CIMMYT REVIEW

1978

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CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO 1978
International Maize and Wheat Improvement Center, Apartado Postal 6-641, Mexico 6, D.F., Mexico

contents

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introduction

THE DIRECTOR GENERAL'S OVERVIEW.

If we profile CIMMYT history in a diagram, we cannot chart a smooth upward-moving line; rather we see a series of steps — each step reflecting a new situation, new problems, new opportunities, and sometimes new leadership chosen for the road ahead.

In 1978, CIMMYT reaches another of those steps.

At the close of the year, CIMMYT's leadership will be taken up by a 48-year-old agricultural administrator, Robert D. Havener. The new Director brings to CIMMYT a mix of experience suited to the needs of CIMMYT in the 1980's. Havener grew up as a farmboy in the U.S. corn belt in the depression years of the 1930's; he earned B.S. and M.S. degrees in agriculture and economics from Ohio State University; he served in the extension service and as manager of an agricultural cooperative in his home state, then moved into an international career. For four years he was advisor to the distinguished Rural Development Academy at Comilla, Bangladesh; then six years as advisor on agricultural research and development projects in Pakistan; then head of the Arid Lands Development Program (ALAD) at Beirut. Under Havener's creative leadership, ALAD services spread to 20 countries in the Mideast, North Africa, and tropical eastern Africa. Havener was designated executive officer to organize CIMMYT's sister institute, ICARDA (International Center for Agricultural Research in Dry Areas).

Next, taking leave from Asia, Havener earned the degree of Master of Public Administration at Harvard University, then joined the New York staff of the Ford Foundation, still responsible for agricultural projects in developing countries. In New York he served with Foundation officers who had helped to create several international agricultural centers and to shape their programs.

Thus Havener brings to CIMMYT seventeen years of successful work with developing countries. He has first-hand knowledge of LDC (less developed country) governments and experience with the financial donors who support the international centers.

To match Havener's fresh leadership, CIMMYT Trustees in 1978 elected four prominent agricultural scientists as new Trustees and appointed them to the Program Committee of the Board. The new members include one each from Ecuador, Sudan, Germany, and Japan.

Problems and opportunities awaiting CIMMYT's new leadership can already be anticipated. But the outlook will be clearer if we first trace CIMMYT's evolution, and describe the momentum which carries over into the years ahead.

1966–71: Formative Years.

Founder's Day for CIMMYT was September 21, 1966. But research on maize and wheat in Mexico carried back at least to 1943, through CIMMYT's predecessor organization – a special office in the Mexican Ministry of Agriculture, jointly staffed by scientists from the Rockefeller Foundation and the Mexican Government. The predecessor organization developed the first semi-dwarf wheats for the tropics. It produced hybrid maize varieties, which were high yielding in Mexico.

Because of this quarter-century of earlier research (1943-1966), CIMMYT made a rapid start. Here are some accomplishments of the formative years under Edwin J. Wellhausen, CIMMYT's first Director General (1966-71):

(1) Land from the Government of Mexico and funds from the Rockefeller Foundation provided a headquarters, both economical and efficient, located 50 kilometers northeast of Mexico City. Access to eight research stations in Mexico offered a wide range of altitudes and climatic conditions for research to serve all developing countries.

(2) From the research stations experimental seed flowed outward to scores of countries – for testing, for further improvement by national scientists, for release to farmers.

(3) A training program took shape in Mexico. Major emphasis was on young scientists from developing countries, who held a first academic degree in agriculture but lacked experience in field research. They participated for one cropping season in Mexico alongside CIMMYT scientists. More experienced scientists from developing countries each spent several months at CIMMYT participating as visiting scientists. Upon returning home, those with Mexico experience were absorbed into the networks of scientists working on maize and wheat in developing countries.

(4) CIMMYT posted some of its own staff to work with local scientists in a developing country. By 1970 these "outreach staff" were serving in five countries on three continents, setting a pattern which CIMMYT still follows.

(5) Financial resources increased. CIMMYT's single donor in 1966 (Rockefeller Foundation) grew by 1971 to five donors, drawing support from the Ford Foundation, USAID, UNDP and the Inter-American Development Bank. Expenditures during this formative period rose from $440,000 to $4 millions a year.

This was the state of CIMMYT's evolution when the Consultative Group on International Agricultural Research (CGIAR) entered the picture in November 1971. The robust rate of growth which CIMMYT experienced in its next phase was dependent on the new resources provided through the Consultative Group.

1972-78: Years of growth.

CIMMYT's activities have expanded greatly during the 1970's – in size, in scope, in creative character. That is the view which CIMMYT holds of itself – biased perhaps – but also corroborated by the impressive growth of wheat and maize production in developing countries, and by the credibility which 19 donors continue to place upon CIMMYT's accomplishments.

Here are some developments of CIMMYT's growth in the 1970's.

(1) Measurable indicators between 1971 and 1978 are easiest to assess. For example: Donors increased from 5 to 19. Total annual budget rose from $4 to $12 millions. International staff positions grew from 57 to 78. International wheat trials expanded from 600 trials in 1971 to 1700 trials in 1977; and the maize trials, from 300 trials in 1971 to 450 trials in 1977. The increase of international trials was especially significant because each trial site for wheat or maize is a show window for the world crop improvement network.

(2) Travel by CIMMYT's international staff in developing countries has expanded to keep pace with increasing trials. Measured in man-days of travel per year, our personnel records show:

1972	*1823 man-days of travel (equals 5 man-years).*
1973	*2297*
1974	*2415*
1975	*3012*
1976	*2958*
1977	*4323 man-days of travel (equals 12 man-years).*

(3) Regional programs for both wheat and maize were introduced in the 1970's, and now represent the largest single change of the decade, because of their direct impact upon research and production in developing countries. In 1978 regional maize programs operate in three areas (Central America, Andes, and southern Asia); and regional wheat programs operate in three areas (Andes, eastern Africa, and the Mediterranean-Mideast). Other regional programs are scheduled to begin in 1979-80. Regional staffs are especially effective, CIMMYT has found, because they improve the quality of trials in developing countries, and persuade governments to supplement their experiment station testing with on-farm research. Both factors add to the effectiveness of the networks.

(4) CIMMYT's economics program was established in the 1970's. In 1978 there are three economists at headquarters in Mexico, contributing to program planning and to training; another three economists serve in regional programs (eastern Africa, southern Asia, and the Andes). Regional economists have developed farm level surveys which give new insights into farmers' practices and attitudes; hence provide guidelines for scientists and policy makers.

(5) Training at CIMMYT was greatly strengthened in the 1970's. Training officers expanded from 2 to 6. Training manuals added substance to instruction. New types of training were introduced — for research station managers, for laboratory technicians, and most important, for production agronomists. Production trainees now participate in on-farm research in Mexico, to prepare themselves for similar work at home. CIMMYT trainers are extending their services into developing countries by assisting with production courses there. So far CIMMYT has participated in this type of training in 10 countries.

(6) Our reporting to donors and to the public has expanded into a major activity. CIMMYT publications have increased in number and are now distributed to a mailing list of 4600. Visitors to CIMMTY headquarters rose from less than 1000 in 1972 to more than 9000 in 1977. CIMMYT introduced "Presentation Week" in 1973 and has repeated

this 6-day briefing program at least once a year, mainly for donors and Trustees.

(7) Growth in itself means little unless it results in a rising production of wheat and maize in developing countries. We find progress here too. During the decade from mid-1960's to mid-1970's, population in developing countries rose 30%, and in the same decade wheat production in developing countries rose 50%, and maize production rose 38%. Thus production of these two major cereals stayed ahead of population growth. (See Table 1.)

(8) A "Special Report" has been included in this publication, CIMMYT Review 1978, *giving recent information on the spread of semi-dwarf wheat varieties developed by CIMMYT-INIA and their predecessor agency.*

This Report indicates that the high yielding wheat varieties were grown in 1976-77 on 29.3 million hectares; that the high yielding "package" varieties and accompanying agronomic practices have now added 24 million metric tons per year to the wheat harvest in developing countries compared to the average harvest in the mid-60's; that if the developing countries had imported this additional wheat instead of growing it themselves, they would have spent at least US$3,400 millions in added foreign exchange for grain imports in the single year 1976-77.

(9) The maize program set a different kind of growth record in 1977. CIMMYT received requests that year for additional seed of experimental maize varieties from 40 national programs among the 55 countries which grew international maize nurseries. Never before had there been such evidence that nations were multiplying maize seed of experimental varieties from Mexico and preparing for tests on farmers' fields. These tests often lead to the naming and release of new varieties.

(10) Not all the news has been favorable. Developing countries have continued in the mid-1970's to import 20-25 million tons of food grain a year. And in the disastrous year of 1974 the developing countries imported almost 50 million tons of grain at a cost of over US$10,000 millions in a single year. That is unfinished business for CIMMYT and other international institutes.

Table 1. Performance of 6 cereals in developing countries 1961-65 compared with 1971-75.

	Annual area			Annual yield			Annual production		
Cereal	1961-65 (million ha)	1971-75 (million ha)	Increase (percent)	1961-65 (kg/ha)	1971-75 (kg/ha)	Increase (percent)	1961-65 (million m.t.)	1971-75 (million m.t.)	Increase (percent)
Rice	85.8	93.0	8	1614	1884	17	138.5	175.4	27
Wheat	50.4	61.3	22	976	1211	24	49.2	74.3	50
Maize	44.8	53.4	19	1132	1313	16	50.7	70.1	38
Sorghum	33.1	35.1	6	628	803	28	20.8	28.1	35
Millet	34.1	36.2	6	521	540	4	17.8	19.6	11
Barley	16.6	15.4	(7**)	937	1083	16	15.5	16.7	8
All cereals*	270.7	299.9	11	1098	1296	18	297.3	388.9	31

Source: FAO Production Yearbooks.
*Includes cereals not listed.
**Decrease.

1979 Onward: Future problems, Future opportunities.

This commentary now turns from past developments to a look at future prospects — assessing some problems which will face CIMMYT in the 1980's, along with new opportunities for effectiveness.

(1) Population growth: From the mid-60's to the mid-70's, the population of developing countries rose 30%: from about 1500 million people to about 1900 millions. For the following decade — from mid-70's to mid-80's — growth will again be about 30% from about 1900 millions to about 2400 millions. Some developing countries will gain less, some more, but the overall momentum of population growth in Asia, Africa, and Latin America is expected to change little by 1985. Even up to 2000 A.D., present forecasts promise no dramatic reduction in the growth rate for LDCs. Projections indicate about 3300 million people in developing countries by the turn of the century. This sets the target for food production.

For example, by 1985 the developing countries will be consuming about 550 million tons of grain per year, up 30 % from 1975. And by 2000 A.D., they will consume 700 million tons of grain, up 67% from 1975. These are straight line projections and do not provide for increased consumption by people whose incomes are rising.

If the future grain requirements in LDCs are restated in yields per hectare, the LDCs will need:

1975 — 1.3 metric tons per hectare (the actual average yield of all cereals in LDCs in 1975).

1985 — 1.7 metric tons per hectare required.

2000 — 2.2 metric tons per hectare required.

This pressure of population growth will continue to confront CIMMYT in the 1980's. Wheat, barley and maize — CIMMYT concerns — contribute 40% of the grain harvest in developing countries.

(2) Another perspective on population growth is the number of persons who depend for food on each arable hectare in developing countries. In 1975, the LDCs used 670 million hectares of arable land to provide food for their 1900 million people. That meant about three persons were supplied food from each hectare in 1975. If we assume that the number of arable hectares cannot be significantly increased, but that population will continue rising at 30% per decade, each arable hectare will be expected to support 3.5 persons in 1985, and 5 persons by 2000 A.D.

These averages, however, conceal dramatic differences between developing countries.

For example, in 1975 Mexico used 28 million hectares to provide food for 60 million people, a little more than 2 persons per hectare. In 1975, Egypt was attempting to support 37 million people from 2.9 million hectares, or 13 people per hectare. And in South Korea, population in 1975 had reached 14 persons per arable hectare. If we project the population increase (at current growth rate) to 1985, Egypt will try to support 16 people per arable hectare, and South Korea 17.

These projections to 2000 A.D. indicate food situations very nearly impossible for some countries, a larger share of populations will need employment off the land.

Table 2 indicates the number of people per arable hectare in 1985 and 2000 A.D. for selected countries, assuming that arable hectares remain constant, and population continues to grow at the same rate as in 1965-1975.

Table 2. Population per arable hectare in selected countries, 1975, 1985, and 2000 A.D., assuming no change in population growth rate.

	Arable hectares (millions)	Population 1975 (millions)	Population per arable hectare 1975 (persons)	Annual rate of natural increase 1965-75	Population 1985 (millions)	Population per arable hectare 1985 (persons)	Population 2000 AD (millions)	Population per arable hectare 2000 AD (persons)
Mexico	28	60	2	3.5 %	85	3	136	5
Korea, Rep.	24	34	14	2.0 %	41	17	54	22
India	167	608	4	2.0 %	741	5	983	6
China P.R.	129	823	6	1.7 %	974	7.5	1241	10
Kenya	1.8	13	7	3.3 %	18	10	28	15
Tanzania	6.1	15	2.5	2.8 %	20	3.5	30	5
Egypt	2.9	37	13	2.3 %	46	16	63	22
All LDCs	670	1900	3	2.5 %	2400	3.5	3343	5

Sources:
Arable hectares from FAO Production Yearbook. Arable hectares includes land used for both annual and permanent crops.
Population levels and rate of natural increase from "Population Growth 1965-75" published by Population Reference Bureau, Washington, D. C.
Ratio of man to land extrapolated.

Figure 1 portrays this information graphically.

These are not forecasts but only the approximate magnitude of the food problem in a few countries, if growth continues without change.

The man-land ratio is another factor influencing CIMMYT's program in the 1980's.

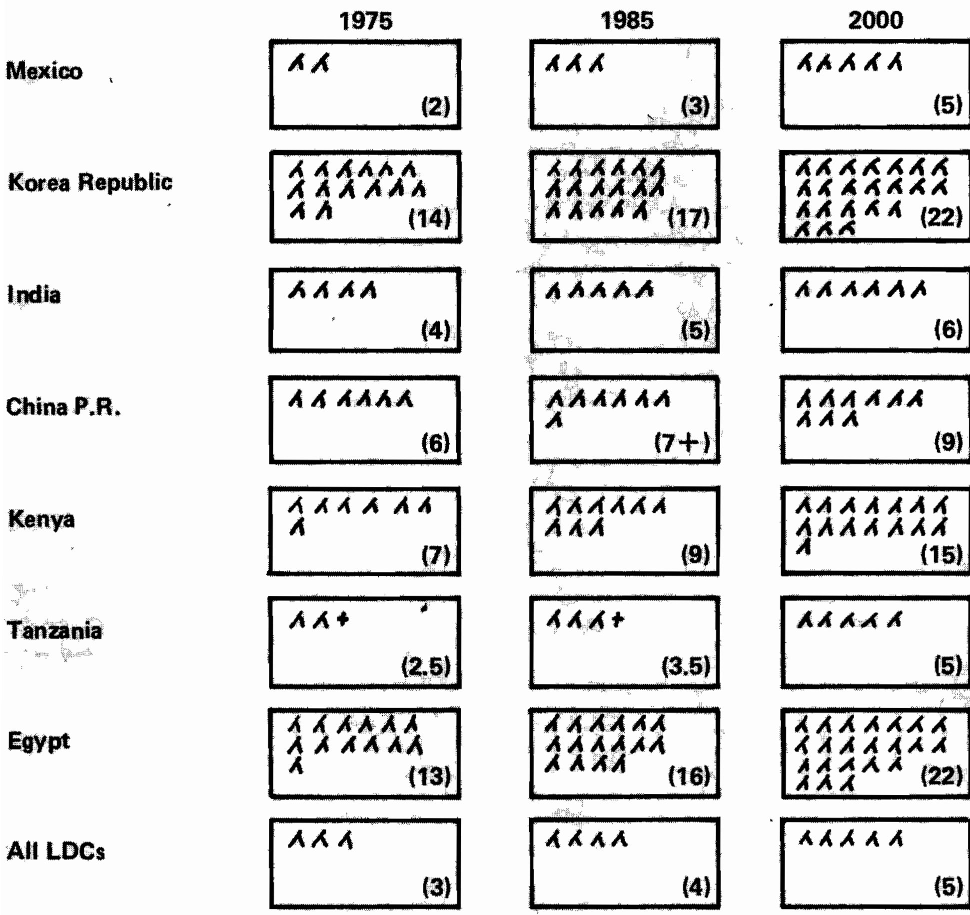
(3) Population pressure upon the land (Figure 1) inevitably brings changes in the farming system. Farmers need shorter season crops so that more crops can be grown each 12 months on the same land. The People's Republic of China achieved a doubling of food production during 1950-75 with the help of shorter season crops which permitted double cropping many areas that grew only one crop before, and triple cropping some areas where two crops were grown before. Greater crop intensity required more irrigation and more fertilizer.

Other changes occur in farming systems as population rises. Farmers substitute higher yielding crops, —for example, cereals replacing legumes in many places.

The cropped area expands — into forests, into pasture land, up the mountain sides, into colder, drier, or poorly drained areas, into problem soils. This expansion creates the need for new kinds of agricultural research.

Changes in farming systems will speed up in the 1980's, requiring further changes in CIMMYT's program.

Figure 1. Persons to be fed from each arable hectare in selected countries, 1975, 1985, and 2000 A.D.



Explanation of Figure 1:

Each rectangle represents 1 arable hectare.

The figures inside the rectangle represent the population requiring to be fed from one arable hectare.

Assumptions:

(1) That arable hectares will not increase significantly during 1975-2000 A.D.

(2) That population growth during 1975-2000 will continue at the same growth rate as in 1965-75.

(4) The role of national research programs will be changing. Farming systems are essentially country-specific or region-specific. Research for changes in farming systems will not be accomplished at international centers like CIMMYT but in national and regional programs. CIMMYT became involved in these studies through collaborative arrangements. For example, studies of the wheat-medicago rotation in Tunisia-Algeria resulted in adapted technology which is now spreading to other countries of the Mediterranean region. The rotation of summer season rice and winter season wheat or barley in the Republic of South Korea has become the government's No. 1 priority. The rotation can be tested only locally, but CIMMYT is assisting with development of early maturity winter cereals for incorporation into the rotation.

In future, national programs may develop more and more of the experimental varieties which are tested around the world. But CIMMYT and other international centers will continue to provide access to the world germ plasm collections, and give leadership to the world-wide testing system. Service functions performed by international centers will thus become even more important in the 1980's.

(5) In the 1980's the CGIAR foresees a slower growth of financial resources. CIMMYT's program leadership will find it necessary to devote more time to the proper briefing of donors, and to the search for new support.

A system of priorities, sufficiently objective to facilitate the allocation of funds, will require comprehensive information on the role of various crops in human nutrition, and on farming practices and constraints.

Fortunately, information on these questions is increasingly available through the widespread use of on-farm research, through farm-level surveys, and through better contacts with the policy makers in developing countries. These activities initiated by CIMMYT program staff in the 1970's will take on even greater importance in the 1980's.

