3 SUGGESTED REGIONS REQUIRING SERVICE

CIMMYT maize staff have been studying the needs of the following regions with respect to present services and future requirements: Southeast Asia and South Asia, East Africa, West Africa, Central America, Andean Region, and the Southern cone of Latin America.

Each of these regions is presently receiving various types of regional services from different organizations in collaboration with CIMMYT:

Southeast Asia and South Asia have been receiving assistance from the Inter-Asian Corn Program financed by the Rockefeller Foun-

dition. Discussions are continuing for CIMMYT to provide regional services to this region.

East and West Africa are being serviced collaboratively by IITA and CIMMYT. Discussions of the type of services, and collaborative arrangements, are proceeding with IITA.

The five Central American countries and Panama have had a collaborative regional program for a number of years with assistance from CIMMYT, financed up until 1972 by the Rockefeller Foundation. Further assistance is being discussed with governments of the region and with the Inter-American Development Bank and the Rockefeller Foundation.

CIAT has operated a regional assistance program for the Andean Region since 1969. Agreement between CIAT and CIMMYT was reached recently on the nature of this program in close cooperation with CIMMYT.

No regional program has operated for the Southern cone of Latin America, although CIMMYT has provided assistance from Mexico. A proposal is currently before the Inter-American Development Bank for support of regional services to be operated by the Instituto Interamericano de Ciencias Agrícolas (IICA). Due to political uncertainties in this region, the proposal is held in abeyance.

13.3.4 AN EXAMPLE

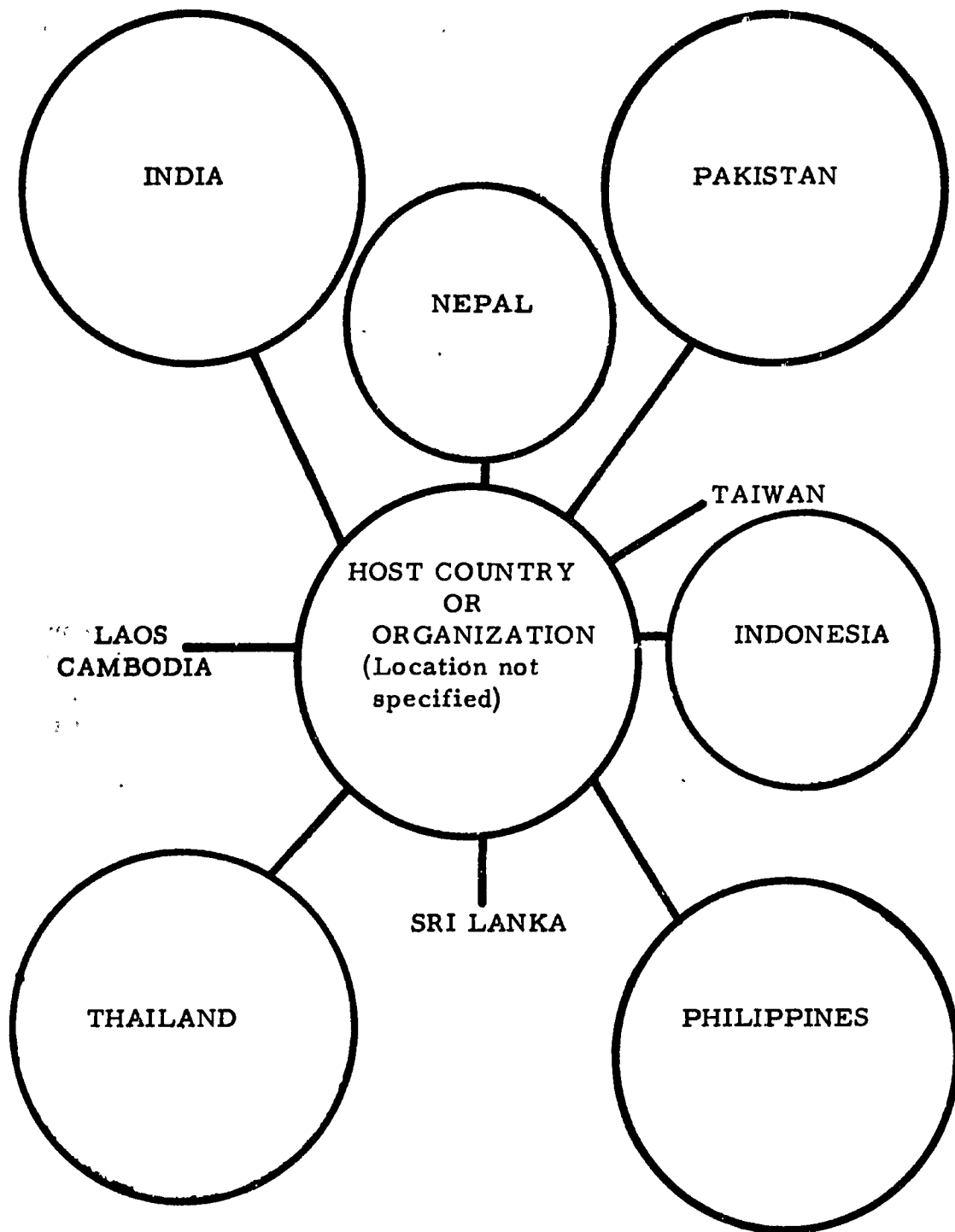
The maize staff envisage regional services in the Asian and Southeast Asian regions. The host country or organization is not yet specified.

Fig. 1 shows the various countries with maize programs: India, Pakistan, Philippines, and Thailand with large national programs; Nepal and Indonesia with smaller programs; and Taiwan, Sri Lanka (Ceylon), Laos, and Cambodia with small national programs.

The regional staff would provide the services discussed previously (13.3.1).

For the development of improved varieties within the region, the CIMMYT maize staff believe that the following arrangement would be effective:

Because it is felt that there are far too many populations being handled in national breeding programs, the entire



Size of circle indicates size of national maize program.

Uncircled countries have lesser maize research capability.

Fig. 1. National maize programs by country.

Asian region will require no more than 12 to 15 populations suited to national programs. This is based on the following estimates:

India--four to eight populations (one or two populations for each of four maize experiment stations)

Pakistan--three populations (for three provinces)

Thailand--two populations

Philippines--three populations

All other national programs should receive one of the above 12 to 15 populations, but should not try to create their own populations. Thus, the Asian maize-growing countries can be divided into three groups: (a) five countries that generate special populations, (b) several countries that test special populations (Sri Lanka, Nepal), and (c) countries that receive experimental varieties (those least supplied with research resources).

13.3.5 RELATIONAL AND REGIONAL SERVICES TO CIMMYT SERVICES

Does the regional service concept replace the services from CIMMYT?

The regional services would provide a far greater volume of consulting contacts with national programs than CIMMYT has been able to supply in the past.

CIMMYT headquarters staff would continue to travel--particularly the senior staff, although junior staff also would be provided with opportunities to visit regional and national programs to build up their experience. When travelling in a region, headquarters staff would be accompanied by a regional specialist whenever possible. And CIMMYT would continue to train researchers, laboratory technicians, and experiment station managers in Mexico. CIMMYT staff also would attend workshops in the region, and would continue to hold some world-wide seminars at CIMMYT.

In short, the regional service program would greatly expand the services to national programs, with continued assistance from Mexico.

13.3.6 FUTURE CIMMYT PERSONNEL REQUIREMENTS FOR OUTREACH

If CIMMYT proceeds to carry out a plan for six suggested regional service programs for maize production over the next five or eight years in regions listed above, this might require eight additional regional staff capable of providing the listed services.

At the same time, replacements will undoubtedly be needed for some of the nine maize staff now assigned outside Mexico. Additional national programs may require bilateral assistance--such as for the present request from Turkey. Thus, there could be a requirement for recruitment of approximately 15 to 20 men during a six-year period.

CIMMYT's best source of new staff is presently the Post-Doctoral program which has now been expanded to five maize fellows every two years, and we are working towards a tempo of five new maize fellows every year.

In a six-year period, the Post-Doctoral program could train 30-40 new maize men; not all of these men will be available for employment. Allowance should be made for a 50% "slippage" or rate of non-availability; either because the individuals come from developing countries (hence, they are expected to serve their own national programs), or because the individuals prefer to engage in some other kind of service after their CIMMYT training. To obtain a total of 15 to 20 new maize scientists in the international program, CIMMYT would have to plan on about 30 to 40 maize Post-Doctoral Fellows in six years. Such a recruitment system, when combined with personnel identified from other sources, should provide up to 20 new maize scientists for employment in Outreach activities.

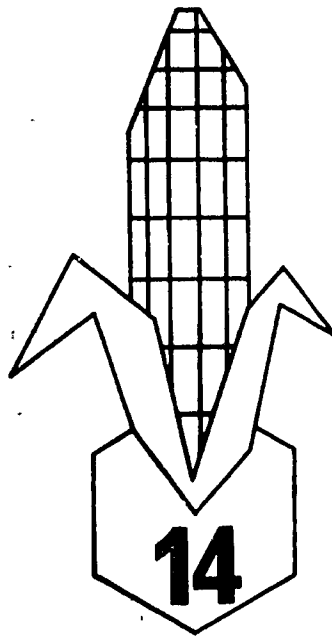
13.3.7 FUTURE OF THE NETWORK

CIMMYT foresees continued expansion of all its Outreach networks--genetic materials, institutions, and men--if it is to keep pace with the demand for services to national programs. Funds are needed to finance the regional services and assistance to national programs.

As activities widen into different environmental and ecological situations, added research support will be required: studies of drought resistance, root growth, insect pests, etc. The network of institutes will require additional linkages, as well as consolidation of some of the ad hoc arrangements presently operating.

The whole program reflects the growing and strengthening network of men--the ultimate strength and hope of the program.

An excellent start has been made, but there is an urgent and difficult job ahead that will require all the goodwill and assistance that can be assembled throughout the world--the job is too big for any one organization. However, the building and strengthening of the world-wide networks of genetic materials, institutes, and men can perhaps shift the balance against major famine until mankind brings population growth under control.



SYMPOSIUM DISCUSSIONS

**(Each Lead Discussant's paper summarized,
with selected questions and answers.)**

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14.0

SYMPOSIUM DISCUSSIONS

14.0 INTRODUCTION

In this section, each of the lead discussant's contributions is reported in abbreviated format, along with selected comments, questions, and answers from the respective discussion sessions. Although the discussion has been condensed and edited for consistency of style, the Symposium Editorial Board has made every effort to retain each participant's emphasis and philosophy.

To protect the participants who presented papers, and those who entered freely into discussions, we request that any quotes or other use of the material be cleared with the respective authors or discussants.

14.1 DISCUSSION TOPIC 1

The Role of Maize in World Food Needs to 1980
by Haldore Hanson, CIMMYT

Lead Discussant: Dr. Don Paarlberg, Director, Agricultural Economics, U.S. Dept. of Agriculture, Washington, D. C.

The discussant said that he agreed with the cautious optimism of the Hanson paper. The discussant observed that the world has suffered a series of shocks since 1972, and their consequences are still hazy. Nevertheless, some of the shocks can be regarded as temporary and others as likely to be important for some time. Among the passing phenomena are the poor crops of 1972--the weather cycle does not seem to have turned adverse, badly depleted food stocks (stocks will not reach levels of five years ago, however), and the fuel and fertilizer crisis (although fertilizer prices will be higher). The changes with more lasting influence are: inflation--prices of all commodities will continue to rise; the pressure of rising incomes on the demand for animal products, and in turn on the grain supply to feed animals; and increased grain trade between Communist and non-Communist nations.

14.2 DISCUSSION TOPIC 2

What Limits World Maize Production?
by E. W. Sprague, CIMMYT

Lead Discussant: Dr. Bill C. Wright, Agricultural Project
Leader, Wheat Research and Training
Center, Ankara, Turkey

In assessing the technical barriers to higher maize production, the discussant agreed that lodging, maturity, grain characteristics, diseases, and insects are major problems of maize improvement; pointing out the additional problems of drainage and weed control. Maize, he said, is a high-risk crop in the tropics, much more so than wheat. Farmers are reluctant to invest in high-risk crops. In addition, where farmers are willing to try innovations, new varieties are slow to reach them because of exaggerated demands for testing in national programs--often three additional years after the breeder has finished testing. Failure to deliver fertilizer to farmers on time is another common problem.

The discussant supported the idea that national research programs should be crop oriented, adding that extension programs should be also. Crop orientation allows a multi-disciplinary attack on crop improvement. Many national programs have too many breeding stations and not enough sites for testing varieties and for production agronomy trials. The scientists must be free to travel and have adequate funds to do so. They need close contact with other national programs and international institutes to stay abreast of mainline research.

Motivated personnel are essential for a successful national program. Personnel become motivated if they have opportunities for training and advanced degrees, adequate pay, freedom of action within their own programs, opportunity to advance within their own discipline (rather than by transfer to some unrelated area), adequate supporting services and institutions, and credit for their own work, the discussant said.

The most difficult problem is convincing political leaders to devote sufficient energy and resources to increasing food production. The technical problems are far easier to solve.

14.2.1 **SELECTED COMMENTS, QUESTIONS, AND ANSWERS**

Q. Countries in Categories II and III are not supposed to generate breeding material. What do you propose doing with existing breeding programs in countries that do not have 55 or so trained people?

A. (Sprague): There are opportunities for regional cooperation.

Q. Are university graduates the only ones adequate for reaching the farmer, or are some lower level personnel usable?

A. (Sprague): Because of a scarcity of personnel, sometimes lower level personnel must be used.

Q. Do on-farm trials have to be replicated in order to generate data for the release of a variety?

A. (Sprague): On-farm testing means research in replicated and large plots. Data should be used to analyze performance. Extension personnel should be involved.

Q. Can most countries afford a separate extension service for each crop?

A. (Wright): No, but it is possible to pick out the most important crops and have extension specialists trained in these crops.

Comment On-farm testing is a 50-year-old idea. Modern statistical methods now permit using micro-plot data to simulate farm tests. And this is much less costly than farm testing.

A. (Sprague): In developing countries, simulating farm conditions lacks precision. Moreover, on-farm testing provides an opportunity to get farmers emotionally involved and this is an important by-product.

Comment In West Africa, where maize is an introduced crop, the variability of the maize population is very low. It is therefore important for us to have new introductions and to engage in testing populations that have variability and diverse genotypes from which to select materials that could prove useful to us. The CIMMYT breeding and international testing programs afford us such opportunity. This is especially so since CIMMYT has the largest collection of maize germplasm in the world.

Now, I think the importance of this work should involve national programs in testing and selecting genetic material best suited to their needs. In this respect, I think national programs should be interested in these materials and their participation should not be limited only to testing. Furthermore, I do not think this work can be left to regional centers.

For example, no one knows the nature of resistance of CIMMYT materials included in the international trials against the maize borers (Sesamia and Busseola species), which are the major insect pests in Ghana. The (local) maize population is susceptible to this insect pest, and we would therefore be interested to test new genetic material from CIMMYT and select resistant lines to serve our purpose.

14.3 DISCUSSION TOPIC 3

Maize Improvement
by Elmer Johnson, CIMMYT

Lead Discussant: Dr. G. F. Sprague, Professor, Plant
Breeding and Genetics, University of
Illinois, Urbana, Illinois

The discussant called for consideration of hybrid maize in long-term breeding goals. He observed that while some people feel that hybrids are unsuited for economies with low per capita incomes or low yields, maize improvement in Kenya during the last decade was based on hybrids and was immensely successful. Although many factors supported the development and adoption of hybrids in Kenya, none of the supporting factors existed before the hybrid program began-- they developed along with the demand for hybrid seed.

The discussant called for the use of recurrent selection techniques to give breeders the option of creating hybrids whenever conditions are appropriate. Basically, all that is required is to have a minimum of two populations, A and B, formed to possess variability for the characteristics of interest and which exhibit considerable heterosis at the F₁ hybrid level. The two populations may then be improved individually by any one of the several recurrent selection schemes."

The emphasis on wide adaptability in the CIMMYT breeding program, the discussant suggested, may be sacrificing yield. The question should be settled quickly by using data from the Advanced Unit testing program, where a common set of genotypes are grown in replicated trials in six environments. If the interaction between genotypes and locations is high, "... selection differential at the family level may be drastically reduced if based on mean performance." Under such circumstances, greater progress would be made by selection within national programs.

14.3.1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

- Q. CIMMYT plans to send approximately 250 selected progenies from each population to six locations in maize growing areas of the developing countries. Do we have any information of genotype x environment interaction of these populations or selected progenies? In case these are high, would it not be better to send the populations per se to these locations and select progenies there?
- A. (Johnson): The first step is to send the populations in trials as varieties to identify as well as possible which are most suitable for a given country. Not until reasonable certainty exists that a particular population is suitable do we send the progeny trials. With selection at different sites on a progeny basis, the recombination of superior progenies, and successive cycles of such selection and recombination, we would expect the environmental interaction to be reduced.
- Q. India has been producing hybrids and composites. Should the experimental hybrids be given up totally?
- A. (Johnson): The decision as to whether to develop hybrids or not depends on many factors. In most countries, I believe, the initial emphasis should be on improved open-pollinated varieties, and hybrids might come later--when and if the seed production, distribution, etc., plus farm conditions, are judged suitable.
- Q. Regarding the differences in yield between tropical and temperate zone maize, don't you feel the superior yield of the latter is simply a function of the long period of selection which has gone into that type of maize? By comparison, tropical maize has received little attention.
- A. (Johnson): That is certainly, at least in part, a logical reason for the difference, but I wonder if the biological pressures exerted in an evolutionary sense may not also be involved. Disease and insect attack pressures over the history of tropical maize have perhaps forced the survival of more woody, leafy, rapid growing types rather than those with high grain proportion--a survival reaction.
- Q. Corn in many countries is being replaced in irrigated areas by cotton, soybeans, etc., which bring in foreign exchange. Thus, shouldn't corn be bred for dryland and marginal conditions?