Summing up

To sum up: CIMMYT has acquired the essential elements of a "Center of Excellence." These are:

A creative staff, including younger scientists rising to future leadership.

Headquarters facilities, adequate for the present, well maintained.

A network of research stations located in climatic zones suited to the needs of developing countries.

A world-wide network of collaborating scientists for wheat and maize, committed to exchange germ plasm and technology.

Good working relationships with the governments of developing countries.

Credibility of donors.

A strong Board of Trustees.

CIMMYT's directing staff will be tested by the changes now foreseeable in the 1980's and will be judged by how well it handles new opportunities for effectiveness. The changes include:

A population growth rate for all LDCs, now 30 % in 10 years.

Pressure of man upon arable land, reaching 16 and 17 persons per arable hectare in some countries by 1985.

Farming systems changing steadily as population density rises, creating the need for new guidelines for research.

The changing role for national programs, and along with it, a changing role for international centers.

Tighter finances.

With this agenda, the 1980's will be a strenuous decade.

Haldore Hanson
Director General
El Batan, July 1978

maize improvement

Introduction To Maize Program

World maize production for the year 1976 was 334 million tons, a record. In developing countries the maize crop of 1976 was 73 million tons, equalling the previous high. *(FAO Production Yearbook 1976.)*

But maize yields are increasing more slowly than population in developing countries. And developing countries as a group continue to import about 5 million tons of maize each year.

Imports indicate a food deficit. Higher yields per unit area are needed if the developing world is to achieve self-sufficiency and stay ahead of population.

Gap between researcher and farmer

A wide gap exists between maize yields in research stations and in farmers' fields. In lowland tropical climates for example, scientists in national programs generally achieve maize yields of 3-6 tons per hectare, whereas national average yields in farmers' fields are typically 0.7 to 1.7 tons, commonly below one ton. In the highland tropics the gap is similarly wide — from 6-10 tons in the research station compared to 1.5-2.0 tons in the farmers' fields.

CIMMYT urges these countries to test and demonstrate new maize varieties on farmers' fields, for two reasons: to prove whether the new technology is actually better than the old, under farmers' conditions; and to persuade the farmer that new technology works on his land. Farmers are not persuaded by what they see at the research station.

Many governments are now introducing on-farm testing for the first time. This will help narrow the gap between research station and farmer.

Delivering new technology

CIMMYT continues to employ many ways for moving new technology to developing countries.

In 1977 our international maize nurseries were grown in 64 countries. These nurseries display experimental material in the developing world where they can be evaluated by scientists and farmers, and the trials provide data which guide the worldwide network of maize scientists.

Sixty more young scientists from developing countries were brought to Mexico in 1977 to work one cropping season with our staff. They are now back home, where they serve in the international network.

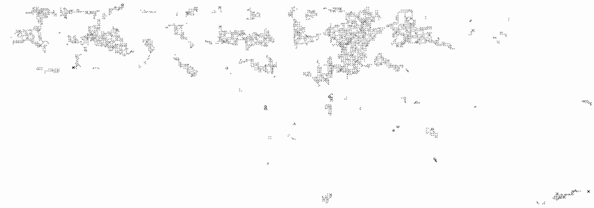
CIMMYT's headquarters staff travelled to 45 countries in 1977 to see the international trials, to visit former trainees, to observe production problems in farmers' fields, and to discuss policy questions which influence maize production.

In 1977 fifteen CIMMYT maize scientists were posted in regional and national programs outside Mexico. The regions are: Central America and the Caribbean (14 countries served); Andean region (5 countries); and South and Southeast Asia (15 countries). CIMMYT also had staff posted in 1977 in the national programs of Egypt, Guatemala, Nepal, Pakistan, Tanzania, and Zaire.

In pages which follow, our staff has assembled an overview of the recent work in maize improvement. It shows some encouraging developments.

From current results we draw confidence that the worldwide network of scientists can develop new technology at a pace which will permit maize production to stay ahead of population growth — for some additional years.

E. W. Sprague



Procedures for Improvement of Maize Populations And Development of New Varieties

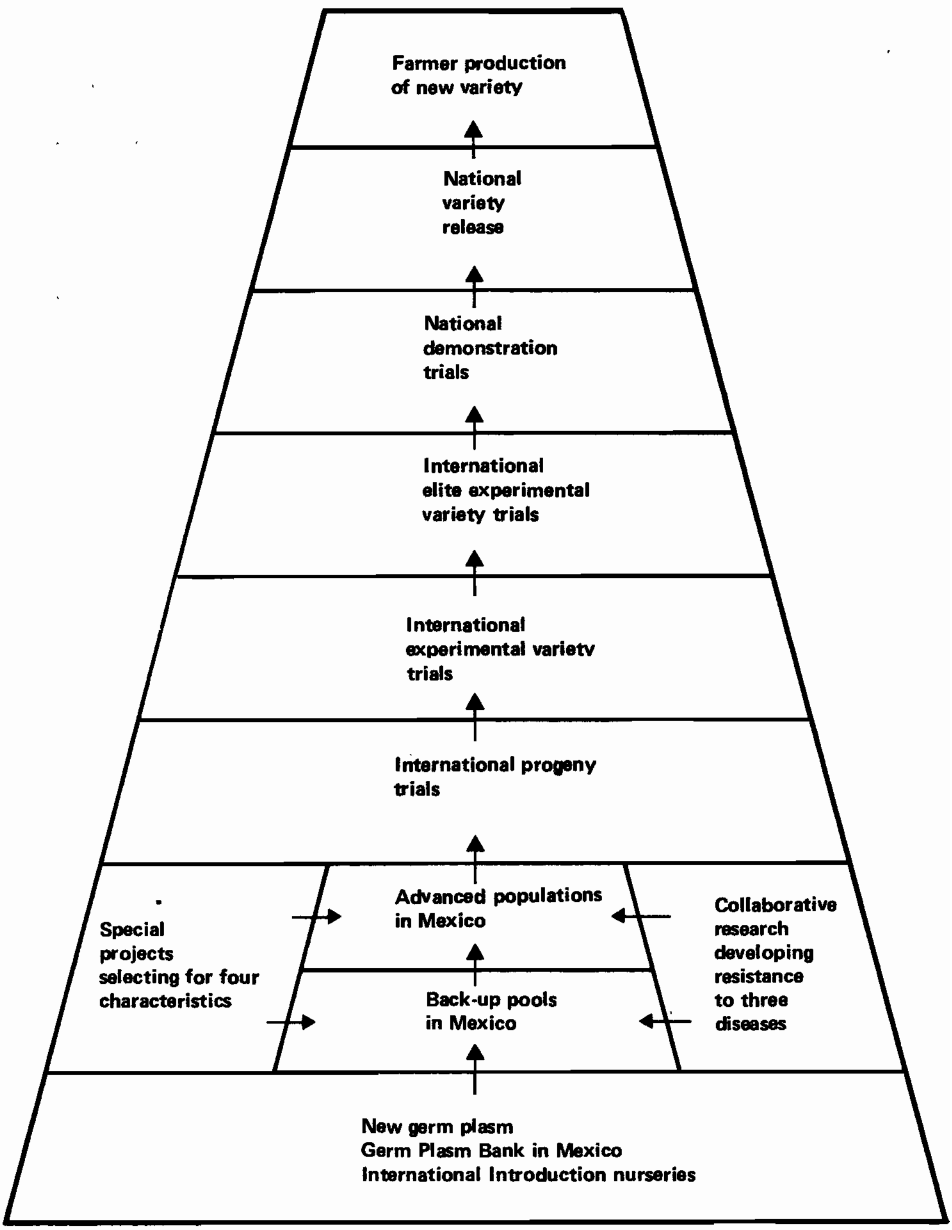
During the 1970's CIMMYT has evolved a number of germ plasm pools (early stages of improvement) and advanced populations (improved over many generations). Each year selections from these pools and populations are tested in Mexico, then the superior materials are tested by a network of more than 500 collaborators in over 60 countries. The judgment of the worldwide network thus guides the national programs, and helps CIMMYT develop more productive populations and varieties for shipment to them.

The release of new varieties to farmers in developing countries is a decision made by each collaborating government.

This process of population improvement and varietal development is summarized in the Maize Pyramid diagram.

Thousands of superior families are tested, and only the best are chosen to generate new advanced populations.

THE MAIZE PYRAMID



National variety release

Based on local farmer demonstrations, and worldwide data, each national program decides whether to release a new variety.

National demonstration

National programs alone decide whether an elite experimental variety justifies wider demonstration on farmers' fields. CIMMYT supplies basic seed for increase by governments. In larger countries, demonstration trials take place at hundreds of sites.

Elite experimental variety trials

Remnant seed of the elite varieties is increased in Mexico to generate the quantity required for 200 test sites the following year. For the first time, some trials are held on private farmers' fields.

International experimental variety trials

In Mexico during the off-season CIMMYT intercrosses the 10 best families from each site using reserve seed and the random mating method, to produce an experimental variety which will be tested by collaborators at 20-40 sites, worldwide, during the following year. Data from these 20-40 sites determine the selection of elite experimental varieties for the following year.

International progeny trials

The 250 progenies from each population are sent to collaborators at five sites, worldwide, to be grown in 250 5-meter rows, with six local checks, forming a 16 x 16 simple lattice with two replications. Ten best progeny are identified by the collaborator at each site, to form one experimental variety for the following year.

From collaborators' data CIMMYT identifies the 10 best families giving superior performance across all test sites, and uses these to develop an "across-site" variety. CIMMYT also identifies 100 families on the basis of across-site performance to reconstitute the advanced population for the next generation.

Advanced populations in Mexico

Here materials continue to be grouped by agro-climates, but unlike the pools, the advanced populations have completed several generations of selection for better plant type, better disease and insect resistance, better yield. These populations are grown in Mexico, and 250 superior families (progeny) are developed from each population for international testing every second year.

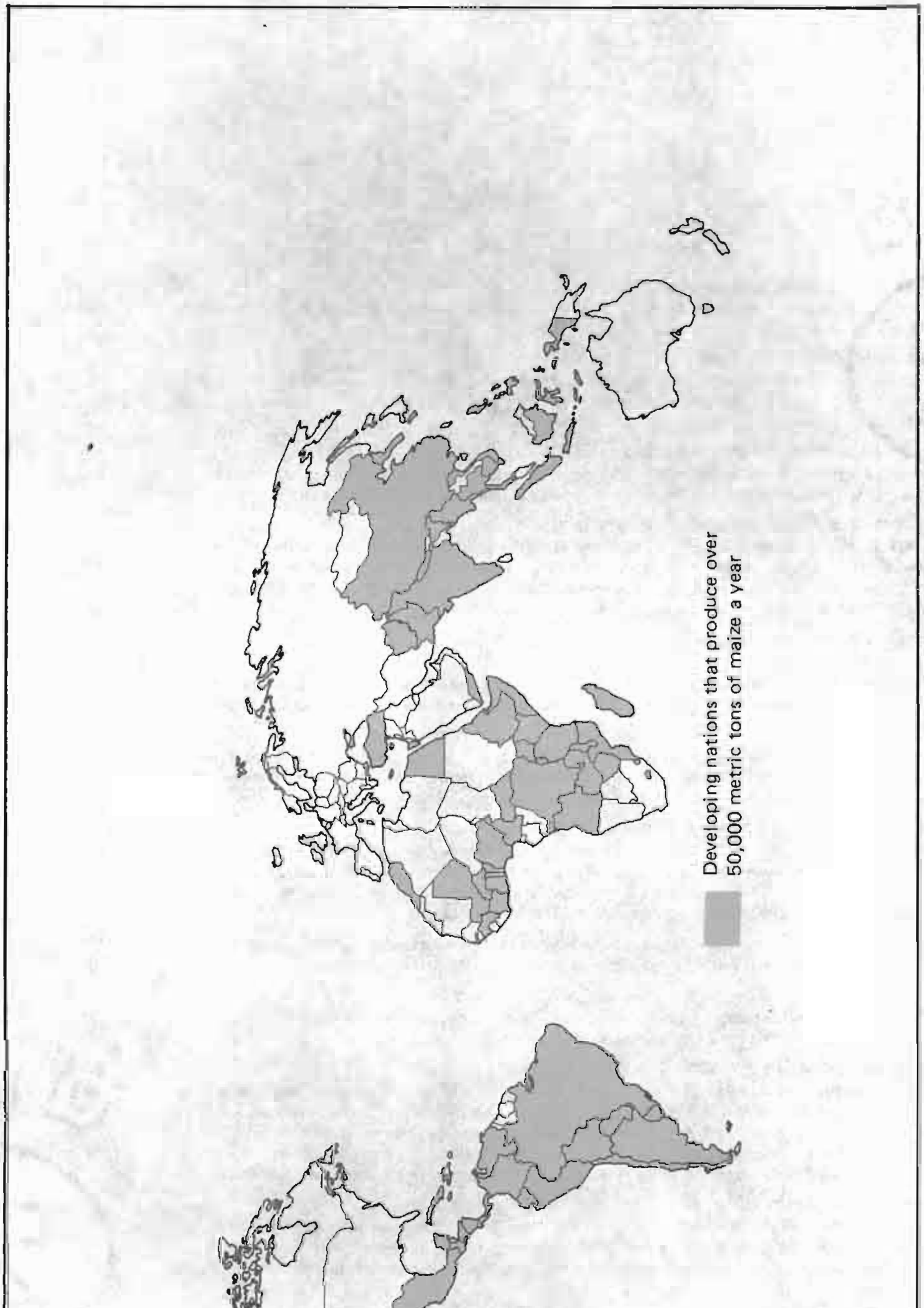
> 'Special projects' deal with specific characteristics like shorter maturity, wider adaptation, more efficient tropical plants (those putting a larger amount of dry matter into grain) and drought tolerance.
>
> 'Collaborative research' develops resistance to three diseases: downy mildew in Asia, streak virus in Africa, corn stunt in Latin America.

Back-up pools in Mexico

Here germ plasm is classified into 34 pools (genetic soups) according to three climatic regions (tropical lowlands, tropical highlands, temperate zone), four grain types (flint or dent, white or yellow), and three lengths of growing season (early, intermediate, full season). There are 12 pools for the lowland tropics, 14 pools for the highland tropics, and 8 pools for the temperate zone. The pools are grown every year in Mexico and seed from superior families is moved into the appropriate advanced populations.

New germ plasm

Each year new germ plasm is tested and some is selected for addition to the back-up pools. Selections may come from the germ plasm bank (13,000 accessions of varieties, lines, wild types) which are continuously being classified; or from introduction nurseries (new materials received from national programs).


Developing nations that produce over
50,000 metric tons of maize a year

Germ Plasm Bank

The germ plasm bank is a service unit for researchers. The bank unit maintains and regenerates seed, tests and catalogs them and ships seed to users.

The 13,000 items in the CIMMYT bank were gathered from 46 countries mainly by an agency of the Mexican Ministry of Agriculture during the 1940's and 1950's. Over 90 percent of the collection consists of the species *Zea mays L.* The collection also contains the near relatives *Zea mexicana* and *Zea perennis.*

Agro-climatic characteristics considered in classifying maize gene pools.

Maturity range	Altitude (m)	Latitude	Temperature*	Days to silking	Duration of crop growth (days)
Tropical lowland					
early	0-1600	0-30° N-S	25-28°C	Up to 50	About 80
medium	0-1600	0-30° N-S	25-28°C	50-60	About 100
late	0-1600	0-30° N-S	25-28°C	60-	About 120
Tropical highland					
early	1600-	0-30° N-S	15-17°C	Up to 70	About 120
medium	1600-	0-30° N-S	15-17°C	70-95	About 160
late	1600-	0-30° N-S	15-17°C	95-120	About 240
Temperate-subtropical					
early	0-1600	30-40° N-S	20-22°C	Up to 60	About 120
medium	0-1600	30-40° N-S	20-22°C	60-75	About 150

*Mean of main growing season.

The bank is held in concrete chambers at a temperature of 0 degrees C. There are over 18,000 labelled storage tins of 2-liter and 4-liter capacity containing 40 tons of seed. The tins are arranged on steel shelving like library stacks.

A duplicate seed supply for the CIMMYT collection (500 grams per item) is being deposited for long term storage at the U.S. National Seed Storage Laboratory in Colorado.

Regeneration

Fresh seed was grown for over 8000 bank accessions between 1969 and 1976. In 1977, seed for another 122 highland accessions and 200 tropical-temperate accessions was regenerated in Mexico and added to the bank.

Classification and cataloging

Over 8000 of the bank items have been documented for agronomic characteristics, and 3000 of them tested in replicated yield trials. A catalog on computer is in preparation giving name of each accession, country of origin, agronomic information, current quantity of seed, location of storage tin, etcetera. Collaborators on the catalog include the Information Service for Genetic Resources, Boulder, Colorado, and the International Board for Plant Genetic Resources.

Superior materials are tested by a network of more than 500 collaborators in over 60 countries.

Shipments to clients

CIMMYT offers free samples of seed from the bank to all research organizations. From 1966 to 1976 the bank made 647 shipments to 80 countries, representing more than 27,000 seed items. During 1977 there were 44 shipments totalling 2461 seed items to 23 countries.

CIMMYT continues to fulfill the role of caretaker of the world's largest maize collection.

Flow of Germ Plasm

Each year, raw germ plasm newly arriving at CIMMYT or drawn from the bank is tested, and the superior materials are added to the back-up gene pools. After recombinations and improvement, superior progenies from the back-up pools are moved into the advanced populations. Superior progenies from the advanced populations are moved to the national programs for use in their research and production programs. This continuous flow of germ plasm is an essential part of CIMMYT's delivery system.

Introduction nurseries

During 1977 over 1000 materials newly arrived in Mexico from national programs were planted in observation nurseries. The best will be moved into the corresponding back-up pools in 1978. A few will be further improved in the breeding nurseries before they are incorporated. New materials are especially needed for earliness and disease-insect resistance.

Materials from the bank

In 1977, 500 bank accessions of tropical character were evaluated at two sites (Poza Rica and Tlaltizapan), 500 temperate accessions were evaluated at Tlaltizapan, and over 300 highland accessions at El Batan and Toluca. Several superior materials were identified on the basis of their multi-site performance and will be added to appropriate back-up pools in 1978. Other selected accessions will be further improved in 1978 in the breeding nursery before being incorporated into the pools.

Improvement of pools

All highland, temperate and tropical pools were improved during 1977 by the method of half-sib selection as modified by CIMMYT. The 400 to 800 families comprising each pool were planted in a pattern of two female rows alternating with one male row. Male rows were planted with a composite of seed giving equal representation to superior families in each pool. Female rows were completely detasseled. Tall, diseased or otherwise undesirable plants in the male rows were also detasseled before shedding pollen. This avoided pollination of female rows from inferior males. In early maturity pools when 70% of the plants in the pool had silked, all male plants were detasseled. This prevented the late male plants from giving pollen, and the late female plants from receiving pollen, thus eliminating both from the pool. This procedure appears to be effective in reducing the maturity period. Each pool was grown at least at two sites. At harvest, best ears from the superior plants from superior families at each site were selected to reconstitute the pool.