A. (Johnson): We have not made any major effort to breed for dryland conditions. It is difficult to breed for a 10 or 15% increase at yield levels of 300 to 400 kg/ha.

A. (Sprague): This question has been avoided world-wide by researchers because of the difficulty in determining differences at those low yields. If someone found a simple, easily recognizable gene for drought tolerance, that would change the picture-- but that is not very likely.

Comment I think we haven't fully explored the possibility of improving maize for marginal rainfall areas. There is a big intermediate area where drought is an important factor, perhaps more so than insects and diseases.

A. (Goldsworthy): Although CIMMYT's testing program involves selection without water stress, much of the testing is at sites with stress. So the point may be to select varieties that fit the drought situation, rather than breeding for drought tolerance.

14.4 DISCUSSION TOPIC 4

Maize Germplasm
by Mario Gutiérrez, CIMMYT

Lead Discussant: Dr. William L. Brown, Executive Vice
President, Director of Research, Pioneer
Hi-Bred International, Des Moines, Iowa

The organization of the CIMMYT maize germplasm bank has greatly improved in recent years and many collections that were almost lost have been salvaged, the discussant said.

He deplored the tendency of maize breeders everywhere to use an increasingly narrow base of germplasm, even though they know this increases genetic vulnerability. This tendency results largely from the belief that known germplasm is superior to unknown germplasm and the speed with which improved populations can be developed from known germplasm relative to unknown germplasm. Yet, the discussant asked, if the usefulness of much of the world's maize germplasm has not yet been critically screened, how do we know that it is inferior to the materials breeders are now using?

In addition to the work CIMMYT is already doing in the evaluation of exotic germplasm, the discussant recommended a system of

cross-performance testing be instituted to identify population crosses which exhibit a maximum heterotic response. He also recommended that the evaluation be done by a breeder and that the work have high priority in the breeding program. Collection, reproduction, documentation, and distribution of germplasm constitute full-time work for one man.

14.5 DISCUSSION TOPIC 5

A. Maize-Tripsacum Crossing at CIMMYT
by Mario Gutiérrez, CIMMYT

B. Wide Crosses
by Dr. Lynn Bates, Kansas State University

Lead Discussant: Dr. L. H. Shebeski, Dean, Faculty of
Agriculture and Home Economics, The
University of Manitoba, Winnipeg, Canada

While advocating continued work on wide crosses, the discussant cautioned against expecting rapid and spectacular results. Wide crosses, he said, will not be a cure-all for future world food needs; improvement of existing cultivars should provide greater gains. Using triticale as an example, he pointed out that even though a parent contains a gene for resistance to a disease, there is no assurance that that gene will provide the same resistance in the recipient species.

The discussant reviewed the scientific and organizational problems that accompanied the development of triticale. Not the least of the problems was finding financial support for the research. "It took 17 years to develop the kind of team that was required at the outset."

The discussant recommended that whenever a new species is synthesized and has potential, it should be made available to CIMMYT, which has the "confidence of funding agencies and resources to quickly exploit the potential."

14.5.1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Comment I don't think we should write off somatic hybridization. The successful tobacco example from Brookhaven depended on an effective system for recognizing that hybridization had occurred, based on earlier work with a conventionally made hybrid in culture. But the field is still young, and other techniques (including viral transduction) offer real promise for somatic hybridization.

Also, the recent work of Knox and Heslop-Harrison on the recognition of proteins released by pollen on contact with the stigma suggests that these can be extracted from compatible pollen and applied with incompatible pollen to make crossing effective. It has been successfully done with poplar trees and could offer considerable promise for wider crosses among the cereals.

A. (Bates): (1) I haven't written off somatic cell fusion completely, but have pointed out the equally difficult problems of either route. I have simply chosen that approach where I think more rapid progress can be made.

(2) The approach of Knox et al. on protein recognition factors is one of four possible approaches I have considered as proof of the SIR hypothesis and the obtaining of hybrids. It may well be that our respective research approaches will complement each other nicely. Again, the immunochemical suppressor route was simply our choice for approaching the problems at hand in making a practical, applied method for the plant breeder and the synthesis of a reasonably large hybrid breeding population.

14.6 DISCUSSION TOPIC 6

Adaptation in Maize
by Peter Goldsworthy, CIMMYT

Lead Discussant: Dr. S. A. Eberhart, Research Geneticist,
ARS, Iowa State University, Ames, Iowa

The discussant observed that to use research resources efficiently, the breeder must define his area of responsibility in terms of ecological zones. To establish ecological zones, the interaction between maize genotypes and environment must be understood. "If varieties of different maturities are grown in a series of environments from very short to very long seasons, the genotype by environment interaction will be very large."

The discussant suggested physiological studies to establish indices of heat-unit accumulation, temperature, solar radiation, and drought stress for use in delineating ecological zones. Indices of susceptibility to pests and pathogens also are needed.

He advised that CIMMYT's program of testing in a large number of the different countries is unlikely to be necessary or efficient. Maize studies in East Africa; in cooperation with breeders in national programs, "... provide data to indicate that general adaptation can be attained in maize without the extensive trials that CIMMYT is proposing, unless the large numbers of progeny are used to increase selection intensity." In East Africa, varieties with different maturities and suitability to different elevations were grown in trials from sea level to 2,400 m., from Zambia to Ethiopia. "The results were analyzed within countries and then pooled across countries within altitudinal zones. The results showed no greater genotype by environment interaction from the pooled data than for each country separately."

CIMMYT's International Maize Adaptation Nursery results should be used to obtain information about genotype x environment interactions in different ecological zones. But "... entries should be carefully selected to include improved breeding populations available from participating breeders. The entries should exhibit a range of maturities and temperature responses." Based on population response to the various indices, the breeder could group similar varieties, the discussant said. "A breeder could determine the index for each ecological zone in his area of responsibility and then predict the yield of all breeding populations in the trials. This information would permit him to select the appropriate populations with greater reliability than in two or three locations per year or two or three years at one location. Depending on resources available and local disease and insect problems, he could decide whether to initiate a breeding program or whether to continue introducing improved versions as they become available if the population is under intensive improvement elsewhere."

The discussant praised CIMMYT's switch from mass selection to progeny testing. But, he urged "comparative trials to determine" if full-sib and modified ear-to-row trials are really the most effective selection methods for all situations. Statistical genetic theory indicates that reciprocal recurrent selection, or S_1S_2 selection, can be as effective as full-sib selection with half as much expense for yield trials and more opportunity for selection for disease resistance in the breeding nursery."

14.6.1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Q. Within your three altitudinal zones in the East Africa study, did you detect differences--yield stability from season to season--that would be of value, for example, if one wished to maximize the minimum yield seen over a given number of seasons within each zone?

- A. (Eberhart): The environmental responses and altitudinal response of varieties from the 1970-1971 East Africa Maize Variety Trial (EAMVT) were essentially the same as for the 1968-1969 EAMVT, indicating that the environmental response is a function of stress factors that vary from year to year. In East Africa, within altitudinal zones, several locations in one year will rank varieties as well as fewer locations in several years.
- Q. Are some systems to estimate stability more adequate to be applied to hybrids of corn and sorghum and others which are more efficient to be used on open-pollinated varieties or segregating populations of corn?
- A. (Eberhart): The response to temperature, to solar radiation, to stress, etc., can be measured by the same system for hybrids and open-pollinated varieties. Deviation from regression can be expected to differ among single cross-hybrids, but not among double crosses, variety crosses, or open-pollinated varieties.
- Q. Given good information on mean yield and regression slope for a set of varieties across a set of environments, how do you select the best ones, especially considering that it seems the two things are often closely correlated to mean and slope?
- A. (Eberhart): You select on mean yield alone over all locations of the progeny trials, and you pick the high yielding families that will respond to improved agriculture. During family formation, intensive mass selection should be practiced for prolific plants with good roots to develop varieties with tolerance to stress conditions.

14.7 DISCUSSION TOPIC 7

Maize Insects and Diseases
by Alejandro Ortega, CIMMYT

Lead Discussant: Dr. William R. Young, The Rockefeller
Foundation, Bangkok, Thailand

Although losses caused by insects and diseases are already a major factor, they will increase in importance as production levels rise, the discussant observed. He commended CIMMYT's approach of incorporating host-plant resistance into superior, widely adapted germplasm, because host-plant resistance involves little cost to the farmer, has a

cumulative and persistent effect on pathogens and pests, and is compatible with other means of control. Chemical control should have a lower priority since it can be handled by national programs.

To make rapid progress in using host-plant resistance, a network of international testing is essential, the discussant said. The first step in a comprehensive testing program, the identification of the major problems, has already been made by the CIMMYT staff: downy mildew in Asia; corn stunt in Latin America; maize streak in tropical Africa; stalk and ear rots, leaf blights, late wilt in UAR and India; maize mosaics; leaf rusts; stem borer complexes; armyworm complexes; ear worms; and stored product pests.

The second step, he said, is development of regional centers of responsibility. Suggested assignments were: IACP (Thailand), downy mildews; CIMMYT (UAR), late wilt; IITA (Nigeria), maize streak; CIMMYT (Mexico), corn stunt, stalk and ear rots, leaf blights, maize mosaics, maize rusts, ear worms, and storage pests.

Stalk borers and armyworms could be studied at CIMMYT, CIAT, IITA, and IACP, with CIMMYT acting as coordinating center.

The discussant suggested that CIMMYT could help the network by developing techniques for mass production of pathogens and insect pests for use in raising the level of resistance of maize populations under improvement and for biological studies; by developing procedures for international trials and coordinating the trials; by training scientists from national programs and by organizing symposia or workshops for scientists involved in international testing and operating pest nurseries.

To expand CIMMYT plant protection work in the way outlined would require an expansion of staff, the discussant said.

14.7.1. SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Q. Considering the great number of materials CIMMYT sends throughout the world, what precautions does CIMMYT take to avoid spreading diseases and insects with the seeds?

A. (Ortega): Seed is dried to about 10% moisture. This should inactivate agents causing disease. In addition, seed is treated soon after harvest and during packaging with a fungicide-insecticide mixture.

Comment In regard to the report from India about downy mildew being seed-borne, the researchers found mycelium of downy mildew

fungus in seeds from severely affected plants when the seeds were freshly harvested. But the fungus was completely inactivated when the seeds were sun dried to 15% moisture or below. Drying the seeds to 12% moisture, which is the usual practice, leaves no chance of dissemination of the fungus with the seed.

Q Do you include biological control of insect pests in your program?

A. (Ortega): We are concerned in maize pest management with naturally occurring biological control by entomophagous agents, that operate at low insect pest population densities. We hope to alter the resistance during the improvement of maize pools and advanced populations and to combine this with selective chemical control. We do not intend to become involved with manipulation of entomophagous agents since there are other institutes actively engaged in this activity. If possible, we will incorporate any useful results in our activities.

14.8 DISCUSSION TOPIC 8

Agronomic Aspects of Maize Improvement
by A. F. E. Palmer, CIMMYT

Lead Discussant: Dr. A. Y. Allan, Project Leader, Maize
Research Station, Kitale, Kenya

The discussant praised CIMMYT's development of improved genotypes as part of a technological package that farmers can use. He warned, however, against excessive testing and refinement of the packages. Most agronomists can design a package that will raise yields substantially. The urgent necessity, the discussant said, is to get the package delivered and put into practice. In Kenya, he said, a major reason for the successful introduction of improved maize varieties can be attributed to a private company that produced and distributed improved seed and made sure that it reached the farmers on time.

Turning to the question of international agronomy trials, the discussant said that such trials would be useful within a fairly uniform region, but that trials stretching over continents would be difficult to coordinate and would be unlikely to yield good results.

In other words, he said, more emphasis should be given to package delivery and somewhat less to package development. The methods of package delivery are well known, e. g., fertility demonstrations, variety demonstrations, etc. The problem has been that such

schemes have lacked continuity and follow-through. The discussant said that these demonstrations must be conducted by the local extension staff, specially trained for maize work. In addition, the local extension staff should be responsible for making sure that the components of the package reach the farmer on time, that the land is correctly prepared, and that market facilities are developed. Their job does not end with the demonstration.

14.8.1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Q. Are you doing any work on associated cropping?

A. (Palmer): CIMMYT is not carrying out agronomic work on maize in needed cropping systems.

A. (Allan): In the Kenya program, virtually nothing has been done about intercropping maize and beans, but slowly we have come around to the view that research on this is needed, since around 50% of maize farmers do it.

Q. Would you not agree that CIMMYT agronomy trials can set a base line, or standard of performance, which can convince otherwise reluctant political leaders to establish the necessary installed capacity for "delivery" to producers, where no such capacity exists, or when there is ignorance about fertilizer requirements?

A. (Allan): I agree that CIMMYT, with its greater prestige and authority based on past work, may be able to coax otherwise reluctant politicians and policy makers to undertake research work, whereas local scientists may tend to be ignored in their own countries by these people.

14.9 DISCUSSION TOPIC 9

Maize Physiology
by Peter Goldsworthy, CIMMYT

Lead Discussant: Dr. Lloyed T. Evans, Chief, Division of
Plant Industry, CSIRO, Canberra, Australia

The discussant observed that maximum yields of maize are higher than those of any other cereal crop, even though far fewer crop physiological studies have been made on maize than on wheat or rice.

The discussant compared the physiology of maize with that of rice and wheat. He noted that the C_4 pathway of CO_2 fixation gives maize a photosynthetic advantage under conditions of high temperature and high light intensity, and also confers greater water-use efficiency. He said that the maize ear is a stronger sink than the many smaller inflorescences in wheat and rice, but the maximum recorded rates of grain growth per unit area for maize is no better than that of several other crops. The long period from anthesis to maturity in maize (about 50 days) may be a key factor in high yields, he noted. The rate of growth per grain in maize must be far higher than that of wheat and rice, even though maize has no vascular tissue entering the ovule.

The discussant urged an examination of the physiological basis of the great yield heterosis in maize by comparing inbreds with their hybrids. He cites several studies that indicated "that the yield increase in hybrids may be due to their differentiation of larger ears with potentially larger, and longer- and faster-growing grains."

To raise maize yields, a coordinated increase in both source and sink will have to occur, the discussant said. "Cultivars whose yield is highly responsive to site conditions may be those with ample potential storage capacity. Those with high and stable yields probably have ample productive capacity. Crosses between these two types may therefore offer the best prospects of coordinate advance in both source and sink capacity, as Finlay has suggested." Although spare photosynthetic capacity, as indicated by the presence of sugar in the stem, may exist at the end of the life cycle, that does not necessarily mean that the photosynthetic rate was adequate during differentiation of the ear. For this reason, the discussant urged equal emphasis on studies of storage capacity and on photosynthetic capacity.

Because its three experiment stations are at about the same latitude, but different altitudes, CIMMYT is in an unparalleled position to study the effects of temperature separate from those of radiation, the discussant said.

Studies of water-stress effects will be vital especially because future crops of maize throughout the world are likely to be increasingly grown without irrigation as water resources become scarcer. The discussant endorsed the plan to assess adaptation to dryland conditions by yield comparisons of genotypes over many sites and years.

14.9.1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Comment At IITA we are finding that seedling tolerance to high soil temperature is one of the major limiting factors of maize yields. Most of the references about tolerance to high temperatures and drought resistance concern flowering time when temperatures in the tropics are no higher than in the Corn Belt. The Corn Belt plants emerge as soon as possible after the danger of killing frost is past. In the tropics, we plant at the end of the dry season when soil temperatures at Ibadan go over 40°C. We have found cultural and genetical methods of overcoming this major limiting factor of high soil temperatures on seedling growth.

A. (Goldsworthy): We have begun to collect data on soil temperature at some of our experiment sites in Mexico. High soil temperatures in the seedling stage may be of general importance where drought conditions occur at this stage in crop growth.

Q. Is the proposed work program for CIMMYT in the next five years going to give the breeder a "handle" or guideline by which to select in the field? Can we become predictive instead of continuing to be descriptive after the fact?

A. (Goldsworthy): The organization of the production studies is such that findings can influence the development of populations undergoing improvement. Several of the findings to date are being incorporated into the breeding program. To this extent we believe the program contributes more than explanation after the facts.

Q. One way of improving the ratio for grain to total dry matter is by using prolificacy. Have you considered this at CIMMYT? Prolificacy is also involved in stability of yield. A peasant farmer is not so much interested in maximum yield as in stability of yield. In a poor season of stress conditions, will he have enough food to feed his children?

A. (Goldsworthy): A large part of the studies proposed and outlined are concerned with the development of the lateral inflorescences and how this influences yield. One aspect of this is prolificacy.

14. 10. DISCUSSION TOPIC 10.

Nutritional Quality in Maize

by S. K. Vasal, CIMMYT

Lead Discussant: Dr. Luis F. Fajardo, Asst. Professor,
Faculty of Medicine, University of the
Valley, Cali, Colombia

The discussant recommended that CIMMYT closely associate itself with an outside organization for biological assays of selected maize materials from the quality improvement program, to confirm the nutritive value of the most promising varieties.

The discussant observed that "traditional measures of protein quality for humans have been inadequate for economic comparison of newly developed varieties." Indices based on the nitrogen intake levels necessary to achieve a zero N balance allow economic comparisons of protein value between crops, as well as between varieties.