Improving pest resistance in the pools:

Five tropical pools were artificially infested with the larvae of the fall army worm *(Spodoptera frugiperda)* in order to raise the level of resistance to this pest. One-half (8 plants) of each half-sib family was infested and the other half protected by insecticide.

This permitted the evaluation of the family for insect resistance as well as other agronomic characteristics simultaneously. Best plants in superior families were hand-pollinated and resulting seed entered the pool the next season.

Artificial inoculation for ear rots was carried out in three tropical pools. Several plants within each family were selfed and then inoculated. Clean ears from inoculated plants formed a significant part of the pool the next season.

While gene pools were being improved for these specific characteristics, care was taken that their genetic diversity was not reduced.

Advanced Populations

In 1977 two new populations were promoted to the Advanced Unit. These are Templado Amarillo O_2 (IPTT41) and Amarillo del Bajío (IPTT45). These are meant to serve the temperate and sub-tropical maize areas of the world which need early maturity in yellow kernel types. CIMMYT now has 24 advanced populations for temperate and tropical lowlands. An additional six populations are being developed for the Andean Highlands.

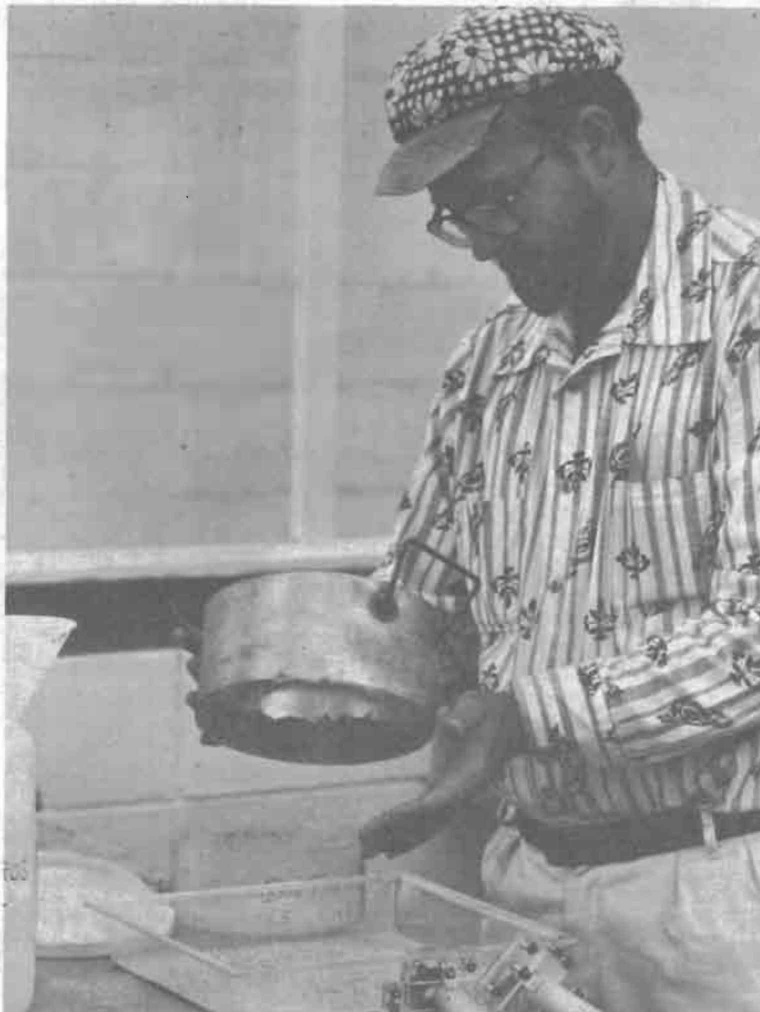
Each advanced population is handled in a two-year cycle — one year of improvement and regeneration in Mexico following a full sib system and a second year of multilocational testing (at six sites) throughout the world. The top 100 families are identified on the basis of across site performance in yield, maturity, plant height and other agronomic characters and remnant seed of these superior families is used to start the next selection cycle of each population.

Populations that have given top performing experimental varieties and elite varieties are Eto x Illinois, Amarillo Subtropical, Blanco Subtropical, Mezcla Tropical Blanco, and Tuxpeño Caribe. Analysis of data indicate that selection for wide adaptation, which is essential for superior performance, has been quite effective.

Families are evaluated for insect resistance and other agronomic characteristics, simultaneously.

Disease and Insect Resistance

The plant protection staff (pathology and entomology) work as part of the interdisciplinary maize team. They assist the process of developing disease and insect resistance by evaluating and selecting in raw germ plasm, the back-up pools, and advanced populations in Mexico. They rear insects and produce disease inoculum. They engage in collaborative research with national programs and help to identify pests and pathogens in many countries.



A new insect infestation technique provides more uniform infestations and speeds up insect resistance studies.

Improvement for insect and disease resistance

To determine how families of maize from populations react to insects and pathogens, the plant protection scientists subject these families to timely artificial uniform infestations and/or inoculations.

For disease resistance advanced populations are inoculated with stalk and ear rotting organisms. At harvest the pathologist scores each family for disease damage, and progenies with the least damage are retained for succeeding generations.

For insect resistance, the populations are artificially infested with larvae of fall army worms and sugarcane borers. These are the most widespread and important maize pests in Mexico and the tropics of the Western Hemisphere. At appropriate intervals after infestation, visual ratings for insect damage are made for each family. Progenies showing the least damage (most resistant) are retained and the most severely damaged (most susceptible) discarded.

Under recurrent selection pressure with the uniform artificial infestation and inoculation techniques which CIMMYT has developed, the populations should gradually increase in resistance to these important diseases and insects.

Insect-rearing laboratory

Large numbers of insect larvae are required to artificially infest the families of the pools and populations. An insect rearing laboratory has been established which has the capacity to produce the insect larvae required to infest the progenies to be evaluated. In the last 2 cycles of 1977 CIMMYT produced over 5,000,000 *Spodoptera frugiperda* larvae that were used for infestation, and over 100,000 *Diatraea saccharalis* larvae. Laboratory colonies of the corn earworm *(Heliothis zea)*, southwestern corn borer *(Diatraea gradiosella)*, and neotropical corn borer *(D. lineolata)* have also been established. As rearing techniques for these species become more efficient, maize materials will be evaluated and selected for resistance to them.

Larvae replace egg masses

In 1977 a new insect infestation technique in the maize plots made infestations more uniform and speeded up insect resistance work.

Previously the entomologists infested the maize plants with egg masses on squares of wax paper which were pinned to the maize leaves, and as the eggs hatched, the larvae began feeding. With the new technique, egg masses are hatched in the laboratory, larvae are mixed in an inert carrier (ground corn cobs), and this mixture is applied in maize plant whorls with a portable field applicator (bazooka). The new technique shows several advantages: (1) use of the larval mixture facilitates handling both in the laboratory and the field, (2) field application is 3 to 4 times faster (up to 1500 plants per man-hour), (3) infestation is more uniform (the number of insects per plant varies only 15%), and (4) escaping plants are very few (1 to 5 plants per 1000).

Collaborative research for resistance to three major diseases

Starting in 1974 a collaborative breeding project was organized between CIMMYT and six strong national maize programs, which are jointly developing germ plasm resistant to three damaging diseases of maize.

The diseases are downy mildew (*Sclerospora* spp.), a fungus disease found in Asia from Indonesia to India but spreading to other continents; maize streak virus, disseminated by a leafhopper (*Cicadulina* spp.) found in tropical Africa; and corn stunt disease disseminated by a leafhopper (*Dalbulus* spp.) in tropical Latin America.

The participating national programs include two Asian countries, Thailand and the Philippines; two African countries, Tanzania and Zaire; and two Latin American countries, Nicaragua and El Salvador. Each country is situated in an area where one of the diseases is severe.

In 1974 CIMMYT assembled in Mexico three broad-based maize populations which could have general acceptance in the tropics if they carried resistance to the three diseases. The three base populations, plus 93 other heterogeneous materials were crossed to sources of resistance to the three diseases.

In 1975, 4000 experimental progenies selected from these crosses were sent to the six participants, to be screened for resistance to the diseases. All 1975 plantings in Africa were lost due to drought, thus delaying the streak virus studies 1 year. But families resistant to downy mildew in Asia and to stunt disease in Latin America were identified by the collaborators and self-pollinated.

In the spring cycle of 1976 those families identified for resistance in Asia and Latin America were recombined in Mexico, using selfed seed from resistant plants identified in the diseased areas. After recombination, plants were selected and seed was again sent to the six collaborators for planting in the autumn of 1976.

The same process for all 3 continents was repeated in 1977 and is proceeding again in 1978. Sub-populations have now been assembled for resistance to each of the three diseases, in each of the three base populations. Over a period of years, the genes for resistance to the three diseases should be pyramided, and the level of resistance improved.

Plant protection scientists subject the families to systematic artificial inoculations to assess population reaction to pathogens.

Protein Improvement

Protein is unsatisfactory in most maize. In a commercial maize crop, protein ranges from 9 to 11 percent of the grain weight, which is adequate for balanced human nutrition if all of it could be utilized. But maize protein is low in lysine and tryptophan, two essential amino acids. Because of inadequate lysine and tryptophan the body can utilize only half the protein in normal maize. Lysine is typically 2 percent of protein in normal maize, whereas 4 percent would be needed to permit use of all the protein.

Scientists at CIMMYT and elsewhere have been working for a decade to improve the quality of maize protein.

Maize protein can be improved by introducing one or more mutant genes affecting endosperm quality but the added genes bring undesirable effects which have to be corrected in order to make the high quality protein maize acceptable to farmers.

One breeding approach is through opaque-2 mutant gene (the name comes from the appearance of the kernel), but opaque-2 maize has serious defects:

1) Reduced kernel weight,
2) Unacceptable kernel appearance,
3) Greater vulnerability to ear rots,
4) Slower drying of grain,
5) More weevil damage during storage.

Since 1969 CIMMYT breeders have been selecting opaque-2 populations with modified hard endosperm, normal in appearance, resistance to ear rots, and higher tolerance for stored grain insects. This is a slow process.

Continued progress in 1977 was indicated by the following:

(1) CIMMYT has now developed 34 gene pools and 5 advanced populations carrying the opaque-2 gene and is growing these materials two cycles a year to select for hard endosperm and other improved characteristics. Some materials have reached F_4 or F_5 generation. Much progress has occurred during the past three years.

(2) We now have opaque-2 maize materials that are very similar in kernel appearance and yield performance to normal materials. In 1977 eight experimental varieties carrying the opaque-2 gene were tested at 38 locations worldwide. Among the first six locations reporting results, the top opaque

experimental variety outyielded all checks at five locations. The checks included commercial hybrids.

(3) Seven national maize programs are each developing open-pollinated maize varieties with improved protein quality suitable for their agro-climate (Ecuador, Ghana, Guatemala, Nepal, Philippines, Tanzania, and Zaire). Twenty-five governments requested additional seed for opaque-2 maizes in 1977 to prepare for on-farm trials.

(4) For Andean countries where farmers prefer floury maizes (large soft kernels) CIMMYT has crossed the local varieties with carriers of the opaque-2 and the progeny are undergoing selection in the South American highlands in 1977 and 1978.

(5) A composite of two mutant genes, called opaque-2x sugary-2 has been made at CIMMYT and is undergoing its second recombination in 1978. Although no results can yet be forecast, biochemical analysis indicates higher total protein but no change in the amino acids lysine and tryptophan when compared to the soft endosperm opaque-2 types.

CIMMYT is developing opaque-2 maize materials that are very similar in kernel appearance and yield performance to normal varieties, with high quality protein as a bonus.

Little maize has been planted commercially with high quality protein. USA, Brazil, Colombia and Yugoslavia have released opaque-2 hybrids which are grown mainly for animal feeds. In the USA less than 200,000 hectares of opaque-2 maize is grown.

CIMMYT believes that a breakthrough on commercial use of high quality protein maize will come only when a variety carrying the opaque-2 gene shows yields and agronomic performance equalling or surpassing the existing normal varieties, and the protein quality is a bonus.

International Maize Testing

In the spring of 1977 CIMMYT shipped seed for maize trials to 55 countries. This was the largest number of collaborating countries in CIMMYT's 12-year history. Participating countries increased from 38 in 1975 to 49 in 1976, to 55 in 1977. In 1978 there will be further expansion to 62 countries. The number of participants is determined by national requests, and reflects the growing awareness that experimental varieties developed from CIMMYT populations are outyielding many commercial varieties and hybrids now used by national programs.

The 1977 shipments included 71 progeny testing trials, 196 experimental variety trials, and 186 elite variety trials.

By December 15, 1977 (cutoff date for the preliminary report) results from 104 of the 1977 trials had been received in Mexico. A preliminary report was issued from a photo copy of the computer printout without need for typing the data tables. This report was distributed to all collaborators within the calendar year when the trials were grown. Such rapid reporting permits the 1977 preliminary report to guide the 1978 plans both for the worldwide collaborators and for CIMMYT.

In May 1978 a supplemental report will be issued on the 1977 trials, incorporating all data received to that date. Data received after May 1978 will be distributed as addenda. Delays in reporting worldwide trials are caused mostly by the range of planting dates for different latitudes.

International progeny testing trials

For the fourth year, progeny trials were distributed to collaborators in 1977, this time to 71 locations in 23 countries. Each collaborator received 250 progenies from an advanced population, which he tested against the best local varieties (checks), and was asked to choose the 10 best progenies. Selection criteria included higher yield, shorter plant height, fewer days to flowering, resistance to diseases, and resistance to lodging.

The 10 best progenies from each site are then intercrossed in all possible combinations by CIMMYT in Mexico during the winter of 1977-78, to create an experimental variety which carries the name of the site where the progenies were tested. The experimental varieties will be tested by many more collaborators in 1978.

Half the collaborators reporting by December 1977 found the 10 best progenies at their location outyielded the best checks by more than 10%, a few by more than 50%. Some of the best progeny also had shorter plant height, fewer days to flowering and superiority in disease resistance and lodging resistance.

So far, CIMMYT has developed 110 experimental varieties based on data from the 1976 progeny trials, and 55 experimental varieties based on the 1977 progeny trials. Additional experimental varieties will be developed when data is received from the remaining locations of 1977 progeny trials.

Experimental variety trials

In 1976, 140 locations submitted data on experimental variety trials. Of these, 75 locations reported yield increases from 10% to 153% over the local check varieties and hybrids.

In 1977 seed for experimental variety trials was distributed to 196 locations in 53 countries. Each collaborator was asked to grow the trial with superior local varieties or hybrids as checks, and to report the results to Mexico. Data from 31 locations were received in time for the preliminary report. In 27 of the 31 trials reported, the best experimental variety outyielded the best check; at 70% of the locations the yield superiority was 11-39%.

From these experimental varieties, about 30 elite varieties will be selected for seed increase and testing by a wider number of collaborators in 1978.

Elite variety trials

In 1976 data were received from 125 locations in the elite variety trials. The reports indicated that at 59 locations the top elite variety outyielded the best check variety or hybrid by a margin of 10 to 79%.

The year 1977 was the second year in which CIMMYT distributed elite varieties for trial.

One of the 1977 trials (No. 18) consisted of 14 elite varieties suitable for the lowland humid tropics, and containing "normal" protein. These were tested in 44 countries of Central America and the Caribbean, the Andean region of South America and Brazil, in 18 countries of Africa south of the Sahara, and the region of South and Southeast Asia. Each collaborator tested the 14 elites against the best local varieties and hybrids.

International Maize Trials 1975-78

Region and nation	1975 trials	1976 trials	1977 trials	1978 trials
Central American and Caribbean	132	196	163	218
Antigua	0	0	1	1
Bahamas	0	2	2	2
Belize	1	7	4	6
Costa Rica	8	11	10	14
Dominica	0	0	0	4
Dominican Republic	4	11	5	7
El Salvador	11	12	9	14
Grenada	0	2	1	2
Guatemala	13	17	11	15
Haiti	4	7	10	12
Honduras	9	15	11	22
Jamaica	4	9	9	12
Mexico	63	76	67	63
Nicaragua	8	10	7	15
Panama	7	10	10	19
St. Kitts	0	0	0	1
St. Vincent	0	0	0	1
Trinidad	0	7	6	8
South America	59	90	96	111
Argentina	2	7	6	6
Bolivia	14	10	12	29
Brazil	6	28	39	29
Chile	1	1	3	2
Colombia	11	17	10	13
Ecuador	8	8	8	10
Guyana	0	3	3	3
Peru	10	13	9	13
Surinam	0	0	3	1
Venezuela	7	3	3	5
Mediterranean/Mideast	19	31	43	54
Algeria	1	0	2	2
Egypt	9	12	12	12
Iraq	0	1	6	6
Iran	3	0	0	2
Saudi Arabia	0	1	3	4

The first reports received indicated that the best elite outproduced the best checks in 10 of 11 locations, by a yield margin of 10-42%.

Elite trial No. 20 contained eight elite varieties considered suitable for the subtropics or temperate zone. These were tested in 28 countries at 48 locations. The participating countries included many in the uplands of the Andes, East Africa, the Mediterranean and Mideast, parts of South and Southeast Asia, and the higher latitudes of the southern hemisphere. Since these testing sites have longer growing seasons, and only four collaborators had reported by December 15, 1977, interpretation of the trial was deferred until the supplemental report.

International Maize Trials 1975-78 (Con't)

Region and nation	1975 trials	1976 trials	1977 trials	1978 trials
Sudan	0	2	3	2
Syria	0	0	0	3
Tunisia	0	0	1	2
Turkey	5	8	4	4
Yemen, A.R.	1	7	12	13
Tropical and Southern Africa	49	93	89	127
Benin (Ex-Dahomey)	0	3	1	1
Botswana	0	2	2	5
Cameroon	0	10	6	7
Central African Rep.	1	2	2	2
Ethiopia	1	6	3	12
Ghana	3	5	3	4
Guinea-Bissau	0	0	3	3
Ivory Coast	9	12	9	11
Kenya	4	5	2	3
Lesotho	0	0	0	2
Malawi	0	4	7	4
Mozambique	3	0	3	6
South and East Asia	53	96	61	87
Afghanistan	0	2	2	2
Bangladesh	2	8	6	7
India	17	19	12	19
Indonesia	1	0	0	5
Khmer	1	0	0	0
Malaysia	0	2	2	3
Nepal	7	24	7	9
Pakistan	10	15	9	10
Philippines	8	14	10	19
Sri Lanka	0	7	2	2
Thailand	7	5	11	11
Other	0	3	1	2
Canada	0	1	0	0
Hungary	0	0	1	2
USA	0	2	0	0
TOTAL TRIALS	312	509	453	599
TOTAL COUNTRIES	38	49	55	62

Requests for seed increase

Forty governments asked CIMMYT for supplemental seed in 1977, with intention to increase the seed for demonstrations on farmers' fields. Such a step often precedes release of a new variety. CIMMYT has never before experienced such widespread response in one year of maize testing. Seventeen governments requested supplemental seed in 1976, which was the largest number up to that time. It appears that two-thirds of all countries collaborating in the maize trials are considering the release of new varieties derived from the international trials. The seed requests came from many continents indicating wide adaptation of the new varieties. Seed requests in 1977 came from:

Central America and the Caribbean, 9 countries
South America, 7 countries
Mediterranean and Mideast, 5 countries
Africa, south of the Sahara, 8 countries
South and East Asia, 8 countries
Oceania and North America, 3 countries.

1978 international trials

The distribution list for maize trials in 1978 will cover 599 locations in 62 countries, another expansion. This includes 72 progeny trials, 321 experimental variety trials, and 206 elite variety trials.

The maize populations in Mexico have now been divided into two groups, and only one group of populations will be planted to produce progeny each year. This schedule permits one full year to retrieve the trial data both north and south of the equator.

In 1978, seed are being prepared for distribution in maize trials that will cover 599 locations in 69 countries, another expansion.

Special Research Projects in Mexico

When CIMMYT investigates new techniques and ideas for improving specific characteristics of the maize plant, it sometimes creates a Special Project, and the researcher confines his study to one or a few populations. Any general conclusions from a Special Project can later be applied to all parts of the program.

Four special studies are now under way, dealing with yield efficiency in tropical maize, shorter maturity, wider adaptation, and drought tolerance.

Yield efficiency in tropical germ plasm

Tropical maize produces too much foliage and not enough grain when compared to maize in the temperate latitudes. A Special Project is looking for more efficient tropical plants with higher harvest index. This means a higher percentage of grain weight in the total dry matter of the plant. Several approaches are being tried.

First, researchers have taken seed of the population Tuxpeño-1, divided it into three parts, and are selecting separately for three specific traits: shorter plant height, reduced tassel size, and reduced foliage. By summer of 1978 five cycles of selection will be completed and an evaluation is planned for possible changes in grain yield efficiency under each trait.

Two other populations — unrelated to Tuxpeño-1 — are being subjected to additional studies. In Eto Blanco, researchers are selecting simultaneously for reduced tassel size and reduced foliage; in Antigua into Republica Dominicana, they are selecting separately for reduced tassel size and reduced foliage. This part of the study will continue for additional cycles of selection before evaluation.

In a third approach, researchers are making crosses between temperate maize varieties with good harvest index, and tropical populations with good survival ability in the tropics. The objective is to combine the two characteristics in a tropical maize. The strategy will require systematic recombination over many generations, and simultaneous selection both for tropical survival ability and temperate plant architecture. CIMMYT has a large number of crosses in various stages of mixing and mild selection. More years of mixing will be required before evaluation.

Shorter maturity in tropical maize

Many tropical maize growing countries seek good yielding varieties which ripen earlier to fit a brief rainy season or a tight cropping sequence.

A Special Project is employing several approaches to develop earlier maturity with good yield. In one, short maturity tropical varieties are assembled from lowland tropical areas all over the world and composited. The present pool contains 33 collections from Indonesia, one from Colombia (Guajira 314), two from Honduras (Mata Hambre), one from El Salvador, and six from Pakistan (Bannu early group). These are being crossed in various combinations, and tested at two locations before deciding which of the combinations will be included in the early maturity population. Initially no attention is paid to color or texture of grain.

Another population being worked under this approach is an Indonesian-Colombian-Honduran mixture, in which the three parent materials had maturities of 72-85 days in their home counties, and the 3-way mixture now matures with good plant type in less than 90 days at Poza Rica, Mexico (lowland humid tropics). This selection continues.

Another approach is the crossing of the best tropical "earlies" with the best temperate "earlies." The first tests by this approach in the summer season at Poza Rica gave maize lines which were harvested in 80 days after planting.

Another approach involves recurrent selection for early maturity in an outstanding tropical population.

Progress to date suggests it should be possible to develop earlier maturing tropical germ plasm giving better grain yield then early varieties now give.

Wider adaptation

In 1978 CIMMYT makes its 11th cycle of crosses in a maize population drawn from many climates (for example, northern Canada, equatorial Brazil, and the southern tip of Argentina). Initially the cold climate materials would not set seed in the lowland tropics, and vice-versa, because of sensitivity to differing day lengths, temperatures, and diseases. Today the mixture sets seed in all maize growing climates. In the winter of

1976-77 selections from this mixture grown in Canada, Colombia, Hungary and South Africa were recombined in Mexico and were tested in 1977-78 in Germany, U.S.A. and at 4 sites in Mexico. This natural selection for wide adaptation continues.

CIMMYT believes the special project in wide adaptation serves several ends: first, one widely adapted population can be used as a parent for transmitting wide adaptation to other populations; second, maize with adaptability gives greater yield stability under climates with fluctuating temperatures; third, wide adaptation in a parent serves as a vehicle for transmitting a variety of genes, almost anywhere in the world.

Selections made in dozens of countries are multiplied in Mexico and re-distributed.

Drought tolerance

Periodic drought is a major cause of yield loss in tropical maize.

In 1976 researchers on a Special Project for drought tolerance indentified some families within the population Tuxpeño-1 which appeared better than others in drought response.

To verify this, a number of experimental varieties were created from families which yielded best under different moisture conditions, such as no stress (full irrigation), moderate stress (irrigation withheld from emergence until 10 days before flowering), and severe stress (no irrigation after emergence).

These entries were grown in a replicated trial at Tlaltizapan station in the 1976-77 winter season. The trial demonstrated that it may be possible to identify criteria of selection for varieties which perform better, in relation to other varieties, under stress conditions.

Selection for drought tolerance continues in one lowland population (Tuxpeño-1) and one site in Mexico (Tlaltizapan).

This research will determine whether several cycles of selection can accumulate or pyramid genes for drought tolerance, thus developing a maize variety that is better in this trait than the base material from which it was derived.

In drought resistance studies, water tension of plant is measured to determine stress.

Crosses Between Genera (Wide Crosses)

The maize crop possesses great variability and potential for improvement. However there are certain specific characteristics that would be desirable to maize, that are not found in the crop at present, and are found in related genera. CIMMYT's wide cross program hopes to break down the breeding barriers that exist between alien genera, and to make available these characteristics to maize. *Tripsacum* and *Sorghum* have been chosen for these crosses. *Tripsacum* is a wild relative of maize which has shown a wide range of resistance to diseases and insects which are a problem to maize, and *Sorghum* is able to yield better in drought and waterlogged conditions than is maize.

Over 10,000 crosses were made between maize and tripsacum in 1977, and ten new hybrids were identified. Six of these were classical hybrids that retain the expected complement of chromosomes from each parent. These six resemble tripsacum in appearance, and like the tripsacum parent they take two years or more to flower. Thus the hybrids produced in 1977 are still in vegetative growth. Of the seven hybrids obtained in 1976 only one has flowered so far. It has produced no viable pollen for backcrossing with maize or tripsacum. This hybrid does exhibit at least partial female fertility and efforts will continue to obtain backcross progeny (BC1), the first step to incorporate desirable characteristics of the alien germ plasm into maize.

Four hybrids identified in 1977 were not of the classical type. Erratic chromosome elimination occurred so that different cells of the same plant contained various numbers of tripsacum chromosomes, less than the expected number. These plants were more maize-like in appearance and, like maize, flowered within three months of germination. These were pollinated with maize and already BC1 seed has been obtained. In such hybrids (if they are fertile) the incorporation of desirable characteristics can be made more rapidly and these can be tested for useful characteristics far earlier than the classical type.

These hybrids have one disadvantage over the classical type. They are annual with one flowering tiller only, and if they are sterile the genotype is lost within a few months. The classical hybrid is perennial, and produces many tillers for experimentation.

Over 17,000 crosses were made between maize and sorghum in 1977 and four new hybrids were identified. All these are more maize-like in appearance, and erratic chromosome elimination has occurred in all of them, giving aneuploid progeny as in some of the maize-tripsacum crosses. A total of eleven maize-sorghum hybrids have been produced at CIMMYT during 1976 and 1977. None has given viable pollen, but two have been partially female fertile, and these have given 33 backcross progeny with maize pollen, from which subsequent crosses have given an array of different plant types. These are being crossed further and assessed for desirable characteristics.

CIMMYT needs a much greater number of hybrids with wider genetic diversity to use in plant improvement. For this purpose the scientists in Mexico are seeking collaboration with other institutions who specialize in related areas of research, so that progress may be speeded.

Ten new hybrids were identified in 1977 from among the more than 10,000 crosses made between maize and tripsacum.

Maize Training

CIMMYT offers several kinds of training and experience to maize scientists from Asia, Africa, and Latin America:

—In-service training: generally 5 to 6 months residence in Mexico.

—Master's degree program in cooperation with universities in Mexico or USA.

—Predoctoral fellows: 12 to 18 months in Mexico to do their thesis research under CIMMYT supervision.

—Postdoctoral fellows: 2-years service as an associate on CIMMYT staff.

—Visiting scientists or short-term residents.

In-service training

The maize in-service training program is only 7 years old but already 345 participants from 47 countries have passed through the course, including 60 in 1977. About one fourth specialize in crop improvement, and the rest in production agronomy.

In-service training is designed to develop skills in field research, production management, and laboratory

Training courses in Mexico stress learning-by-doing; and the discipline of working long hours under heat, humidity, and torrential rains.

techniques, to give experience on an interdisciplinary team, and to teach the relationship between improved technology and development. The typical participant has had 5 to 10 years experience in a government agency. The courses in Mexico stress learning by doing, and the discipline of working long hours under heat, humidity, and torrential rains.

One feature of production training is the layout of agronomic trials on private farmers' lands, and organizing field days for farmers. This work is performed by trainees under supervision of the CIMMYT training officers and the Mexican extension service. The on-farm research helps identify the limiting factors in yield, and permits farmers to select their own technology.

Training in national programs

Starting in 1974 CIMMYT offered in-service training for officers from national programs who were preparing to give short courses for production agronomists in their own country. Nine trainers have now been trained (Ecuador-3, El Salvador-3, Philippines-1, Pakistan-2).

CIMMYT training staff members in Mexico are occasionally lent to national programs outside Mexico where they assist with local courses. During 1977 the maize trainers in Mexico participated in short courses for production agronomists in El Salvador, Nicaragua, Ecuador, and Nepal.

Academic training

During 1977 the maize program cooperated in the training of three master's degree candidates in Mexico, two predoctoral fellows, and 11 postdoctoral fellows at CIMMYT in Mexico.

At the beginning of 1978 the predoctoral and postdoctoral fellows came from 6 countries: El Salvador-1, Germany Fed. Rep.-1, Iceland-1, New Zealand-1, UK-2, USA-1.

Visiting scientists

During 1977 the maize program received 25 visiting scientists and 64 short-term visitors. Visiting scientists are senior crop researchers or experiment station managers who spend a week to a year at CIMMYT to become familiar with world germ plasm and CIMMYT research methods and philosophy, which may be useful in their own national programs. Short-term visitors are often agricultural policy makers and administrators who spend 2 to 7 days at CIMMYT.

Maize in-service trainees 1971-77

Region & Country	1971-1977	1977
Latin America	165	25
Argentina	11	0
Belize	5	0
Bolivia	7	0
Brazil	3	0
Colombia	6	1
Costa Rica	4	1
Chile	2	0
Dominica	1	1
Dominican Republic	9	3
Ecuador	12	3
El Salvador	20	0
Grenada	1	0
Guatemala	14	0
Guyana	1	0
Haiti	7	2
Honduras	23	5
Mexico	14	4
Nicaragua	8	0
Panama	4	1
Peru	8	3
Venezuela	5	1
South and East Asia	65	14
India	2	0
Japan	4	1
Korea	1	0
Nepal	13	4
Pakistan	19	3
Philippines	16	2
Thailand	10	4
North Africa and Mideast	22	5
Algeria	1	0
Egypt	12	2
Tunisia	3	2
Turkey	3	0
Yemen A R	3	1
Tropical Africa	91	15
Cameroon	1	0
Ethiopia	3	1
Ghana	6	0
Ivory Coast	4	0
Kenya	3	0
Malawi	1	0
Nigeria	12	0
Senegal	1	1
Tanzania	37	12
Uganda	1	0
Zaire	20	0
Zambia	2	1
Other	2	1
Total	345	60

Led by Alejandro Violic (right), the maize in-service training program has had 345 participants from 47 countries since it began seven years ago, including 60 in 1977.

Maize Cooperative Projects Outside Mexico

During 1977 and 1978 CIMMYT has posted 15 maize scientists to work with cooperative projects outside Mexico. Six scientists were assigned to regional programs and nine to national programs.

Regional programs

A regional maize program represents a linkage between CIMMYT and its collaborators. In several parts of the world, groups of maize-growing countries have entered into cooperative arrangements to improve their maize production. Regional groupings generally comprise neighboring countries in which maize is a major crop, grown under similar climatic conditions, encountering similar diseases and insects, and therefore benefiting from continuous exchange of technology and germ plasm within the region.

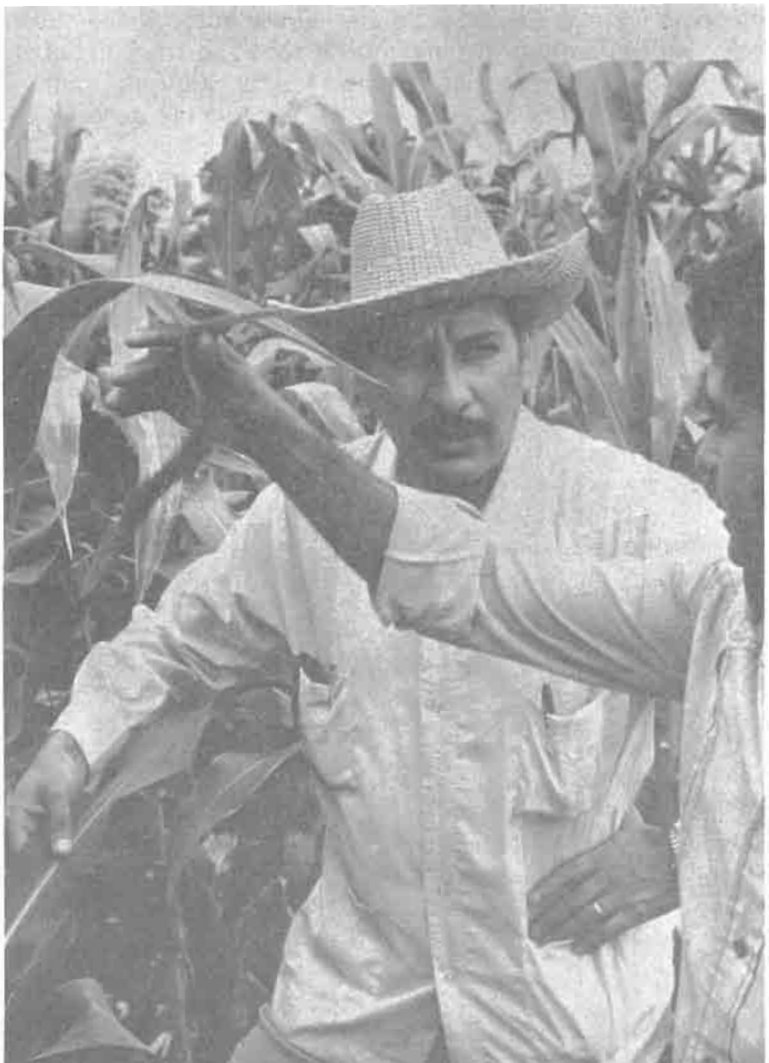
Typically a regional program will sponsor: (1) periodic workshops among maize scientists of the region to review their past year's research and make plans for the following year; (2) circulation of nurseries to be grown by all cooperators in the region, followed by exchange of trial data; (3) visits of local scientists to observe research in neighboring countries; (4) training for maize workers, and (5) consultation by CIMMYT scientists posted in the region or travelling from Mexico.

In 1977 CIMMYT maize scientists shared the activities in the following regions:

Region & Headquarters	Number of cooperating countries	1977 population (million)	Approximate maize crop (tons)	CIMMYT assigned staff	Donor	Years of CIMMYT Arrangement
Central America and Caribbean (Mexico)	14	33	2,200,000	2	IDB Switzerland	1974-76 1977-
South and Southeast Asia (India)	15	1183	17,300,000	1	UNDP	1976
Andean (Colombia & Ecuador)	5	69	2,500,000	3	Canada	1976

Prior to 1974 CIMMYT attempted to monitor the international maize trials of these regions by travel of CIMMYT staff from Mexico. But the volume of consultation made it impossible to provide adequate service.

CIMMYT staff for regional programs are attached to other international centers or to strong national programs.



Regional maize programs link CIMMYT with collaborators. Willy Villena (left) works with the Central American and Caribbean Region.

National programs

A national maize program typically serves the following purposes: (1) to improve maize research in local experiment stations; (2) to test experimental varieties on local farmers' fields, thus helping to transfer technology from experiment station to the farmer; (3) to multiply seed for improved varieties; and (4) to provide additional training for local scientists. CIMMYT's assigned staff share in these activities, including the testing of germ plasm received from national programs and from Mexico, and the feedback of information on the suitability of these materials to the whole network of maize scientists.

The following national programs participated in cooperative arrangements with CIMMYT in 1977:

Country	Population 1978 (millions)	Start of CIMMYT arrangement	CIMMYT assigned staff 1977	Approximate maize crop (tons)	Donor *
Pakistan	76.7	1968	1	700,000	USAID/Ford
Egypt	39.9	1968	1	2,500,000	Ford
Zaire	26.9	1972	2	500,000	Zaire
Nepal	13.5	1972	1	800,000	USAID
Tanzania	16.4	1973	2	800,000	USAID
Guatemala	6.6	1976	2	600,000	USAID

* CIMMYT requires 'extra core funds' for support of each national arrangement.

Ernie Sprague (left) heads a staff that travelled to 45 countries in 1977 to observe trials, visit former trainees, and help with production problems in regional and national programs.

Regional program: Central America and Caribbean

The fourteen countries comprising this regional maize program have a population of 33 millions, increasing at 3 percent a year. This is a food deficit area: local grain production is 3.7 million tons a year, supplemented by imports averaging 1.5 million tons.

Most people in the region are maize eaters. Maize represents 60% of local grain production, and probably contributes 60% of calories and protein in the diet.

Starting in 1974 CIMMYT assigned two maize scientists to work in this region. They spend more than a third of their time consulting with maize scientists in participating countries, and meeting with agricultural policy makers. In their remaining time, they provide research and training services from Mexico specifically adapted to this region.

The breeder on this team helps plan the annual research programs of the governments, recommends what experimental nurseries should be shipped from Mexico, advises local policy makers on the requirements for research budget, staff, and inputs; and helps organize workshops among maize scientists of the region.

The CIMMYT regional agronomist promotes on-farm trials for experimental maize varieties and conducts training courses for extension agronomists.

Training in Mexico of young scientists from this region has continued: 16 participants in 1975, 21 in 1976, and 12 in 1977. Upon returning home, these young men join the collaborators who conduct research on new varieties, and organize trials on farmers' fields.