14. 10. 1 SELECTED COMMENTS, QUESTIONS, AND ANSWERS

Comment I would like to attempt a clarification of the action of the opaque-2 gene and what to expect in the resulting protein synthesis. It is generally believed from the work of Dalby from Purdue and Alexander from the University of Illinois, that the opaque-2 gene produces an RNase against zein messenger RNA. The zein message is thus destroyed early. Modifier genes may or may not affect the opaque-2 allele itself. The modifiers may affect closely linked genes associated with opaque-2. In any event, modifiers do appear to affect opaque-2 grain characteristics, but the zein concentration appears directly related to the opaque-2 gene.

Opaque-2 maize protein synthesis reflects lowered zein synthesis, with the remaining protein synthesis capacity being channeled into glutelin and albumin-globulin. Since glutelin is commonly believed to be a polymer, in some as yet unspecified form, of zein and water-soluble protein, the observed increases in water-soluble protein would be expected. The increased opaque-2 glutelin synthesis is not so easily explained.

14.11.1 DISCUSSION TOPIC 11

Training

by Alejandro Violić, CIMMYT

Lead Discussant: Dr. Dale Smeltzer, The Rockefeller Foundation, Bangkok, Thailand
(Regional Training)

Lead Discussant: Dr. P. L. Plaisted, Professor, Head, Dept. of Plant Breeding and Biometry, Cornell University, Ithica, New York
(Academic Training)

14.11.1 REGIONAL TRAINING

The discussant emphasized that if training is to make a contribution to national development there is need for commitment by the national government, by the trainee himself, and by the trainer. He said that the national government must recognize the need for improving staff capabilities to help achieve national goals. It must be committed to fully using the increased capability of an individual after his training.

The trainee must be committed to increasing his contribution to national goals. He must be motivated. Salary is only one motivation. He must be aware of the importance of his role and of the reasons he was selected for training. And someone must care whether or not he does his job well.

The trainers should be aware of the role the trainee is expected to fill in the national program. The training course should be shaped to the trainee's needs. When the trainee is back on the job, the trainers should make follow-up visits to support the trainee and to get feedback that will progressively improve the training program.

The discussant compared the Asian regional training programs with the CIMMYT training program and cited four advantages of regional training: it keeps the trainee in an environment where he can work with familiar materials and practices, it causes less cultural shock, it takes place within a national program, and it is less expensive. The disadvantages: fewer sites than the CIMMYT program, narrower scope, and those involved in CIMMYT outreach programs have no opportunity to become familiar with CIMMYT staff and projects.

International groups and national programs should each have a role in training. The national program should focus on individuals who are expected to perform a specific task such as conducting demonstrations to promote new technology. The technology may differ from

district to district, but the extension worker will handle only demonstrations for his district. In addition, he must understand the local farmers well enough to select the best way to teach them. In contrast, a research technician has many tasks to perform, many of which are not predictable in advance. Problems such as an insect outbreak may arise during the course of an experiment requiring the use of unanticipated skills. The research technician must have flexibility. The best training for such individuals is within a broad-based research program where experienced specialists can guide trainees. Few national programs have this capability, so the international centers should handle this type of training.

The discussant argued against major emphasis on training trainers in regional or international programs. "The need for massive numbers of trained people will arise with location-specific activities. These can best be taken care of within national programs where specific training teams can be placed high on the personnel priority list."

14.11.2 ACADEMIC TRAINING

The discussant noted that the plant breeding department of Cornell University is increasingly relying on organizations such as CIMMYT, national programs, and foundations to help select foreign students. This procedure has improved the quality of students and has helped assure that the students will find employment when they finish their degrees.

Although the research and coursework should be directed toward areas that can be applied when the student returns home, that should not be at the sacrifice of the "individual nature of graduate education," the discussant warned. The student must learn to think for himself and to gain confidence in his own judgment.

On the question of thesis research in the student's home country, the discussant said that this is desirable, provided that a qualified group of scientists exists in the home country to act as advisors and that it is clearly understood that the student's primary job is to conduct thesis research, not to help with research unrelated to his thesis. Doing thesis research at an institution like CIMMYT is quite acceptable.

Not all students will benefit from research away from campus, the discussant said. Those with minimal research experience or those whose thesis is particularly adapted to the climate or facilities of a center like CIMMYT will benefit. But those who have had experience at CIMMYT or in their home country may benefit from extra time and extra classroom work on campus.

The discussant praised the concept of interdisciplinary teams of graduate students who do two years of coursework at Cornell and then go to CIMMYT to jointly work on a thesis problem.

14.12 DISCUSSION TOPIC 12

The Role of the Economist in Increasing Maize Production
by Don Winkleman, CIMMYT

Lead Discussant: Dr. Vernon Ruttan, President, Agricultural Development Council, New York, New York

The discussant examined the value of social science research (in particular, economics), by first identifying the source of derived demand for knowledge in the social sciences. The demand for knowledge in the social sciences, he said, is derived from demand for improvements in efficiency in institutional performance and demand for institutional innovation. This hypothesis is not easy to test, but the limited investment in, or even suppression of, social science research in "societies in which the institutional system is derived from ideological commitments which are believed, or decreed--not subject to evaluation" is perhaps the best evidence.

The value of economics research, the discussant observed, has traditionally been measured by peer evaluation, by how many times a paper is cited, etc. "I am not familiar with a single example in which a body of social science research has been evaluated in terms of its contribution to institutional efficiency in the same way that the research leading to the invention and diffusion of hybrid corn has been evaluated."

The discussant suggested that new knowledge in social sciences should be valued by measuring "the new income streams made available to society from the institutional innovations resulting from the embodiment of the new social science knowledge in institutional innovations or in the efficiency of institutional performance." Similarly, research priorities in social sciences might be decided on the basis of the "potential value of the improvement in institutional performance that will result from the research."

This approach, the discussant said, is equally valid for allocation of research resources by a ministry of agriculture or by an organization such as CIMMYT. He proposed that the objective of maize research at CIMMYT is to help double world maize production during the next two decades or so, and not simply maize improvement. For this reason, the discussant stated, the question of what limits maize production must be answered quantitatively. Only in this way can we decide how much it is worth to remove a constraint. "Whether it is a yield

ceiling; inadequate knowledge on the part of producers; tenure relations which remove incentives to use existing technology; organization of credit, fertilizer, or product markets; or inadequate investment in irrigation or roads--failure to pose and answer the question in this way leads to the allocation of resources to the solution of problems that when solved contribute relatively little to the growth of production. " Only by allocating research resources to areas where the pay-off from removing a constraint is great "will agricultural research continue to return the high social dividends that we have come to expect of it. "

Moreover, the international agricultural research system is in trouble, the discussant stated. The diffusion of new varieties has slowed, national yields are not growing as fast as previously, production input prices have risen, and the system is under attack by those who are concerned that the new technology is leading tropical agriculture into a high-energy system that cannot be sustained and that the new technology is benefiting some segments of society to the disadvantage of others. The discussant said he was "skeptical of the claims of both the 'distributional impact' critics and the 'technological trap' critics. But my skepticism is not firmly grounded in empirical knowledge. And I am convinced that our resource allocation decisions must be made with much greater precision in the future than in the past. "

Turning to the role of the economist within a research institute such as CIMMYT, the discussant cited the economist's potential contribution to allocating the institute's research resources. For example, the most comprehensive agronomic trials fail to account for more than a fraction of the difference between farm yields and experiments stations' yields because they do not reflect the economic, social, and political environment in which the farmer lives, the discussant said. "The attempt to quantify the constraints on growth involves principally the skills of the agronomist, the economist, and the statistician. " The discussant called for high priority on economic-agronomic study of the constraints to growth of maize production and the institutional and technological steps that can be used to overcome those constraints. In particular, areas where low production is due to lack of knowledge or lack of technology should be identified.

A second important role for the economist is helping interpret institute technical and economic research for planners in the countries in which CIMMYT works. "The economist working in an institute such as CIMMYT has the unique advantage of being close to the source of scientific imagination." From this vantagepoint, the economist "is in a position to model the macro-economic implications of technical change or this potential for technical change, while the changes are still in the design state, or in the initial stages of distribution, enabling planners and policy makers to employ policies that will contribute to more rapid

diffusion of new technology, to minimize distortions in availability of of the technology to different elements in the rural community, and to adjust to anticipated changes in commodity markets."

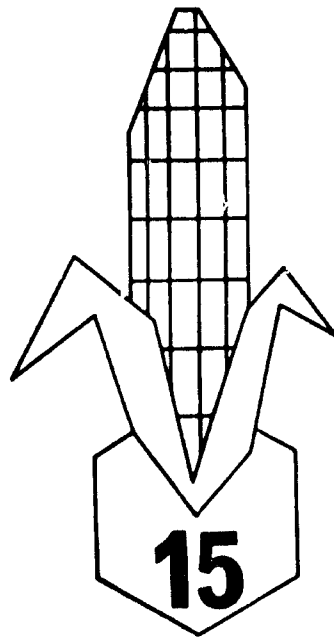
14.13 DISCUSSION TOPIC 13

CIMMYT's Outreach Program
by Keith W. Finlay, CIMMYT

Lead Discussant: Dr. Gordon McLean, Team Leader, ALAD-CAIRO, The Ford Foundation, Cairo, Egypt

Two indispensable ingredients for a successful regional project are a budget, preferably in foreign exchange, and vehicles for the scientists, the discussant said. Regional projects are particularly suited for areas where enough scientific knowledge exists, yet is not widely used. A regional project can start things moving faster than would be possible if a new research institute was established.