The year 1977 was the most active year so far for this regional program. The CIMMYT breeder and agronomist spent seven months in consultations to national programs. Participating countries planted 114 nursery trials in their research stations, and more than 500 on-farm trials. Four workshops were held in the region during 1977. Short courses were held for 120 production workers in three countries (Dominican Republic, Panama, and Nicaragua). An economist from CIMMYT-Mexico began working with local production workers in Honduras on farmer surveys to determine what constraints are affecting maize production. These surveys will extend to other countries in 1978.

When the regional activities began in 1974, average maize yields in countries of the region ranged from 0.7 to 1.7 tons per hectare, mostly below 1 ton. Success of the program will be judged by the increase in yields over a period of years.

Regional program: South and Southeast Asia

Fifteen countries of South and Southeast Asia have a population of about 1200 million people in 1978, increasing at more than 2.5 percent a year. They have a food deficit: local grain production is about 225 million tons a year, supplemented by imports of about 16 million tons. Maize is the third ranking cereal in this region, after rice and wheat, but under population pressure maize has been expanding faster than the other crops. In 1977 maize produced about 17 million tons of grain, with average yields in different countries of less than one ton/hectare, ranging from 0.8 to 2.2 tons, thus suggesting the feasibility of further improvement.

Four countries in the region each produce more than 2.5 million tons of maize a year (India, Indonesia, Philippines, Thailand).

Regional agronomist Roberto Soza (left) planting a trial in a farmer's field in Panama.

In 1976 CIMMYT assigned a maize breeder-agronomist to this region to help in stimulating the exchange of technology between governments, with efforts concentrated on: (1) regional maize trials, (2) promoting the trials of new varieties in farmers' fields, (3) organizing workshops among maize workers of the region, (4) arranging training for maize workers either within their own country or elsewhere, and (5) consulting with participating governments on problems constraining the maize crop.

A new regional nursery trial for maize resistant to downy mildew, a fungus disease, is being circulated by Thailand and the Philippines, with assistance from CIMMYT's regional scientist.

The national maize coordinator of India is assisting in circulating other nurseries, for which seed is multiplied at ICRISAT (International Center for Research in the Semi-Arid Tropics).

Regional program: Andean countries

Five Andean countries — Bolivia, Colombia, Ecuador, Peru, and Venezuela — each had an overall food deficit during the first half of the 1970's. The region produces approximately 6 million tons of grain annually and imports 3 million tons. Maize and rice are the largest local grain crops, and wheat is the largest import.

In 1978 the population of this region will pass 69 million, increasing at 2.9 percent a year.

CIMMYT maintains three maize scientists in the region, headquartered in Colombia and Ecuador, to assist in the exchange of technology between countries. Program activities include: (1) workshops for maize scientists of the region; (2) maize nurseries exchanged within the region, containing the best varieties of the participating countries; (3) a breeding program for "floury maize" (large soft kernels, preferred in the highlands), assisted by a CIMMYT breeder posted at Quito, Ecuador; (4) trials of experimental maize on farmers' fields, encouraged in each country; (5) more training for local maize scientists, either in local courses or in Mexico (38 maize scientists from this region received one season of maize training at CIMMYT-Mexico during 1970-77); and (6) consulting by CIMMYT scientists on scientific problems which restrict maize production.

The breeding program for highland maize has organized five gene pools (3 floury-type, and 2 flint-type) which are now undergoing improvement at Quito, Ecuador.

Average maize yields in the Andean countries have been 1.0 to 1.7 tons per hectare. The success of the Andean program will be measured over years by the increase in these relatively low yields.

Suketoshi Taba is one of three CIMMYT scientists working in the Andean region, assisting in the exchange of technology between countries.

Pakistan National Maize Program

Maize is the No. 3 food crop of Pakistan, after wheat and rice, and helps to feed a Pakistan population of 76.7 million (1978) increasing 2.9 percent a year.

Since 1968 CIMMYT has continously posted one or two maize scientists to collaborate with Pakistani maize research and training. In 1977 one CIMMYT agronomist was attached to the Pakistan Agricultural Research Council at Islamabad. Over 90 percent of Pakistani maize is produced in two provinces, the Punjab and Northwest Frontier.

In 1977 the Agricultural Research Council program with the provinces included the following: (1) testing national maize nurseries and international trials from CIMMYT and FAO; (2) organizing workshops for provincial maize workers; (3) conducting two training courses within Pakistan, and sending three maize workers for training in Mexico; (4) working with the World Bank agricultural mission to Azad Kashmir Province; and (5) working with the Australian Government in the improvement of the Pirsabak maize-sorghum research station.

The average yield of maize in Pakistan has risen 20 percent in the past decade, but population has increased 30 percent in the same period.

Fifteen countries in South and Southeast Asia are included in the regional maize program assisted by Takumi Izuno (left).

Egypt National Maize Program

Egypt now imports a million tons of maize a year and 3 to 4 million tons of wheat a year, and the deficit is rising. Population has passed 39 million, and grows at 2.3 percent a year.

Maize, wheat, and rice are the three largest grain crops of Egypt, in the order of area sown.

CIMMYT has maintained one maize scientist to collaborate with the Egyptian program since 1968. The present breeder-agronomist in Cairo shared with Egyptian scientists during 1977 the following activities: (1) growing of international maize trials from CIMMYT and FAO; (2) organizing trials of experimental varieties of maize on farmers' fields, in order to speed the adoption of new technology; (3) agronomy trials to develop better production practices; (4) arranging training courses for maize workers outside Egypt (sixteen Egyptian scientists received training in Mexico during 1971-76, including two each year in 1976 and 1977). Egyptian economists continued their surveys of the constraints experienced by maize farmers.

Despite these well managed efforts, the increase in maize yields over the last decade has not kept pace with population growth of 25% in the same period.

Zaire National Maize Program

Zaire's 27 million people are primarily maize and cassava eaters but also consume some wheat and rice. As a food-deficit country, Zaire has been importing most of its wheat and rice, and 160,000 tons of maize a year.

Since 1972 Zaire has utilized its own funds to finance a scientific team from CIMMYT to help develop a national maize research and production program. The annual maize crop of 400,000 to 600,000 tons represents two thirds of the national grain production, and the low average maize yield (about 700 kg/ha) offers substantial opportunity for improvement.

By 1978 five elite maize varieties, open pollinated, had been selected and the seed multiplied for farmer use.

Twenty young Zairian university graduates have been sent to CIMMYT for one cropping season of training and seven Zairians were sent for higher degrees at agricultural universities in the USA. By the end of 1978 three more candidates will be sent for university degrees and four more will participate in CIMMYT training.

From all this training, a nucleus staff for the Zaire National Maize Program has been organized.

Zaire participates in international maize nursery trials shipped from Mexico, Kenya and Nigeria. The best of the experimental varieties have been widely tested on farmers' fields. Three elite varieties have now been multiplied for general use in Zaire.

Since 1972, Zaire has funded a scientific team from CIMMYT to help develop a national maize research and production program. Tom Hart (left) is a key member of this team.

Nepal National Maize Programs

Nepal is one Asian national program which has been feeding itself. But food production per capita has gradually declined during the 1970's because grain production plateaued (about 3.8 million tons a year) whereas population has been rising 2.3 percent a year, and exceeds 13 million in 1978.

CIMMYT first posted a maize scientist to Nepal in 1972.

In 1976 Nepal invited several international organizations to assign staff to collaborate with local agricultural services, including IRRI for rice (local crop 2,500,000 tons), CIMMYT for maize and wheat (maize 800,000 tons, wheat 300,000 tons) and the International Agricultural Development Service (to assist cropping systems and agricultural planning). In mid-1977 IADS took over the leadership of all the foreign assistance for crop improvement.

Twelve Nepali maize scientists have received training in Mexico during 1971-77, and they now constitute the nucleus of Nepali collaborators who grow international maize nurseries, breed local varieties, and place trials on farmers' fields.

Tanzania National Maize Program

Like most countries in tropical Africa, Tanzania eats more maize than other cereals. It is a food deficit country, partly because a semi-arid climate has caused local grain production to fluctuate from 1.3 to 2.7 million tons a year during the 1970's. With a population of 16.4 million (1978) growing 2.7 percent a year, the government found it necessary to import 250,000 tons of maize per year in 1974 and 1975.

CIMMYT's work in Tanzania is part of a joint IITA-CIMMYT effort, in which IITA is responsible for overall crop improvement.

CIMMYT has stationed two maize scientists in Tanzania since 1973 to assist the national maize program. Thirty-three young Tanzanian scientists have been sent to Mexico for one season of maize training during 1973-76, 12 of them in 1977. Four Tanzanians have been sent to U.S. universities for agricultural degrees.

The Tanzanian maize breeding program, centered at Ilonga Station 200 kilometers west of Dar-Es-Salaam has identified experimental maize varieties which out-perform the varieties previously in commercial use.

Two donors, World Bank and USAID, have pooled US $30 million to support a 7-year maize production program concentrating on ujamaa-type villages (cooperative production units.)

A training program for maize extension workers has been organized at Mbeya research station, using the CIMMYT on-farm trial system as the means of communicating with farmers. Thus new maize technology can be given immediate use in the national production scheme.

Guatemala National Maize Program

CIMMYT assigned two maize scientists to collaborate with the Guatemalan national maize program starting in 1976. This program seeks to expand and stabilize the national maize crop which has fluctuated between 600,000 and 800,000 tons a year during the 1970's.

Guatemala participates in the international maize testing program. Trials indicate that some experimental varieties are well adapted to the Guatemalan lowlands where the larger part of the Guatemalan crop is grown; but improved maize materials adapted to the Guatemalan highlands (above 1500 meters) are yet to be developed.

An effort toward nutritional improvement through the use of opaque-2 and modified germ/endosperm ratio is being conducted in association with the Institute of Nutrition for Central America and Panama (INCAP).

The Guatemala program for the tropical lowlands includes a novel approach, deriving both open-pollinated varieties and hybrids from the same source materials. The breeders have tested the combining ability of families from CIMMYT's experimental maize varieties, and based upon the results, are creating new synthetic varieties and F_1 family hybrids. The new varieties and hybrids will be available for extensive on-farm testing in Guatemala at more than 50 locations in 1978 to confirm their yield potential and environmental stability. Materials which prove adapted in Guatemala will probably be usable in neighboring countries of Central America.

For the highlands, where a very ancient corn-oriented culture exists, the major effort is to identify local varieties with wide adaptation as a means of compensating for the strong genetic-environment interaction that prevails in the many scattered valleys of the region.

wheat improvement

Dr. Borlaug (left) and CIMMYT Trustee O. M. Solandt discuss priorities of the Wheat Program.

High yield potential across different climates, semi-dwarf stature, broad disease resistance and daylight insensitivity are primary characteristics sought by CIMMTY's wheat scientists.

Introduction to the Wheat Program

World wheat production for the year ending mid-1977 was 413 million metric tons, an all-time record (U.S. Department of Agriculture, World Grain Situation, November 11, 1977).

In developing countries the wheat harvest of 1976 reached 95 million metric tons, also a record *(FAO Production Yearbook 1976)*.

Despite these achievements, developing countries continue to import about 35 million tons of wheat flour each year *(FAO Trade Yearbook 1976)*.

Imports indicate a deficit of about one quarter in the wheat requirements of developing countries. This deficit serves as a reminder to the wheat scientist that greater changes are needed in the farmers' wheat fields, because that is where the food gap of developing countries must be solved.

Stable resistance comes first

Stable resistance to the three rusts remains the first objective of the wheat scientist. Northwest Mexico experienced an outbreak of leaf rust in 1977, most severe for that area in one third of a century. The outbreak was encouraged by events that allowed much land to remain uncultivated in the summer of 1976, providing a bridge of volunteer wheat plants to serve as hosts for rust spores which are usually destroyed by summer cultivation.

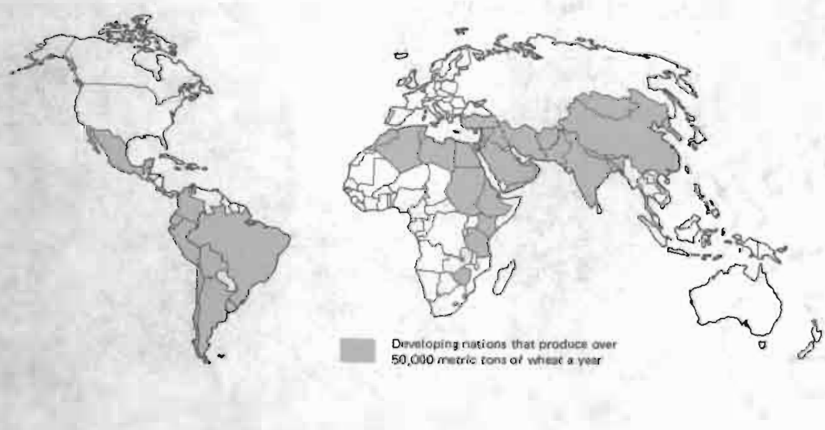
Rust has been a threat to the wheat crop for thousands of years — like the common cold in human beings — long researched, but still with us. Constant mutation of the rust pathogens provide new threats to wheat varieties, including the varieties previously considered resistant to the three rusts. Stable rust resistance in the long term is unlikely to be achieved in pure-line varieties and the breeder must continue to give first attention to the development of new varieties which combine different sources of resistance to the three rusts, and thus provide replacements for today's commercial varieties when they are found susceptible.

The multiline offers one option for slowing down a rust epidemic — probably the best way to introduce a measure of stability for resistance. CIMMYT's work on the multiline is described elsewhere in this report.

Raising the yield ceiling

Semi-dwarf wheats distributed from Mexico in the 1960's raised the yield potential for wheat from 3.5 t/ha to the 7.0-8.0 ton range. Since that time the yield potential has gradually increased to the range 8.0-9.0 tons. But in general, a "yield plateau" has existed for a decade.

This "yield ceiling" is a problem of secondary importance compared to the three rusts, but our scientists are simultaneously searching for new ways to penetrate the yield barrier. Crossing winter and spring wheats offers one possibility described later in these pages. Other staff are studying upright leaves on wheat, or branched heads, or longer heads with more spikelets and more grains in each spikelet. This work is also described later. No conclusions are yet possible, but work on the "yield ceiling" will continue.



Delivery systems

Our wheat staff continues to use many delivery systems for moving new technology to developing countries.

In 1977 our international nurseries for experimental bread wheat, durum wheat, barley and triticale were grown in 96 countries. This puts new germ plasm on display, and generates testing data which guide the worldwide wheat network in further breeding.

Forty-one young scientists from developing countries were brought to Mexico in 1977 to work one cropping season with CIMMYT scientists. These men and women are now back in their home countries, where they become part of the network of wheat scientists.

CIMMYT's Mexico wheat staff travelled to 66 countries in 1977 to see the international trials, to talk with farmers, to consult with government policy makers. CIMMYT believes that first-hand knowledge of developing countries is necessary to guide each cycle of research.

In 1977 CIMMYT posted nine wheat scientists to work in regional and national programs outside Mexico. The regions are the Mediterranean and Mideast, headquartered in Egypt and Turkey; highland East Africa, based in Kenya; and the Andean countries, based in Ecuador. The four national programs served by posted staff were Algeria, Tunisia, Pakistan, and Nepal.

These activities are discussed in the following pages.

N. E. Borlaug

Bread Wheat

In the 1970's the bread wheat program in Mexico has expanded to cover additional problems, including *Septoria* resistance, *Helminthosporium* resistance, and tolerance to acid soils. But the central objective continues to be the development of germ plasm with high yield potential and wide adaptation.

About 1500 advanced lines were tested in Northwest Mexico during 1977. Of these, roughly one-in-five plants was selected for subsequent testing in the 11th International Bread Wheat Screening Nursery at 188 locations around the world.

Research procedures

The breeders believe that wide adaptation can best be obtained by a combination of the following four characteristics:

1. High yield potential across different climates.
2. Semi dwarf character.
3. Broad disease resistance.
4. Day length insensitivity.

Several approaches are used:

First, wheat research in Mexico is conducted two cycles a year, one a winter crop at sea level and 27° N latitude; the other a summer crop at 2600 m elevation and 19° N latitude. The winter cycle is sown in an irrigated desert where leaf and stem rust are endemic; the summer cycle is sown under heavy rainfall and cool temperatures where severe epidemics of stripe rust occur every year. The movement of successive generations between these constrasting climates enables the breeder to select daylength insensitive, widely adapted lines with high levels of rust resistance.

To ensure heavier pressure from diseases, CIMMYT supplements the natural presence of pathogens with artificial inoculation.

Pollinations being made in plots in front of CIMMYT's headquarters building in Mexico.

This program cuts in half the time needed to develop a new variety, and selection in alternate segregating generations under contrasting environments leads to adapted types which may be grown under widely differing conditions.

Finally, bread wheats which prove superior in the Mexico trials are subjected to worldwide testing in over 90 countries, across many environments. This testing process serves both to distribute new germ plasm to the national programs and feeds information to the world network of scientists about disease resistance and wide adaptation, on which the next cycle of improvement will be based.

After years of this research strategy, progress continues but problems remain:

1) The pathogen which causes leaf rust continues to mutate unpredictably and varieties resistant to leaf rust continue to be short-lived in some areas. For stripe rust, resistance has improved markedly in the 1970's.

2) *Septoria leaf blotch*, a fungus disease which causes major epidemics in North Africa, the Mideast and South America, awaits effective control. Starting in 1975, wheat lines with good resistance to *Septoria* have been increasing in the CIMMYT international nurseries.

3) Some 40-50 percent of the wheat crop in developing countries is now planted with high yielding varieties. But traditional varieties with tall stems are still widely grown, and the development of improved agronomic practices lags in most countries.

Variety releases 1977

The Mexican Government released three new bread wheats from the CIMMYT-INIA program in 1977. Two were given the names Jauhara 77 and Hermosillo 77, both double dwarfs with red grain, suitable for breadmaking. The third was Pima 77, a single dwarf with white grain and soft biscuit-making quality. All three had good resistance to the races of the three rusts existing in Sonora, Mexico in 1977.

The 1977 releases illustrate the broad germ plasm sources now used. For example, the parents entering into Jauhara 77 are Mexican and Argentine wheats; for Hermosillo 77, Mexican, Argentine, and Ecuadorean; for Pima 77, Mexican and Colombian. All crosses were made in Mexico.

One of the releases, Pima 77, resulted from a chain of international collaboration. The original cross was made by CIMMYT-INIA in 1964. Subsequently an F_2 bulk of seed was sent to Chile. There the seed was grown and reselected by breeders until the F_5 generation. Seed then passed to Ecuador, where it was tested in a trial for resistance to stripe rust, and found outstanding. Ecuador shipped seed back to Mexico with other advanced lines carrying stripe rust resistance. Here final selection was made by CIMMYT at the Toluca station, 13 years after the original cross, and the Mexican Government released the variety.

Selected spring bread wheat varieties bred by CIMMYT-INIA or predecessors, released in Mexico, 1950-77

Year of Mexican release	Variety name	Year of cross	Yield potential kg/ha *	Plant ht cm	Grain Color	Disease rating in Mexico 1977 ** Stem rust	Leaf rust	Stripe rust	Septoria
1950	Yaqui 50	1945	3500	110	Red	TMS	20MS	10MS	MR
1960	Nainari 60	1958	4000	110	Red	10MS	5R	0	—
1962	Pitic 62	1956	5370	100	Red	100S	60S	80S	MR
1962	Penjamo 62	1956	5870	100	Red	50MS	0	80S	MR
1964	Sonora 64	1957	5580	85	Red	20MS	70S	80S	S
1964	Lerma Rojo 64	1958	6000	100	Red	30MR	80S	80S	S
1966	INIA 66	1962	7000	100	Red	5MR	100S	80S	S
1966	Siete Cerros 66	1957	7000	100	Amber	TMS	20S	100S	S
1970	Yecora 70	1966	7000	80	Amber	TR	100S	100S	S
1971	Cajeme 71	1966	7000	80	Red	TR	100S	100S	S
1971	Tanori 71	1968	7000	90	Red	20MR	80S	60S	S
1973	Jupateco 73	1969	7000	95	Red	TMR	80S	60S	S
1973	Torim 73	1967	7000	75	Amber	TMR	20MS	40S	S
1975	Cocoraque 75	1969	7000	90	Red	TR	TR	20MR	S
1975	Salamanca 75	1967	7000	90	Red	TMR	20MS	20MS	S
1975	Zaragoza 75	1964	8000	90	Red	0	30MS	80S	S
1976	Nacozari 76	1969	7500***	90	Amber	0	TMR	10MR	S
1976	Pavon 76	1970	7500***	100	Amber	0	TMR	10MR	MS
1976	Tezopaco 76	1969	7500***	105	Red	10MS	20MS	20MS	MR
1977	Pima 77	1964	7500***	85	Amber	5MR	TMR	30MS-MS	S
1977	Hermosillo 77	1972	7500***	100	Red	5MR	5MR	TR	S
1977	Jauhara 77	1969	7500***	87	Red	5MR	TR	TR	S

*Measured at experiment stations in Mexico, irrigated under high soil fertility, and essentially disease free.

**All varieties were resistant to all three rusts under Mexican conditions at time of release. R - resistant; S - susceptible; O - no rust; MR - moderately resistant; MS - moderately susceptible; 20MS - moderately susceptible type lesion on 20 percent of plant surface, balance of surface is lesion-free; TMS - moderately susceptible type lesion in trace amount, balance is lesion-free; TR - resistant type lesion present in trace amount, balance is lesion-free.

***Yield of varieties released in 1976 and 1977 has ranged 7500-9500 kg/ha in different seasons and trials, but the conservative minimum of 7500 kg/ha as given here for all six releases.

Yield testing of advanced lines

About 1500 advanced lines were yield-tested in northwest Mexico during 1977. Of these, 347 were selected for their high yield, rust resistance, and good agronomic characters and included in the Eleventh International Bread Wheat Screening Nursery. This nursery was sent to 188 locations around the world in June 1977. Results are expected in June 1978. The remainder of the 1500 lines are being tested by CIMMYT personnel for possible use in regional nursery trials. This avoids loss of potentially useful materials without overburdening national programs.

Six of the advanced lines tested in 1977 outyielded all checks by 700-1300 kg/ha. Checks included the previously highest yielding varieties in northwest Mexico, headed by Pavon 76.

Of the advanced lines tested in Mexico in 1977, six out-yielded all checks by 100-1300 kg/ha; with checks including the previously highest yielding varieties in Northwest Mexico.

Disease resistance

In the 1970's CIMMYT has made continuing efforts in cooperation with national programs, to achieve wide and stable resistance to stripe rust, leaf rust, stem rust, and *Septoria*.

Results of the Tenth International Bread Wheat Screening Nursery show that this effort is paying off. In this trial at 180 locations in 83 countries, 35 bread wheats were found to have a high level of resistance to leaf rust based on reports from 22 locations, and 39 lines had strong resistance to stripe rust based on reports from 12 locations. These lines are again being used in the crossing block to produce a wide range of combinations.

Until the 1970's most CIMMYT germ plasm had inadequate resistance to *Septoria tritici* especially for use in North Africa, Turkey, Ethiopia, and Argentina. Because some of the first semidwarf wheats introduced in these areas were susceptible to *Septoria*, the local programs for introducing high yielding varieties were set back. More recently some advanced lines tested in those countries have shown a good level of resistance to *Septoria*. Of the 386 entries in the 9th IBWSN 51 advanced lines showed good *Septoria* resistance, 268 showed intermediate level of resistance, and only 67 were highly susceptible.

The 8156 multiline

Occasionally in the past decade, disease epidemics of wheat have caused great economic losses in individual countries. Examples are the 1967 *Septoria* outbreak in Morocco, the 1972 *Septoria* epidemic in Brazil, the 1975 barley yellow dwarf epidemic in Chile, the 1976 stem rust epidemic in Brazil, and the 1977 leaf rust epidemic in Mexico. These disasters in limited areas were less significant than the pandemics of half a century ago, but the recent happenings serve as a warning to the breeders of the still present dangers when dealing with disease-causing micro-organisms with their genetic variability and tremendous speed of reproduction.

As a buffer against major rust outbreaks, the breeders have been developing lines based upon the 8156 cross which can be used as components for multiline varieties in different countries. A multiline is derived from crosses between 8156 progeny and other parents which resemble each other and their common parent in height, maturity, grain color, etc. But each line derives genes for disease resistance from different parents. The multiline is a mixture of these individual components. When a multiline is grown, and a new race of rust appears, only a small percentage of plants in the field are likely to be susceptible. The typical epidemic which spreads from plant to plant is thus checked.

CIMMYT scientists continue to work alongside national programs to develop wheats with wide and stable resistance to stripe rust, leaf rust, stem rust and septoria.

When new seed is multiplied for a multiline, the susceptible component is replaced and the new multiline mixture is again fully resistant until the next mutation of pathogen occurs.

In 1977 in continuation of this program, more than 400 additional crosses were made in Mexico between lines from the 8156 cross and sources of rust resistance from such countries as Argentina, Australia, Canada, Ecuador, India, Kenya, and countries of North Africa.

The Fifth International Multiline (8156) Nursery was tested at 31 locations, worldwide. Preliminary results indicate that among the 92 entries, 30 entries were highly resistant to leaf rust in Egypt, Turkey, India, and Bangladesh. Twelve entries were highly resistant to stripe rust in Turkey, Egypt, Algeria, and Ecuador.

Research has now confirmed that the breeders are using at least 15 different genes for resistance to leaf rust, and 10 different genes each for stem rust and stripe rust. The number of genes for *Septoria* resistance is not established. Distinguishing the genes is accomplished first by the differential response of wheat lines to the pathogens over a broad geographic range in the international trials, and then by laboratory work of collaborators who are assisting CIMMYT.

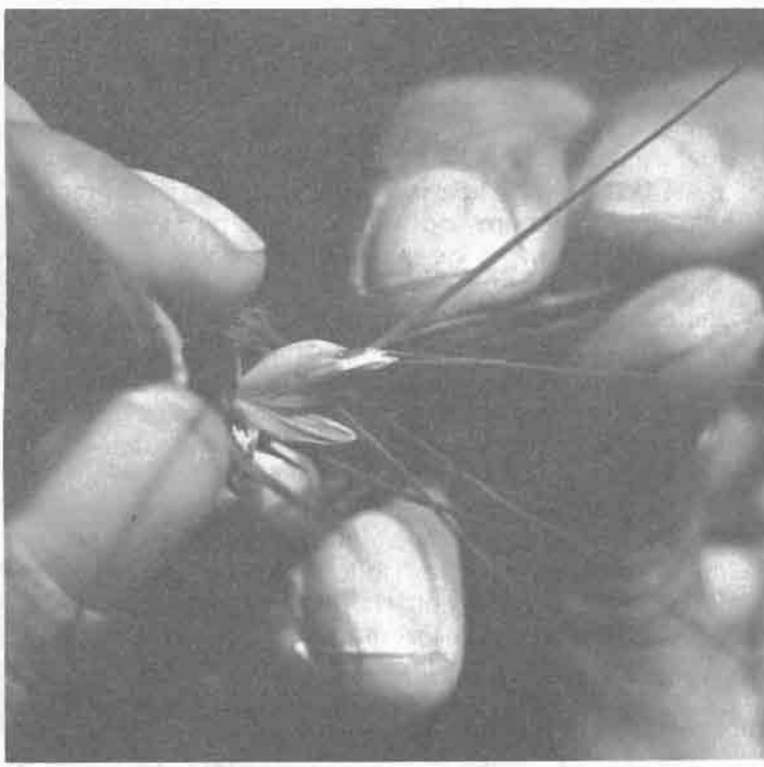
The collaborators include: Dr. Alan Roelfs of the USDA Rust Laboratory in Minnesota (USA), for stem rust; Dr. D. J. Samborski and Dr. Gordon Green of the Canadian Department of Agriculture, Winnipeg, for leaf and stem rust respectively; Dr. Irvine Watson of University of Sydney, Australia, for stem and leaf rust; Dr. M. Boskovic, Yugoslavia, for stripe rust; Dr. R. W. Stubbs, Holland, for stripe rust; Dr. A. Dinoor of Israel, leaf rust; Dr. Moshe Eyal and Dr. Isaac Wahl of Israel, *Septoria;* Dr. W. Wolfe, England, powdery mildew; and Dr. M. Djerbi of Tunisia, *Septoria.*

Since each country planning to use a multiline will require a different set of multiline components selected locally, researchers are concentrating their preliminary efforts for the multiline in Mexico, and India. The Indian Wheat Program has developed many lines suitable for components in a multiline mixture. Seventeen entries in the Fifth Multiline Nursery were found resistant to all rusts in northern India, and gave yields equal to Kalyansona, one of India's leading varieties derived from 8156.

Spring x winter wheat crossing

CIMMYT is attempting to raise the present plateau in yield potentials by crossing spring wheats with winter wheats. These are two separate gene pools, and the scientists believe that intercrossing can produce yield increases in both types. Crossing can also improve other characteristics; for example, in the spring wheats, the winter germ plasm can contribute greater drought tolerance, and greater resistance to such diseases as *Septoria*, powdery mildew, and stripe rust. For winter wheats, spring germ plasm can contribute better stem and leaf rust resistance, and better baking quality. A wider range of maturity can be selected for both springs and winters.

The crossing procedures are simple. At the Toluca station winter wheats are planted in November and are vernalized naturally (flowering is induced) by cold weather in December. Weather is mild enough in January to plant spring wheats, and both types flower in May-June. About 1500 crosses are made each year.



Crossing of spring wheats and winter wheats is one of the methods CIMMYT is using in an attempt to raise the present plateau in yield potentials.

About half the F_1 seed is sent to Oregon State University (USA) where the F_1 plants are crossed again to winter wheats to preserve the basic character of the winters. At CIMMYT the F_1 plants are crossed again to spring wheats to preserve the basic character of the spring type. A portion of the F_1 seed is also sent to India and Turkey.

In 1977 about 100 spring x winter advanced lines were distributed internationally for the first time as part of the 11th International Bread Wheat Screening Nursery. When the results of this trial are received in Mexico in 1978, they hopefully will provide the strongest evidence so far of the gains achieved during six years of spring x winter crossing.

Prior to the international trial, the advanced lines from spring x winter crosses were yield tested in northwest Mexico during the winter season 1976-77. The 13 highest yielding lines gave yields of 6.4 to 7.8 t/ha and nine of the 13 outyielded all check varieties, which included the leading commercial varieties of Mexico, headed by Pavon 76.

Wheat for the humid tropics

Historically wheat was poorly adapted to the humid tropics, but a number of wheat importing countries — notably those in Central America, West Africa, and Southeast Asia — are interested in growing wheat in their "winter" season (the period of mildest temperature and lowest humidity) as a means of reducing foreign exchange expenditures for imported wheats.

CIMMYT's initial tests in 1972 at Poza Rica, a hot humid location on Mexico's Gulf coast, revealed two major problems: that wheat in that location did not tiller adequately (form supplementary stems), and the fungus disease caused by *Helminthosporium sativum* destroyed most plants.

Additional trials served to identify a few Mexico wheats that do tiller adequately under these warm humid conditions.

From a screening of 5000 lines from the world wheat collection, 18 entries were found to be resistant or tolerant to *Helminthosporium.* Moreover, four F_1 crosses from the variety Horizon, which was previously found to be resistant, were grown at Poza Rica and all of these F_1's were resistant.

The disease resistant lines generally have many defects, aside from their disease resistance. So a general program of improvement is required.

Fortunately, preliminary reports from the 9th International Bread Wheat Screening Nursery indicated that 22 advanced lines in that trial did better than all others under tropical conditions in Nicaragua, Costa Rica, Zaire and Cameroon. These lines have good plant type and good yield.

So the next step for 1978 is to cross the 22 advanced lines to the *Helminthosporium*-resistant wheats. F_2 seed will then be sent to many tropical countries to identify the best combinations of heat tolerance and disease resistance.

A research station at the University of the Philippines, Los Bãnos, is providing special tropical wheat testing services to CIMMYT.

Wheat must yield about 2 t/ha in farmers' fields of the tropics in order to compete with alternate crops. It is still too early to forecast how successfully wheat can be grown under these conditions.

Shuttle breeding

For special wheat problems in some countries, the breeders practice a form of "shuttle breeding," in which alternate generations are grown in Mexico and in the collaborating country.

Breeders grow alternate generations in Mexico and collaborating countries in a form of "shuttle breeding" designed to combat special wheat problems.

For example, Brazil has special problems of acid soils and *Septoria* disease, for which some Brazilian varieties have tolerance, but they lack the high yielding qualities of the dwarf wheats. Beginning in 1974 F_1's of Brazilian wheat crosses have been sown at Cd. Obregon, Mexico, each November; Brazilian breeders come to Mexico to select the Mexican parents of F_1's and make the crosses in late winter; and the F_1 seed of these crosses is returned to Brazil for planting the following generation under Brazilian soil and disease conditions, and selections are made there for the next round. This Brazilian shuttle procedure enters its fifth year in 1978.

Argentine breeders have participated in a somewhat similar crossing arrangement with Mexico for a number of years, which gave rise to the highly successful variety Marcos Juarez INTA.

Another shuttle is developing between South Korea and CIMMYT. Here the breeders are attempting to combine the earliness and cold tolerance of Korean wheats with the better yielding qualities of Mexican wheats. Two hundred Korean lines were received in 1976, crossed to Mexican lines, and returned to Korea, where they were top crossed or double crossed with Korean materials. This exchange continues.

The People's Republic of China gave to CIMMYT 200 varieties of Chinese wheat in 1977, which are being grown in Mexico in winter 1977-78 to determine whether a Chinese-Mexican crossing arrangement would be useful, especially for *Gibberella* resistance and early maturity.

The possibility of other such cooperative shuttle programs is at the discussion stage with Ecuador for stripe rust resistance, and Israel for *Septoria* resistance.

International nursery trials

During the 1970's the number of participants in international bread wheat testing has more than doubled. This cooperation of many national programs is of the utmost importance.

Since 1964, CIMMYT has annually distributed a group of 50 varieties as the International Spring Wheat Yield Nursery. In 1977 the 14th nursery in this series of replicated yield trials was sent to 105 locations in 82 countries.

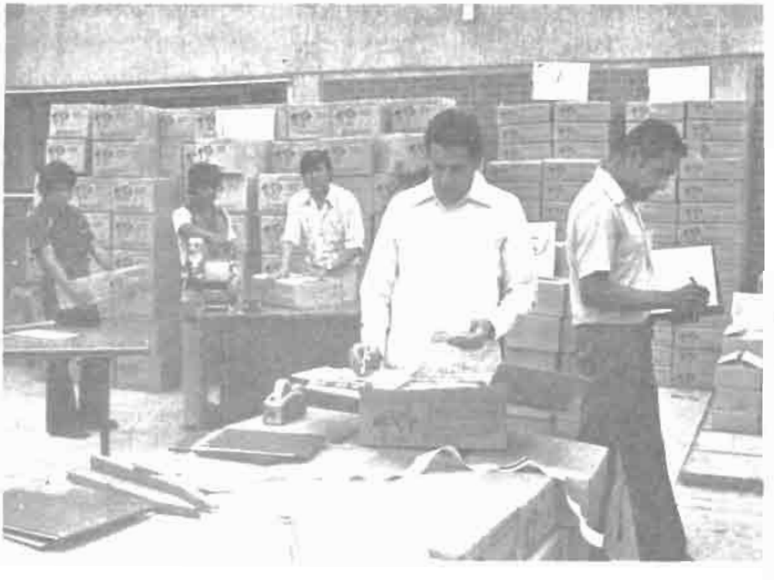
Since 1967 CIMMYT has annually distributed about 300 advanced lines from the CIMMYT-INIA breeding program as the International Bread Wheat Screening Nursery. The purpose of IBWSN is to distribute germ plasm to national programs and receive in return information on their yield and disease resistance. In 1977 the 11th IBWSN contained 347 entries, sent to 188 locations in 95 countries.

CIMMYT also distributes a crossing block. This is a group of varieties, each of which is one of the world's best sources for one or more characteristics. Seed of 300 entries was sent to 46 locations in 1977 so that breeders can evaluate them and use them in crosses if they wish.

Two regional screening nurseries are coordinated by CIMMYT scientists. The Regional Disease and Insect Screening Nursery serves countries from Morocco to India and in East Africa. The Latin American Disease and Insect Screening Nursery tests the disease resistance of experimental wheat lines in countries throughout the western Hemisphere. Regular interchange of materials between the two regional nurseries ensures worldwide testing of materials developed by national programs.

A trap nursery of commercial wheat varieties is grown throughout the Mediterranean and Midwest regions to monitor changes in the vulnerability to rust of varieties farmers are growing.

The results of all these nurseries are summarized and published to provide information to national programs.



CIMMYT's crossing block contains varieties that are the best available sources for one or more characteristics. Seed of 300 entries was sent to 46 locations in 1977 for evaluation and use in crosses.

Durum Wheat

Durum wheat is an important food in the Mediterranean region, the Mideast, parts of India, USSR, the Andean countries, Argentina, Chile, Canada and USA. In developing countries durum is eaten as couscous (Arabic for steamed cracked grain), chapatis (flat cakes in India), bread, and more rarely as macaroni and other pasta products.

Durum is grown on about 30 million hectares of land worldwide, which produce 20 million metric tons of grain, at the poor average yield of 667 kg/ha. Low yield is caused by poor agronomic plant type, susceptibility to disease, and poor crop management.

Durums were first dwarfed in Mexico in the early 1960s by crossing tall durums to dwarf bread wheats. In 1968 CIMMYT expanded its work on durums and progress in the 1970s has been rapid.

Potential yields of durums in the research station in Mexico have reached the same level as the best bread wheats. The linkage of the dwarfing gene with sterility has been weakened but not eliminated.

Breeders have identified many lines with disease resistance, which are being crossed with higher yielding dwarf durums to "pyramid the genes" for resistance. In 1977 another 5700 durum crosses were made, largely directed toward improving disease resistance.

Durum varieties derived from crosses in Mexico have now been released to farmers in Algeria, Argentina, Chile, Cyprus, Iraq, Lebanon, Saudi Arabia, Tunisia, Turkey, and USA.