The discussant cited several advantages of regional projects: adaptive agronomic research can be conducted (especially for countries too small to do their own), training and workshops can be conducted in the local language and under local conditions, regional records of diseases and insect outbreaks can be kept. In addition, because the regional program is transnational, seed can be moved around easily for regional nurseries, and funds can be moved to countries that need them most. The drawbacks of a regional program, he said, are that a regional representative has less day-to-day knowledge of a national program than someone assigned directly to the national program, and that time-consuming protocol visits must be made by a regional man every time he enters a country.



SYMPOSIUM REVIEW AND FOLLOW-THROUGH

15.0

SYMPOSIUM REVIEW AND FOLLOW-THROUGH

15.1 INTRODUCTION

This paper mirrors Symposium presentations of the week and summarizes some maize program objectives. In capsule format, each of the presentations is analysed for its implications toward maize improvement for the 1970's. Similarly, discussant observations and comments from the participants are taken into account.

In a final section, the maize staff responds to those issues raised at the Symposium that they felt might not have received adequate definition or treatment during the individual sessions.

The summaries that follow should not be regarded as a statement of consensus, but as a necessary step toward consensus. Another pamphlet is being developed by the CIMMYT staff to complement these Proceedings, to be entitled: "Maize in the 1970's", and subtitled "CIMMYT Strategies to 1980". This proposed publication, drawing much from the presentations and observations made here this week, will more fully outline the Maize staff projections and initial plans and strategies for accomplishing their objectives. Sufficient flexibility will be built into these strategies, so that modifications can be made, if necessary, as a result of each year's research and field findings.

15.2 SUMMARY OF MAIZE PROGRAM OBJECTIVES

15.2.1 ROLE OF MAIZE

In the lead-off presentation for this Symposium, Haldore Hanson talked about the role of maize.

He noted a world maize crop of 302 million tons (FAO, 1972) and a maize crop in developing countries of 62 million tons (FAO, 1972). Maize was then the second ranking cereal crop in the world (after wheat), and the third ranking cereal crop in developing countries (after rice and wheat).

Hanson observed that population in developing countries is increasing at a rate of more than 2.5% a year, therefore the population of these countries will double in about 25 years. These countries will need twice as much food just to maintain their present levels of food intake which are already at a low level. Very little future increase in food can come from new cropland. Most food increases must come from higher yields on present cropland. That requires better technology to achieve more intensive production.

During the 1960's, the production of maize in developing countries rose at more than 3% a year, but over half this increase was achieved by using more land area, and less than half by increasing yields. In other words, while population grew more than 2.5% a year in the 1960's, the maize yields were rising less than 2.0% a year. These developing countries must do better in the 1970's if maize is expected to provide its share of the food supply.

The need for better protein also was documented by Hanson. Developing countries are dependent, more and more, on cereals for their protein supply. This places heavy emphasis on the development of high quality protein in cereals, including maize.

Hanson provided data to show that fertilizer supplies will remain short for a few years in the mid-1970's, because of inadequate factory capacity, and that fertilizer prices will probably remain higher than in 1972.

15.2.2 WHAT LIMITS MAIZE PRODUCTION?

E.W. Sprague discussed the present limitations to maize production under two headings: first, the limitations of technology which the scientist can help solve; second, the limitations of government and social institutions that the national policy maker can help solve.

He named six problems as technological barriers, with special attention to the tropics and sub-tropics, where most developing countries are located:

(1) Tropical maize plants are too tall, and frequently lodge. Breeders must develop short, stiff straw, which will make a more

efficient plant, giving more grain per pound of fertilizer nutrients, and more grain per hectare.

(2) Insects and diseases can be more destructive in the tropics than in the temperate zone. Maize varieties that are genetically resistant to a broad range of insects and diseases must be developed.

(3) In most maize growing countries the research station is getting maize yields which are double the yields of the better farmers, and four times the national average yield. Production practices which fit the needs of the average farmer and enable him to close part of this gap between the scientist and the farmer must be developed.

(4) Lack of "adaptation" is another technical limitation. CIMMYT uses the term "adaptation" to describe the ability of some maize varieties to produce satisfactory yields of grain, over a period of years, and over a range of locations, under different conditions of temperature, moisture, and pests. ("Adaptation" is another name for stability of yield).

(5) Protein in traditional maize is low in quality. There is a poor balance among the amino acids, which prevents the maize eater from digesting part of the protein. Breeders must develop a high quality protein in maize that will compete in yield with normal maize.

(6) Maturity range of plants available to farmers is not sufficiently broad. Farmers on rainfed lands need a short season maize to fit a short rainy season, or to fit a rotation with other crops; they should be able to get a variety which matures in 90 or 100 days. By contrast, if the farmer is fortunate enough to have irrigation, and wants a full season maize, he should be offered a variety which matures in 130-150 days or more.

Sprague also listed some institutional limitations on maize production which require solution by policy makers in developing countries. He cited the restrictions imposed by inadequate service for research, extension, fertilizer, credit, seed and marketing.

Unless attention is given to all of these needs, the production of maize is not likely to rise rapidly enough to keep pace with population growth.

Vernon Ruttan, speaking later, urged that the constraints to production listed by Sprague should be given more precise quantitative measure, in order to establish priorities for CIMMYT's maize research.

15.2.3 MAIZE IMPROVEMENT

Elmer Johnson described the process by which germ plasm at CIMMYT now moves in a continuous flow of testing and recombination, from the Bank accessions, to the germ plasm pools in Mexico, to the advanced populations internationally tested, to the experimental varieties tested in foreign countries, and finally to the elite experimental varieties.

This process will continue through the 1970's; two cycles a year -- one for testing, another for recombination. There will be 12 more generations before the end of the decade. During that period, CIMMYT will send to collaborating governments outside Mexico, a few experimental varieties each year. If the expected progress is achieved, some of those experimental varieties will become elite varieties. After testing the elite varieties, some will be recommended to farmers by collaborating governments. (Release to farmers is a function of government, not of CIMMYT).

The lead discussant, George F. Sprague, questioned the CIMMYT viewpoint that hybrid maize has only limited potential in most developing countries at this time. He also suggested that wide adaptation may involve a sacrifice in yield potential.

15.2.4 GERM PLASM BANK

Mario Gutiérrez presented information about the CIMMYT germ plasm bank. Objectives for the bank are that by 1980:

(1) All seed in the bank will be less than 10-years-old. That means the renovation of the collection will be completed and thereafter rejuvenation will continue only on a maintenance basis.

(2) All Bank accessions which can be grown in Mexico will be tested in replicated trials for the following characters: yield, maturity (days to anthesis), number of tillers, percentage of stalk breakage, ear height, length and thickness, prolificacy (average ears per plant), kernel color and endosperm texture, racial classification.

(3) The Bank will publish an open-ended catalog, listing each accession and the location and elevation where collection was made; information supplied by the collector; observations from the rejuvenation cycle; and agronomic characters listed for the trials above.

(4) The collection of historic land varieties should be almost completed. To reach that point, additional collecting will be needed during the 1970's in northeast India and in the Amazon basin -- two areas not adequately represented today.

(5) CIMMYT will increase the collection of three near relatives of maize, Zea mexicana, Tripsacum, and members of the Maydeae tribe, all useful for a program of wide crosses with maize.

Completion of the five year plan will make the CIMMYT germ plasm bank as useful a breeding tool as the germ plasm collection of any other major food crop in the world.

The lead discussant, William Brown, endorsed the work plans for the bank, and added one proposal of his own: that testing for cross performance (heterosis) should be included in the CIMMYT Bank evaluations.

15.2.5 WIDE CROSSES

Mario Gutiérrez described the successful crossing at CIMMYT of maize x Tripsacum. Tripsacum is a near relative of maize.

Lynn Bates summarized recent cooperative work between Kansas State University and CIMMYT, including attempts to cross maize x sorghum, using chemicals control of barriers to crossability.

Looking ahead to 1980, CIMMYT expects this work to continue with the following objectives:

(1) Maize staff members at CIMMYT will continue to make crosses between maize and its near relatives, such as Tripsacum, to determine which genotypes cross most readily, and to assess whether this research route should be enlarged or discontinued.

(2) In collaboration with Kansas State University, CIMMYT will continue to explore the maize x sorghum cross, and expects to achieve a successful hybrid within the 1970's. This hybrid should be carried to the point where techniques for overcoming incompatibility are available and the F_1 's help to identify the plant characters which might be transferrable from sorghum to maize, and vice versa.

(3) In collaboration with a center like the Plant Breeding Institute of Cambridge, England, CIMMYT will seek a better knowledge of the genetics and cytology involved in wide crosses of maize.

(4) CIMMYT will play a catalytic role in promoting research on wide crosses, and the needed resources from donors.

Under a policy approved by our Trustees, CIMMYT will provide leadership in the field of wide crosses for maize and wheat,

but it is expected that no more than 5% of our staff time and 5% of our budget will go to this work. We shall encourage other qualified institutions to do the exploratory work. CIMMYT plans to make a major investment only when a wide cross has proved feasible; after hundreds or thousands of primary crosses have been made. CIMMYT can then help convert this new hybrid into a commercial crop. That is the policy CIMMYT followed in the development of triticale, which is also a wide cross (wheat x rye).

The lead discussant Dean Shebeski has been characterized as the father of triticale, and from his 20 years of experience with triticale he offered several comments on other wide crosses. He noted that CIMMYT has made successful hybridization between maize and *Tripsacum*, but there is no report of the successful transfer of useful genes from *Tripsacum* to maize. He admired Bates' optimism in forecasting a successful maize x sorghum hybrid within a few years. "Successful crosses do not necessarily mean useful crosses".

Dean Shebeski said that he does not accept the view that wide crosses will provide an easy road to a larger food supply. Continued improvement of existing cultivars should provide greater gains in the next one or two decades.

In conclusion, Dean Shebeski endorsed CIMMYT leadership in wide crosses. He expressed the belief that with improvement of techniques, man should be able to synthesize some new species of crops which can prove more productive and more nutritive.

15.2.6 ADAPTATION IN MAIZE

Peter Goldsworthy described the studies CIMMYT has made on adaptation, the analysis methods, and how these methods will now be applied to the experimental variety trials which CIMMYT is sending to a few countries outside Mexico, beginning in 1974.

CIMMYT uses the term "adaptation" to describe the ability of some maize varieties to produce a satisfactory yield of grain, over a period of years and over a range of locations, under variations of temperature, moisture and pest conditions.

Adaptation can produce stability of yield, and therefore adaptation is highly prized by farmers in developing countries who depend heavily on the maize crop for family subsistence and some cash income.

Two more reasons justify the importance of "adaptation" to world food production:

Maize producing countries with a range of climates cannot afford the cost of developing a separate maize variety for each climatic zone. With wide adaptation, fewer varieties will serve the needs of a national program.

The benefits of maize research in one climatic region of the world cannot be transferred to maize growers in other climatic regions, unless varieties with wide adaptation are employed.

The lead discussant, Steven Eberhart, responded with a carefully stated critique based upon his own international experience. He included this comment: "The scientific approach used in Eastern Africa and Western Africa by the USAID/USDA Major Cereals in Africa Project, cooperating with breeders in national programs, provides data to indicate that general adaptation can be attained in maize without the extensive trials that CIMMYT is proposing".

15.2.7 MAIZE INSECTS AND DISEASES

Alejandro Ortega listed objectives for CIMMYT's plant protection unit during the remainder of the 1970's, including:

(1) Completing streamlining of techniques for mass rearing of insects to be used on experimental crops; mass production of inoculum to be used on experimental crops; determination of the most efficient methods for mass infestation and mass inoculation; and determination of the most efficient way to read susceptibility or resistance in experimental crops.

(2) Completing the evaluation of CIMMYT's germ plasm Bank accessions for reaction to insects and diseases.

(3) Reading the disease and insect response in each cycle of selection of all germ plasm in CIMMYT's Back-up and Advanced units.

(4) Contributing to the evaluation of pesticides, their formulation, and procedures that provide ecological selectivity to reduce ecological side-effects.

(5) Continuing the development of pest management approaches within the context of efficient production practices.

15.2.8 AGRONOMIC ASPECTS OF MAIZE IMPROVEMENT

Frederick Palmer described the role of the CIMMYT agronomy staff in Mexico, where tests are organized both on experiment stations and in farmers' fields. He described his own work in Pakistan, organizing on-farm demonstrations, and training the Pakistani production agronomists.

Objectives of the agronomists to 1980 include the following activities:

(1) In Mexico, the agronomist will participate in the germ plasm bank evaluations and share in the work associated with the Back-up and Advanced Units by helping identify the most efficient materials.

(2) Agronomists assigned the national programs outside Mexico carry the central responsibility for organizing the progeny trials and the experimental variety trials, both on experiment stations and in farmers fields.

(3) Training of extension agronomists in national program is becoming a central role for CIMMYT agronomists.

Palmer stated that by 1980, he expects the work of the CIMMYT agronomists now located in Pakistan, Zaire, Egypt, Nepal and Tanzania to prove its effectiveness in raising national average yields. Similar work is needed in other national programs.

The lead discussant, Alistair Allan of Kenya, followed Palmer with two challenges: (a) Is it really necessary to spend so much time and money developing agronomic packages the way CIMMYT describes? Isn't the urgent business to deliver the package to farmers? (b) Is there a role for international agronomy trials with multifactors?

After participant discussion, it was clarified that inter-national agronomy trials of 1972-73 have now been replaced by CIMMYT's experimental variety trials, and there is no need for a separate series of agronomy trials on an international scale.

15.2.9 MAIZE PHYSIOLOGY STUDIES

Peter Goldsworthy's presentation on physiology described CIMMYT's past studies on the tropical maize plant and why it places more of its dry matter in the stalk and leaves, whereas temperate zone maize places more of its dry matter in the grain.

He described two other studies in progress: the reaction of maize to environment, as measured by climatic data in the international trials; and the adaptation of the maize plant to water stress.

Objectives in the physiology work include:

(1) Continued inquiries into factors defining the limits of storage capacity in tropical varieties of maize. CIMMYT stations at different elevations in Mexico offer opportunities to study the separate contributions of temperature and radiation to grain filling. The effects of light intensity and rate of photosynthesis at different stages of plant development will also be studied. Answers to these questions will help guide the breeders in developing higher yielding varieties.

(2) Continued studies of water stress in maize. In Mexico, CIMMYT will investigate maize features which confer less sensitivity to water stress. The adaptation of maize to dryland conditions will also be studied through yield comparisons of genotypes over many sites and cycles.

L. T. Evans of Australia, lead discussant, offered the following critique: CIMMYT's maize physiology program has already contributed substantially to our understanding of yield development in maize. During the remainder of the 1970's, similar studies should be completed on the effects of temperature, light intensity, and water stress.

Studies of water stress are at a less advanced stage. The program proposed by Goldsworthy should result in a better definition of the type of maize adapted to dryland production.

15.2.10 NUTRITIONAL QUALITY IN MAIZE

S.K. Vasal's report on protein problems in maize indicated that the world is still receiving very little benefit from the opaque-2 gene, 10 years after the remarkable nutritional value of this gene was discovered. CIMMYT's objectives to 1980 are:

(1) To continue to develop better agronomic plant types carrying the opaque-2 gene. Today the plant types are not yet fully acceptable to farmers, because of slightly lower yield, and slightly greater vulnerability to fusarium ear rot and stored grain weevils.

(2) To continue to develop better grain type for opaque-2 materials. Some varieties now carry grain which is acceptable to maize eaters, but most varieties do not, and the grain must be made

fully competitive with normal grain before it can be widely accepted.

(3) To study the interaction of the modifier genes to the environment. We are not certain that the hard endosperm - opaque-2 character will remain stable in some climates.

(4) To continue to raise still higher the protein quantity and quality in our opaque-2 plants. There remains variability for total protein, for lysine, and for tryptophan.

(5) To study the problem of contamination of opaque-2 varieties in farmers' fields. When high lysine maize is grown in the same area with normal maize, we get a mixture of pollen that may adversely affect the nutritional quality of the high lysine maize in succeeding generations. This problem must be dealt with by extension methods.

(6) To help with the special problems which governments face when they promote opaque-2 maize (in which the superior nutritional value cannot be seen). Such promotion will require special government campaigns employing: government seed distribution, massive demonstrations in farmers fields, intensive educational campaigns among small farmers who use maize for home consumption, on-farm demonstrations of animal feeding with high lysine maize, and home demonstrations for the cooking quality of the new maize.

The critical period for solving the problems of high lysine maize will probably occur during the last half of the 1970's.

15.2.11 TRAINING

Alejandro Violic described maize training at CIMMYT. Dale Smeltzer described regional training in Thailand. R. L. Plaisted discussed advanced degree training in universities, including a description of team research for the Ph.D., jointly organized by Cornell University and CIMMYT.

If these presentations are translated into objectives for 1980, the projections are as follows:

(1) CIMMYT will continue its in-service training programs at the present level of about 50 trainees a year. This will add 300 alumni by 1980, which should more than double the number of such trained men employed in national programs.