Scientists working on durums in many countries have formed a network for testing new lines, which has speeded progress.

Higher yield

Eighteen durum yield trials were harvested at Ciudad Obregon in 1977. Among newer durum lines 39 outyielded the best checks by 10-22 percent. The checks included Mexicali 75, the highest yielding commercial durum variety in Mexico.

Internationally, durums performed better in 1977 than in any previous year. Average yield of all entries in the Seventh International Durum Yield Nursury, grown at 45 locations in 30 countries, was 4239 kg/ha. This was 15 percent better than the previous year and 21 percent better than the average of the previous five years.

Durum yield trials at Toluca and El Batan on the Mexican central plateau in the 1977 summer season continued to be attacked by root rot and head scab. These are problems which the CIMMYT breeders are trying to solve.

Disease resistance

Breeders in Mexico continue to introduce new sources of disease resistance selected from disease "hot spots" outside Mexico. The Seventh IDYN, mentioned above, identified 5 durum lines with exceptionally low infection for stripe rust, 3 lines for leaf rust, and 4 lines for stem rust. These lines are now used as donors in the crossing program. Greater resistance is required for still other diseases, including powdery mildew and *Septoria*.

Additional buffers are being sought against disease causing micro-organisms that are extremely hazardous because of their great genetic variability and tremendous speed of reproduction.

Improved agronomic types

Breeders are seeking better agronomic type with medium plant height, reduced foliage, and semi-lax heads. Entries from the world durum collection with these characteristics were crossed in 1977 to the highest yielding durums in Mexico, producing four outstanding lines with improved agronomic traits.

Drought tolerance has been sought by crossing four of India's most drought tolerant durums to Mexico's widely adapted varieties, Cocorit 71, Mexicali 75, and Anhinga.

For cold tolerance, 64 new crosses were harvested at Toluca in the winter season 1976-77, produced with parental materials from Turkey, Afghanistan, Spain and Portugal which had withstood temperatures as low as -7°C. These cold tolerant parents are generally deficient in other characteristics, and more cycles of crossing and selection will be needed to correct the faults.

Improving fertility

Introduction of the Norin-10 dwarfing gene in the 1960's caused some sterility in durums. Many durum plants have lower fertility than bread wheats, and selection for higher spikelet fertility must be repeated after every cross. During 1977 at least five new lines were harvested with outstanding fertility. These will now be crossed in many combinations.

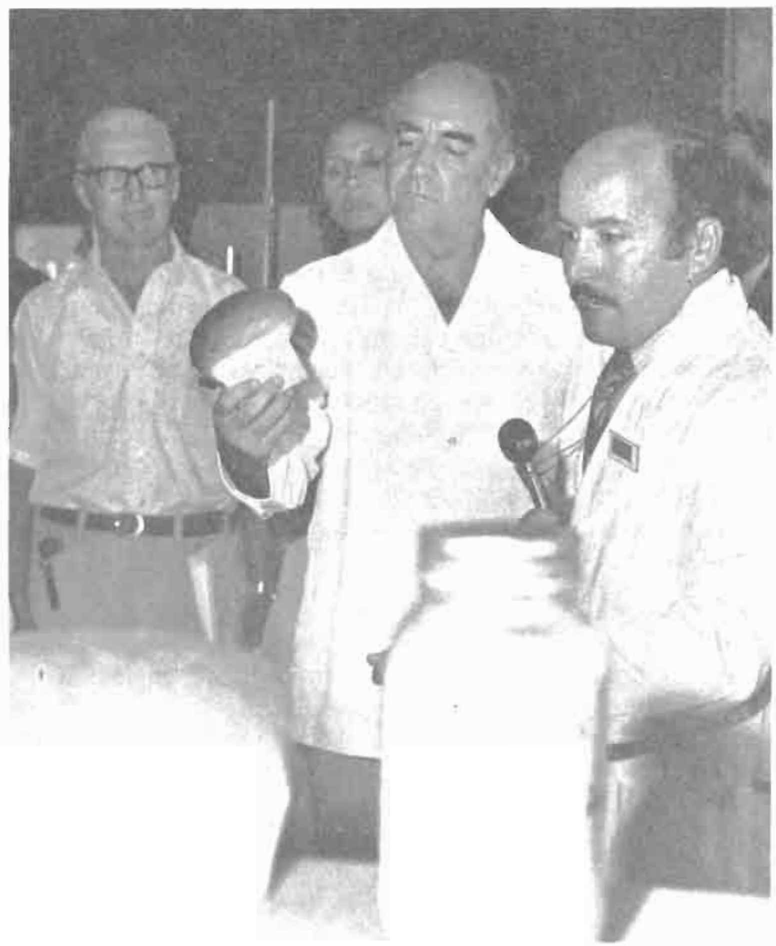
Durum varieties released in Mexico between 1950 and 1975.

Year of Mexican release	Variety Name	Year of cross	Yield potential[a] kg/ha	Plant ht.[a] cm	Disease reaction[b] Stem rust	Leaf rust	Stripe rust	Sept. tritici	Test weight kg/hl	pigment[c] ppm
1941	Barrigon-Yaqui	*d*	4000	130	0	TS	70S	R	75	4.5
1960	Tehuacan 60	1954	4200	150	0	10MR	20MS	R	81	5.5
1965	Oviachic 65	1960	7000	90	0-40MS	30S	5MR	S	81	7.2
1967	Chapala 67	1961	7000	85	0	10MS	10MR	MS	—	4.0
1969	Jori C 69	1963	7700	85	0	TR	5MS	S	81	3.7
1971	Cocorit 71	1965	8300	85	0	5MR	5MS	MS	81	3.6
1975	Mexicali 75	1969	8600	90	0	TR	5MR	S	78	5.8

a/ Measured at CIANO experiment station, at high rates of fertilizer with irrigation, and in the absence of diseases. *b/* In Mexico, 1975. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. Figures before letters indicate percentage of infection. *c/* Carotinoids. *d/* Farmer's selection.

Milling and baking quality.

CIMMYT's wheat technology laboratory continues to test advanced durum lines for milling and cooking quality. Test weight of the best durums is well maintained at 80 kilograms per hectoliter and some high yielding lines have reached 85 kg/hl. This equals the test weight of the best bread wheats. Carotene content has improved to levels over 5 ppm, which compares well with Italian macaroni durums. Carotene content combined with a low level of lipoxidase, the enzyme which destroys carotene in flour, is a measure of the preferred color in pastas and is important as a characteristic to those countries which export durum grain to Italy and similar markets.



Tests for milling and cooking qualities are a daily task of CIMMYT's wheat technology laboratory, one of units visited by Mexico's president Lopez Portillo (center).

Triticale

Triticale is a man-made cereal. It results from a cross between wheat and rye. Although the cross was demonstrated by British scientists over 100 years ago, it was not until the 1950's that researchers in Europe and North America began intensive efforts to transform triticale into a commercial crop. CIMMYT's work on triticale had its origins in Mexico before the establishment of CIMMYT in 1966. This research is conducted cooperatively with the University of Manitoba in Canada.

Many obstacles facing triticale 10 years ago have been overcome or reduced. Yield of the best triticales then was half that of the best bread wheats but now is equal. Disease resistance in triticale has been broadened but still requires improvement. Lodging in the triticale crop has been reduced. Protein quality has been stabilized at a level superior to bread wheat. Baking quality in triticale has been found satisfactory for many food products on all continents.

But problems remain. In 1977 CIMMYT scientists made 10,000 additional triticale crosses, many aimed at the principal problems of improving kernel quality and giving greater dormancy (preventing sprouting of the head before harvest). Testing of triticale continues in farmers' fields to develop better production practices, and CIMMYT staff made consulting trips to developing countries where triticale lines are on trial.

Triticale now grows commercially in Hungary, USSR, China, Spain, South Africa, Argentina, Mexico, Canada and the USA. The crop is expected to continue to expand its production, initially in areas where triticale tolerance for acid soils and its superior disease resistance, gives advantage over bread wheat.

Higher yield

Infertility was a major cause of low yields until the late 1960's. Only a part of the florets (flowers) in the triticale spike became fertilized and produced grains. In 1968 a triticale line was found that had a high degree of floret fertility. Since then the resultant line called Armadillo has been used extensively in crosses. All advanced hexaploid triticales (those resulting from crosses between durum and rye) now have Armadillo or a derivative of Armadillo in their parentage. Good floret fertility combined with longer spikes and stronger straw has permitted yields of the top triticales to achieve yield superiority over the best bread wheats and durums.

Test weight

Triticale kernels are often shrivelled, a liability that affects test weight (weight per unit volume). The best triticales have test weight of 72 to 76 kg/hl (kilograms per hectoliter) compared with over 80 kg/hl for the best bread wheats. Progress in improving the test weights of triticales has not been rapid, and basic studies of the causes have thus far failed to provide an explanation.

During 1977 some selections from the breeding line called Camel gave test weights ranging between 76-79 kg/hl. Crosses between these lines and others of better agronomic type are being made in 1978.

Triticale is now grown commercially in several countries, and its production is expected to continue expansion — especially in areas where triticale's tolerance for acid soils and its superior disease resistance are an advantage over bread wheat.

Lodging resistance

The increasing resistance of triticales to lodging (the tendency of plants to fall over near harvest) has contributed significantly to rising yields. Dwarfing genes from wheat have been extensively used to reduce the height — and therefore the lodging tendency — of triticale lines. Single and double dwarfs in triticale are somewhat taller than wheats with the same dwarfing sources.

Lodging resistance in triticales has been achieved by combining a moderate reduction in height with stronger stems. The best lines in the triticale program such as Beagle are equal to the best bread wheats in maturity and yield, but remain taller.

Dormancy

Breeders have found two excellent breeding materials to correct the tendency of triticale to sprout in the field when rains occur shortly before harvest. One is a Swedish rye called Othello. The other is a CIMMYT bread wheat named Alondra. Crosses between these donors and the best triticales were made in the winter of 1977-78.

Earliness

Breeders have thus far found it difficult to combine early maturity in triticale with short stature. At present most high yielding triticales are medium to late maturing. Breeders are continuing to incorporate earliness to overcome this characteristic, which gives bread wheat an advantage in some areas.

Protein

Since 1973 when yields of the best triticales first closely approached those of the best bread wheats, the protein content of the best triticales has held at about 13 percent. The content of lysine in triticale protein rose from 2.8 percent in 1968 to 3.4 percent in 1973 and has remained at that level since then. Lysine is a commonly limiting amino acid in cereal protein. (The comparable figures for most bread wheat would be 10-12 percent protein and 2.7 percent lysine.)

Disease resistance

A new crop like triticale poses many disease problems, first in identifying the diseases to which the species is susceptible under research conditions; second, in observing changes in disease susceptibility as the area of production expands.

Triticales continue to show strong resistance to the virulences of leaf rust and stem rust present in northwest Mexico. In the cool, high altitude stations of El Batan and Toluca, Mexico, triticales were resistant to both stem rust and leaf rust but bacterial leaf blight has been severe on some winter-planted triticale lines. Leaf blotching, caused by *Fusarium nivale* a snow mold fungus, was also serious at Toluca.

Infection ratings for stem and stripe rust on triticales in international yield nurseries show lower susceptibility than the ratings given to bread wheats in the same trials.

Triticales grown in the international nursery trials maintain their near immunity to loose and covered smuts, and resistance to powdery mildew.

Many of the problems of earlier triticale crosses, such as floret infertility, have been largely overcome.

Milling and baking quality

The flour yield of triticale lines has ranged from about 52 to 70 percent since 1974, compared to 70 percent in most bread wheats.

Baking tests showed that many triticale lines are capable of producing loaves with volumes up to 700 cubic centimeters (Yecora, a good bread wheat, produces loaf volume of 765 cubic centimeters).

For cookie-making, some triticale lines provide flour that is more suitable than soft bread wheat flour. Mexican tortillas made from triticale flour are equal in quality to tortillas made from wheat flour. Indian chapatis made from triticale meal keep moist longer than chapatis made from bread wheat flour.

Results from milling and baking trials made since 1974 suggest that triticale will find widest acceptance in chapatis, tortillas, cookies, and unleavened bread.

Winter triticales

Winter-type triticales are needed for such areas of the world as Afghanistan and Turkey where cereals are planted in the autumn and flower in the spring. In such areas, spring-type triticales would be damaged by cold and frost during the winter, and, if they survived, would flower in cold weather, resulting in sterility. Winter types from Europe and North America are later in maturity than desired in these areas.

CIMMYT is making crosses between Mexican spring triticales and the winter triticales developed in Europe and USA. The crosses are made at Toluca station where the December weather is cold enough to induce flowering in winter types yet the January weather is mild enough to allow spring types to be planted. Under this pattern the two types flower at the same time and large numbers of crosses can be made.

Winter-type progeny of these crosses are shorter, have higher fertility, better seed development, earlier maturity, and more rust resistance. Spring-type progeny have better root development, improved resistance to certain diseases and possibly better drought tolerance.

In addition, crosses between winter ryes and winter wheats are being produced at Toluca to provide new winter-type germ plasm.

Improvement in winter types progresses slowly because of defects of the winter parents and because only one crop can be grown each year. Winter progeny cannot be tested for cold tolerance in Mexico so they are sent to cooperating scientists in Europe, South America, Canada and USA for screening.

Forage triticales

Some triticales have the ability to produce large amounts of dry matter even when repeatedly clipped or grazed. Trials have been conducted to test the ability of triticale strains to produce forage and, after regrowth, grain. Oats, a crop commonly used for forage and grain, was included in the trials for comparison. Sheep have been used in grazing trials in Argentina.

While no strain of triticale has yet been found to equal the rate of recovery by the best oats, promising triticale lines are on test.

Some triticales can produce large amounts of dry matter, even when clipped or grazed. Promising lines are under test for their ability to produce forage, and after regrowth, grain.

Trials on farmers' fields

During the period 1974-77 CIMMYT placed demonstrations of triticales on farmers' fields in several regions of Mexico. These trials give farmers an opportunity to compare triticales with other cereals, and give scientists the opportunity to study agronomic management problems.

In acidic soils of Mexico's central plateau triticales showed great promise and are now replacing wheat. Even in traditional irrigated wheat areas, triticale yielded at par or better than commercial wheat. Some characteristics still to be improved are earliness, resistance to sprouting under wet harvest conditions, and hardness of kernel, the latter for protection against stored grain insects. Occasional poor stands of triticale in farmers' fields were found attributable to poor land preparation, seeding too deep, or seeding at too low a rate. Present seeding recommendations in Mexico call for 125 kg/ha at a depth of 5-7 cm.

These on-farm trials reveal both advantages and disadvantages of present triticales.

Broad adaptation

The International Triticale Yield Nurseries which have been grown since 1970 provide evidence of the broadening adaptation of triticales to diverse environments. These nurseries consisting of approximately 20 advanced triticales with bread wheat, durum, and triticale check varieties, are grown at several dozen locations around the world. In the Seventh International Triticale Yield Nursery, grown at 60 locations, the five highest triticales averaged 4400 kg/ha compared with 4070 kg/ha for Jupateco, the bread wheat check, and 3450 kg/ha for Cocorit, the durum check.

The transfer of insensitivity to daylength from Mexican bread wheat to triticale has improved the adaptation of triticale within regions of low latitude (30°N to 30°S). In higher latitude locations in the northern Hemisphere, such as Sweden, Poland, Quebec Province in Canada, or Idaho State in the USA, triticales seem less well adapted than the best local wheats.

National programs

Several nations have vigorous programs for triticale testing.

Pantnagar University in India has provided leadership in the introduction of triticales in the hill region of northern India, for both food and fodder. Some 80 demonstration plots on farmers' fields and 4000 "minikits" for farmers' use were supervised in 1977.

In western Asia triticale demonstrations were planted in 1977 in Iran (Karaj Experiment Station) and Turkey (University of Izmir). Triticale lines were undergoing seed increase at higher elevations of Ethiopia and Kenya. Other African countries such as Tanzania, Malawi, Burundi, Rwanda, Zambia, and Malagasy reported triticales had outyielded bread wheats in local 1977 trials.

Among South American countries, Brazil and Chile each has a national triticale research project, and trials have been held in the Andean countries of Colombia, Peru, and Bolivia.

To the scientists in Mexico, it appears that commercial triticales will spread next in three regions:

(1) The hill area of India-Nepal-Pakistan.
(2) The East African highlands, centered on Kenya.
(3) The Southern Cone countries of South America, particularly southern Brazil.

Progress on the Development of High Yielding Triticale Strains at CIMMYT since 1967.

Year in advanced trials	Identity	Sonora Nursery* Yield kg/ha	Test wt kg/hl	Plant ht cm	ITYN** Year	Yield kg/ha	No. of Locations
1967-68	Bronco X224	2356	64.4	150	1969-70	2578	39
1968-69	Arm. T909	3100	65.8	125	1970-71	3272	17
1969-70	Badger PM122	4492	68.5	125	1971-72	3274	34
1970-71	Arm. X208-14Y	5490	65.4	125	1972-73	3506	25
1971-72	Cinnamon	5550	66.8	100	1972-73	3409	25
1972-73	Maya IIxArm	6300	70.0	90	1973-74	4200	47
1973-74	Yoreme	7000	71.0	90	1973-74	4400	47
1974-75	Beagle	7500	68.0	110	1974-75	4480	45
1975-76	Mapache	8000	69.0	111	1975-76	4483	60
1976-77	KLA-M2A	7802	71.9	100	NA		

*Northwest Mexico.
**Average at all locations in the International Triticale Yield Nursery.

Barley

Barley is perhaps the hardiest of cereal crops and a basic food in regions where the growing season is too short or the rainfall inadequate for other cereals. A substantial number of people eat barley in the Mediterranean region, Mideast, India, China, Korea, Japan, the Andean region, and eastern and northern Europe.

Although improved barley varieties have been developed in the past for brewing beer and for cattle feed, varieties for human food were virtually ignored by plant breeders. Most barleys eaten by human populations have been low yielding and susceptible to disease. The grains of most barleys have hulls that are useful in making beer or feeding cattle, but the hulls are generally removed before the grain is eaten by humans, thus reducing weight and nutrients. Additionally, barleys for brewing beer have been bred for low protein content, a disadvantage for a staple human diet.

Since 1972 CIMMYT has assembled good breeding sources for nearly all characters needed in food barleys. Some advanced lines now combine high yield potential, wide adaptability, and naked (hull-less) kernels. But these lines as yet do not have a sufficient range of disease resistance.

Wider adaptation

Lack of adaptation is caused in part by sensitivity to daylength. Varieties with sensitivity flower only in longer days. If temperate zone barleys are planted in the tropics they may flower too late, or not at all. CIMMYT breeders are able to eliminate daylength sensitivity by growing lines in the winter at a Mexican location 27°N and in the summer at 19°N at El Batan. Since the winter location is on a desert at sea level and the summer location is on a humid plateau 2200 m above sea level, the barley lines are subjected to different environments, and only those that show wide adaptation survive.