(2) CIMMYT will receive predoctoral and postdoctoral fellows at a rate up to ten a year. Over the next six years, 40 to 50 more fellows should finish their training and become available for employment in national programs, or in Centers like CIMMYT.

(3) Regional training, as described by Smeltzer should continue in regional programs, for southeast Asia, tropical Africa, and the Andean region. Precise numbers cannot be forecast, but training for production agronomists at regional centers should at least equal the quantity of training at CIMMYT.

(4) Training within national programs will continue. Some very impressive data was presented for such training in India, Pakistan, and the Philippines. Probably 10 to 20 more countries will begin such training within their own institutions before 1980.

Adding all these figures together, it is possible that twice as much training will be provided for maize scientists in the last half of the 1970's, compared to the first half of the decade. The total training requirements as presented by Violic were an estimated 2,200 trained men for the national maize programs by the end of the 1970's.

15.2.12 ROLE OF ECONOMICS IN MAIZE IMPROVEMENT

Winkelmann described the work of the Economics Unit in support of maize production, which will continue through the 1970's. The objectives are: (1) Continued study of the constraints on the farmer, to learn why some farmers adopt new technology and others do not. The lessons will help guide CIMMYT leadership and the leadership of national programs; (2) Continued study of the kinds of data needed by policy makers in developing countries, in order to promote new technology; CIMMYT will assist in organizing research which produces that data. Actual field work will be done by social scientists resident in the producing countries. And (3) Continued development of research cooperation between agronomists and economists, both in Mexico and in producing countries. We believe this collaboration will keep maize research relevant to the factors which limit production.

Vernon Ruttan, the lead discussant, commended the plans for economics and reinforced several of the points. He said:

(a) The economist can add to the efficiency of his institute by providing the research tools for better allocation of resources among the obstacles which limit farmers' production. The better the analysis on what limits production, and the more relevant the distribution of research funds, the greater the results CIMMYT should achieve in raising production.

(b) Therefore, over the next decade, the economist should give high priority to a joint economic-agronomic research effort, directed at an analysis of technical and institutional constraints to maize production.

(c) The economist should also help interpret the research results, obtained by his institute, to other economists and to administrators who are working at the planning level. This should contribute to the adoption of new technology.

By 1980, according to Winkelmann, there should be an effective network of social science researchers in maize-producing countries, a group trained to produce farm and market data needed by local policy makers. CIMMYT economists should share in the leadership of that network. And in return, the network should exercise great influence upon the future research plans selected by CIMMYT.

15.2.13 OUTREACH PROGRAM

K.W. Finlay described present outreach activities, and gave his judgment that the volume of services must be increased during this decade. Finlay's ideas can be translated to program objectives as follows:

(1) More national programs will be created by 1980. There are now no more than 15 effective national maize programs; there may be 30 to 40 such programs by 1980. Each new program will add to the need for international training of staff, for international nurseries, for international consultants. Such an increase in production efforts will stretch present outreach services to the breaking point.

(2) CIMMYT now has stationed nine of its maize staff for work in the national programs. That number will increase over the next few years, possibly to 15 or 20 by 1980.

(3) The formation of new national programs will create, in addition, a demand for more consulting services which can best be rendered -- not by expanding CIMMYT staff in Mexico -- but by strengthening the services within each producing region. Such regional services will be needed in six areas of the world, which Dr. Finlay listed as follows: South and southeast Asia, Tropical east Africa, Tropical west Africa, Central America and the Caribbean, the Andean Region of South America, the Southern Cone of South America.

Each region will require several consulting scientists assigned on a regional basis, perhaps two and possibly three scientists

per region. They will be responsible for increased circulation of germ plasm in the region, for training in the region, for annual workshops in the region, for consulting with governments in the region. These activities will supplement the services from Mexico.

(4) CIMMYT does not expect to provide all these services. Other institutions will need to help, as William Young has advocated. But CIMMYT must find ways, acceptable to all, whereby these regional services will operate as a collaborative network, with coordinated leadership, so that all programs can reinforce each other.

15.2.14 CIMMYT'S COLLABORATION WITH OTHER RESEARCH INSTITUTIONS

This maize symposium contained no paper on the subject of CIMMYT's growing dependence upon basic research conducted in other institutions. But for at least six of our presentations, it was necessary to refer to needs for more basic research.

Some discussions on wide crosses referred to collaboration with other institutions to develop more basic information on incompatibility between plants, and the means of overcoming these barriers.

Advocates of varieties with wide adaptation called for help from universities and other centers of excellence in devising mathematical procedures for selection.

In discussing insects and diseases, it was noted that there is need for more research on the genetic factors which control inheritance of resistance, and more basic work on insect physiology.

Discussions of maize physiology cited the value of parallel studies between cereals -- comparing physiology studies of rice, wheat and maize. This work can best be done outside of CIMMYT.

It was observed that CIMMYT's protein research is dependent to a considerable degree upon basic research by other institutions, especially on amino acids and modifier genes.

Finally, CIMMYT's economic program looks to other centers for the development of research tools in a pioneering collaboration between the biological and social sciences.

CIMMYT will continue to look for outside collaboration in all these fields, and will work with other institutes to help them obtain research funds that will develop the basic research needed by CIMMYT.

By 1980, CIMMYT should benefit from a continuous flow of basic scientific data, generated by centers of excellence in North America, Europe, Japan, Australia, and some of the developing countries.

15.3 THREE SYMPOSIUM ISSUES

During the Symposium there were at least three issues raised by our lead discussants that did not receive adequate response. The maize staff, in this post-Symposium review, offers a more comprehensive comment on these issues.

15.3.1 ISSUE No. 1: Is CIMMYT's maize breeding effort properly oriented?

Many breeding theories and modes of operation were suggested to us during the Symposium. Each of these suggestions has an appropriate place, either in basic research or applied research. Our job at CIMMYT is to find the most efficient means of handling the plant material and providing services for national programs, as outlined in our mandate. It is our considered judgment that most developing countries have found great difficulty in producing and distributing hybrid seed. CIMMYT, therefore, has chosen the option for open-pollinated varieties. In our present estimation, this commitment to open-pollinated varieties will continue through the 1970's. This judgment does not preclude the use of one or more types of hybrids as a CIMMYT activity in the future. Our present program of population improvement will contribute to the later development of hybrid parents, if we should make that shift.

Moreover, CIMMYT nurseries are now going to several countries that have national programs with emphasis on hybrids, and these countries are using CIMMYT breeding materials at the present time to develop their hybrids.

Ours is a pragmatic approach: whenever CIMMYT finds that a developing country will benefit from a change in our strategy, we are prepared to reconsider our views. Taking this into consideration, our appraisal remains that CIMMYT will continue with a stress upon open-pollinated varieties throughout the 1970's.

15.3.2 ISSUE No. 2: What is CIMMYT's thinking about international agronomy?

Because of our concern for increased production, agronomy trials on an international scale probably received more attention in the agronomy discussion than they deserved. It is true that in 1972 and 1973 we had some trials that we called "international agronomy trials".

These trials formed a preliminary test of the principles that are now incorporated in our Advanced Unit Trials.

It is also true that we discussed whether we would need any kind of international agronomy trials, at our workshop at El Batán in September 1973 and at Kuala Lumpur in December 1973.

Discussions this week have prompted us to revise our thinking on international agronomy trials, and any later consideration will depend on a year or two of experience with the new pattern of international testing that we have described this week.

We do believe, however, that our agronomy program will contribute internationally by: (1) Designing production trials that are appropriate and meaningful for training production scientists that come to CIMMYT for training; (2) Assisting with production trial designs and layouts where the level of treatments will be chosen to suit local needs; and (3) Assisting in the analysis and interpretation of the Experimental Variety Trials within the ecological areas of adaptation, for a better understanding of adaptation in the broadest sense.

15.3.3 **ISSUE No. 3: Is CIMMYT trying to play too large a role on a world-wide basis?**

We assure you that CIMMYT has no illusions that the task of maize improvement can be handled without a great deal of help from each of you and from many other institutions. To simplify, we will restate our thinking about cooperation of networks of scientists in the broadest possible terms.

It is the concepts and functions that are important. For example, in Mexico, CIMMYT should conduct only that work for which the operations in Mexico offer comparative advantage, and we should look for help from every other institution that can offer its own advantages. That is, we should look to national programs for those things they do best, and to regional programs for their strengths. We also should look to centers of excellence in Europe, North America, Australia, and elsewhere for their strongest basic research contributions.

These aims are stated in perfectionist term, but we all know that neither institutions nor individuals are perfect. Putting the pieces of this program together is a learning process, and we at CIMMYT do not have all of the answers. We have no illusions. As stated previously, concepts and functions are most important, and there seem to be no real conflicts about meeting central needs and functions.

By 1980, we feel confident that the network for maize will be operating more efficiently than it is today. Certainly, the contribution of this Symposium will greatly assist us in meeting the responsibilities of the CIMMYT mandate.

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