Greater disease resistance

Drought and high temperatures which occurred at CIMMYT's El Batan station in the summer of 1977 produced excellent epidemics of stripe rust and scald, permitting selection of resistant materials; and the epidemic of leaf rust in 1977 was the most severe ever observed at this location. Pathologists identified 22 advanced barley lines with excellent resistance to leaf rust. These are now used for top and double crosses to improve other lines.

Barley growing countries in the Andean region, including Colombia, Ecuador, and Peru are suffering epidemics from a new race of stripe rust for which local breeders have identified resistant lines. Seed for these lines has been added to the CIMMYT crossing block.

Good progress is being made on other diseases (scald, powdery mildew, common leaf spot, net blotch, and virus stripe disease). Resistant lines are now used extensively in crosses.

CIMMYT has assembled good breeding sources for nearly all characters needed in food barleys. Some advanced lines now combine high yield potential, wide adaptability, and naked (hull-less) kernels — but improved disease resistance is needed.

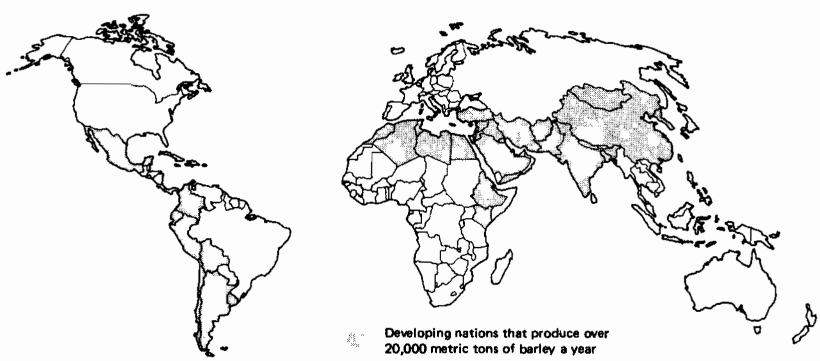
Earliness

Quick-maturing barley is the only cereal which will produce grain in many areas of the world with a brief rainy season or a short frost-free summer. But barleys with short maturity generally are low yielding. Breeders are seeking varieties which mature 20-30 days before existing commercial varieties, and give acceptable yields.

A Russian line, Super Precoz, flowers in 40 days and can be harvested in 70 days in Mexico's summer season. But yield is not adequate.

In 1976 CIMMYT conducted a yield trial in C. Obregon station for early barleys. The most notable line was HjaC4725 x Olli which yielded 4.7 tons in 92 days, while the commercial check gave similar yield in 118 days.

A related line M69.69-HjaC4715 tested for yield at El Batan station in summer 1977 gave 2.9 tons in 86 days in a dry season. This is 25-35 days earlier than commercial varieties, and yield is acceptable, despite only moderate disease resistance. Early varieties tend to escape drought and the full effects of disease epidemics.



Another 54 advanced lines of early barleys were placed in yield tests at C. Obregon in winter season 1977-78. These lines have maturities ranging 70-95 days in the summer season at El Batan, and 90-115 days in the winter season at C. Obregon. The best will later be tested internationally.

Naked grain

Hull-less (naked) barley has several advantages as food:

The edible dry matter is greater in the naked type.

The naked barley preserves the vitamins and minerals in the grain, whereas the hulled type loses part of the nutritive value when the grain is pearled (peeled).

The naked grain threshes easier, and can be eaten immediately after threshing.

Through crosses to Godiva, a variety from USA, and other naked types, almost half the barley lines in early generations at CIMMYT now have naked grains. These materials still require improvement for grain size, plumpness, and resistance to germ damage during threshing.

In 1977, the Third International Barley Yield Nursery, with 24 entries was sent to 45 locations. The Fifth International Barley Observation Nursery, with over 300 entries, was sent to 60 locations.

Better protein

CIMMYT breeders aim to raise the nutritional quality of barley protein. Protein quality can be improved by increasing the amount of lysine, an essential amino acid.

About 40 percent of early generation lines now have one or two sources of improved protein quality in their parentage. The Hiproly variety, an Ethiopian barley, has a high protein content, and also a gene for high lysine content. Riso Mutant 1508, a source obtained from Denmark, is an induced mutant with about the same protein content as Hiproly and about 15 percent higher lysine. Unfortunately, both varieties cause shrivelled grain in their progeny. Since the linkage between lysine content and shrivelled grain is less difficult to break in Hiproly progeny, the program emphasis is on Hiproly as a source of better protein. Some progenies of crosses with Hiproly have up to 3.5 percent lysine which is less than that of Hiproly itself, but still well above the average for barley. To eliminate grain shrivelling, breeders are crossing these lines with Egyptian barleys characterized by their heavy plump grains.

Straw strength

Resistance to lodging — the tendency of the crop to fall over near harvest — is another problem that has been improved. Breeders have used barleys from India, USA and Mexico to improve lodging resistance. Barleys have also been shortened to reduce the tendency to lodge in areas where fertilizer and irrigation are used. Lines in advanced generations now have a high degree of lodging resistance.

Higher yield potential

In the summer of 1977 approximately 100 advanced lines of barley, developed by CIMMYT, were yield tested at El Batan station. Despite a drought which cut short the growing season and hastened maturity, the four best lines of hulled barley gave yields of 4.7 to 5.3 tons per hectare, exceeding the best bread wheat check in this dry season by more than 50 percent. In the same trials, the four best lines of hull-less barley gave yields of 4.5 to 5.3 tons per hectare. These are remarkable yields when one considers the loss of weight from lack of hull.

In the preceding cropping season at Ciudad Obregon (1976-77 winter) 68 advanced lines of CIMMYT-developed barleys were yield tested against checks of bread wheat, durum, and triticale. The ten best barleys gave yields of 6.0-7.1 tons per hectare, with three irrigations and a moderate fertilizer treatment of 120N-60P. The best wheat checks gave slightly higher yields. During the five-year period 1972-77 the best barleys in CIMMYT program have reached yield levels just below the best bread wheats and durums, under disease-free conditions.

International testing

Two large international barley trials were distributed by CIMMYT in 1977. The Third International Barley Yield Nursery containing 24 entries was sent to 45 locations.

The Fifth International Barley Observation Nursery, with over 300 entries was sent to 60 locations. It is the aim of this nursery to obtain broad information on the disease resistance of early generation lines.

The number of countries participating in international barley trials rose from 30 (1975) to 63 (1977).

Winter x spring crosses

Countries such as Korea require winter hardiness in their barley, combined with the ability of the plant to tiller fast in the spring and ripen early, so that barley can be replaced by summer paddy by June 1. These varieties are most likely to be achieved by the crossing of winter and spring barleys. And the crosses cannot be made in Korea.

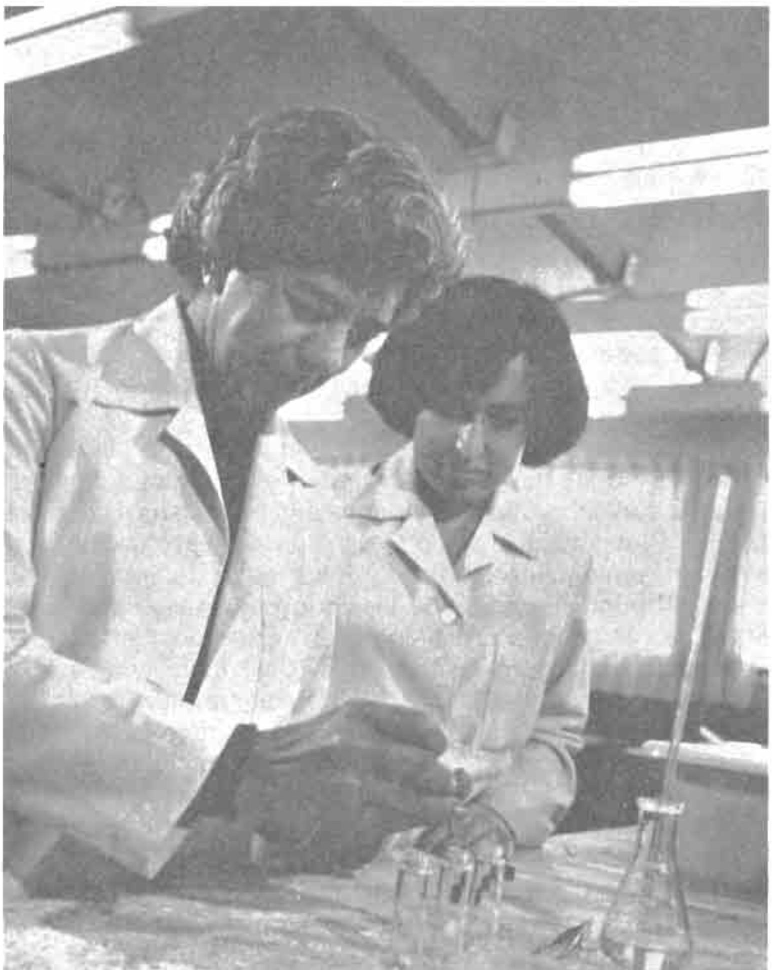
Winter barleys are types that must be exposed to a cold period to induce flowering. Winter barleys are planted in the autumn, survive winter as seedlings and resume growth in the spring. Since winter and spring barleys have evolved in different ecological zones they have quite distinct genetic pools. Through interbreeding each pool becomes a rich source of additional genetic variability for the other pool.

Winter barleys from Korea, the USA, Turkey, and eastern Europe are now planted in CIMMYT's Toluca station each fall. The weather at Toluca is cold enough to induce flowering in winter barley yet spring barley can be planted in January and large numbers of crosses can be made. Part of the F_2 seed is sent to cooperating winter barley breeders including Korea so that winter barleys can be selected under their conditions. CIMMYT also develops spring barleys from the crosses.

By using appropriate parents, breeders believe winter barley x spring barley crosses will lead to both winter and spring types that have higher protein content, better disease resistance, better cold tolerance, and a broad spectrum of maturities.

Barley perspective in 1978

Up to 1978 no national program had released a new barley variety bred in Mexico. But the 64 countries now collaborating in the international barley trials are obtaining new and better breeding materials from CIMMYT each year, and commercial varieties suitable for most climatic zones should be available in the early 1980's.



Protein quality in barley can be improved by increasing the amount of lysine, an essential amino acid. About 40 percent of early generation lines now have one or two sources of improved protein quality in their parentage.

Development of New Germ Plasm

Some wheat varieties carry only a single character useful to the breeder, but this one is often intermixed with undesirable characters. One breeding unit at CIMMYT is making the painstaking transfer of genes for single useful characters into lines with good agronomic type and "pyramiding" the useful genes. These modified lines can then be used as parents to make many crosses to improve higher yielding, widely adapted lines. Some of these efforts are described below. Substantial gains from this work occurred in 1977.

New sources of dwarfing

Most of the world's semi-dwarf spring wheats derive their short height from the Japanese winter variety Norin-10. To broaden this base CIMMYT is employing three other varieties — Tom Thumb (Tibet), S948A1 (Rhodesia) and Hisumi (Tibet via Japan) — three short varieties whose genes for shortness are unrelated to Norin-10.

CIMMYT has crossed S948A1 to older Mexican varieties such as Huamantla Rojo, Nainari 60, and Pitic 62, aiming to add more dwarfness to their proven yield potential and adaptability.

At the same time the dwarfing gene S948A1 has been incorporated into the latest and highest yielding Mexican wheats, which already include Norin-10 in their pedigree. These crosses involve Jupateco 73, Tezopaco 76, and Pavon 76. It is hoped that a further shortening of the straw will enable the progeny to convert even more of their dry matter into grain.

Hisumi is a very short winter dwarf, 45-55 cm tall when grown in northwest Mexico. It has been backcrossed for several generations to some of Mexico's leading spring wheats, and seeds from the hybrids are being tested in the 1977-78 winter season. The most advanced materials are derived from the commercial varieties Jupateco 73, Chris, Santa Elena, and Nariño 59.

Protein improvement

Higher protein content or protein quality have been found in a few spring wheats, but these materials are generally associated with weaknesses such as susceptibility to rusts, incompletely filled kernels and poor spikelet fertility. CIMMYT is transferring these genes for better protein into better plant types.

In the first round of crosses the breeders were able to move superior protein into progenies of the varieties Frondosa, Nap Hal, Kenya C, Pioneer, and Mahratta. Some of these lines had 15-19 percent total protein compared to 10-13 percent in most commercial bread wheats.

In the second round of breeding, best progeny from the first crosses were backcrossed to superior advanced lines in the CIMMYT bread wheat program. Several offspring from the second round show better agronomic characteristics and better grain type than their parents, yet retain high protein content. Enough seed will be available in the spring of 1978 to permit yield trials. One promising line gave 14.5 percent total protein in a yield of 5.6 tons/ha. The check variety Siete Cerros gave 5.7 tons yield with protein level of 9.8 percent.

This indicates the possibility that future crosses can stabilize the combination of high-yield and high-protein.

CIMMYT recognizes that extremely high protein levels in grain comes at a price. Very high protein grain requires more soil nitrogen, and part of the increased protein is in a form which does not improve the nutritional value of the grain. However, a protein level of 14.5 percent should provide very good bread making properties.

Research on wheat plants with branched heads seeks to determine whether branched heads will permit a larger number of grains per square meter of plants, and thus increase the yield.

Rust resistance

Leaf rust is caused by a pathogen which is the most unstable among the diseases of wheat, and some of the best genes for resistance to leaf rust are found in older varieties like Yaqui 50, Bonza 55, Andes 56 and Era, which have plant types unsuitable for commercial varieties in most developing countries.

So the breeders are attempting to transfer genes for leaf rust resistance in two ways: first, into a single breeding line that can serve as a parent; second, by direct crosses into some of the latest and highest yielding Mexican spring wheats which are susceptible to leaf rust, including Super X, Inia 66, Cajeme 70, Yecora 70, Potam 70, Jupateco 73 and Zaragoza 75.

In another approach to leaf rust resistance, the breeders are using the varieties Agatha and RL6010, each with one dominant gene for leaf rust resistance, in a series of back crosses to high yielding varieties like Inia 66, Yecora 70, Potam 70 and Morocco. Cycles alternate between back crosses to the resistant parent, then a screening cycle which permits susceptible offspring to be discarded and resistant offspring to be retained. This program will complete its third backcross in 1978.

The breeders are confident they can select a plant with all the desirable characteristics of Inia 66, for example, combined with the leaf rust resistance of the variety Agatha (gene LR19). This procedure should be equally effective with other genes for leaf rust resistance (LR9, LR21, LR22, LR24).

Branch-headed grains

Research continued in 1977 on the development of wheat plants with branched heads. The purpose of this work is to determine whether branched heads will permit a larger number of grains per square meter and thus increase the yield ceiling.

In the early 1970's CIMMYT developed branched heads which carried more grains per plant, but this novel architecture was generally associated with poor agronomic type, poor fertility, and poor grain quality. In 1977 most of these characteristics were corrected. Twelve lines of branch-headed bread wheats gave yields similar to the variety Super X, with more spikelets and more grains per square meter. The grains were small but well developed and test weight was high. Problems with fertility and grain plumpness still remain.

The breeders now believe it is possible to combine the branched head with the best characters of the wheat plant. But whether this will raise the yield ceiling is still to be proven.

More spikelets per head, more grains per spikelet

Another approach to higher yield ceiling is the breeder's search for a longer conventional head, with more spikelets per head, and more grains per spikelet.

The winter wheat variety Tetrastichon has a head twice as long as most spring wheats, giving 30-40 spikelets per spike, compared to 10-13 spikelets in some of the highest yielding commercial spring wheats. This character of Tetrastichon has been transferred to spring wheats at CIMMYT.

In addition, the breeders have found some varieties which produce more grains per spikelet. The variety Morocco regularly gives 10 grains per spikelet when grown in northwest Mexico, compared to 3-6 grains per spikelet in most bread wheats. Some progeny from the variety Morocco are giving up to 14 grains per spikelet.

Now the breeders are making crosses to combine these two characters — more spikelets per head, and more-grains per spikelet. One line in 1977 was giving 27-30 spikelets and 7-9 grains per spikelet when grown under commercial crop spacing. This would produce 2 to 4 times more grains per head, compared to current commercial spring wheats.

But the question remains: will this increase the yield? Mother nature tends to offset each increase of one yield factor by a reduction in another. For example, these plants with a remarkable number of grains per spike might produce fewer tillers (extra stems), or show greater spikelet sterility (fewer grains would fill), or lower test weight per 1000 kernels. The breeders are trying to maximize all these characters simultaneously.

Tolerance to aluminum toxicity

Brazil has more than 20 million hectares of acid soils (Campos Cerrados) which could grow wheat when varieties are developed with tolerance for aluminum toxicity in the soil. Other countries have the same problem.

Breeders have found that one Mexican spring wheat Alondra, and segregates of the Brazilian cross Pelotas 72380 x Arthur 71, both confer tolerance to aluminum toxicity, and this character is now being transferred to improved bread wheats.

Wheat x triticale crosses are also being used as an approach to the aluminum problem. Triticale shows greater tolerance to aluminum toxicity than do present bread wheats, and the breeders hope to transfer the triticale character to the wheats. Several of CIMMYT's wheat x triticale crosses will be tested in Brazil during 1978.

Wide crosses (intergeneric crosses)

In 1977 crossing between wheat x barley continued. Eight of the crosses produced adult plants with good fertility, but all characters are similar to the female parent. Although there is no confirmation whether genes from the male parent are present, the plants will be carried forward to advanced generations in expectation that even partial hybrids (insertion crosses) would have important use in CIMMYT breeding.

Crosses between wheat and grasses (wheat x Agropyron, wheat x Aegilops, wheat x Elymus) were continued. These are near relatives of wheat from which new sources of disease resistance are sought. True hybrids have been developed from all three crosses, but there has been no success in developing fertile offspring from the third genera cross.

All work on new germ plasm described above must be judged over 5-year or 10-year periods, not on a year-to-year basis.

Physiology-Agronomy

The physiologists have been assigned the task of identifying for the breeder more efficient ways of selecting wheat plants for higher yield. The physiologist studies plant characters which may limit yield potential, and factors correlated with higher yield. He screens materials for drought tolerance. He works on the frontiers between applied science and the basic biological sciences. This is slow work but each year some new developments are reported.

Plant selection in early generations

In early segregating populations (F_2, F_3) plants are grown at CIMMYT at wide spacings in the row so that the breeder can select visually for differences. This arrangement is very different from the density of plants in a commercial crop. Some plant characters such as plant height, disease resistance, and days to maturity are comparable at both wide and close spacings, but the yield of widely spaced plants bears little relation to the yield of a crop planted at normal densities. For this reason it is more difficult for the breeder to select those plants with the highest yield potential in early generations.

Physiologists at CIMMYT are studying early segregating populations to see if they can identify characters at an early generation (F_2) which correlate with high yield potential in later generations. (F_4, F_5, F_6).

To make this study, plants were randomly selected in F_2 from many CIMMYT crosses. Observations were made of more than 30 characters in F_2. Thereafter seed from the plants was increased to permit yield trials grown at commercial density in generations F_4, F_5, and F_6. Correlation is then made between high yield in advanced generations and the characters observed at F_2. For those characters which show good correlation, further studies are made to define more accurately how they might be used as selection criteria in early generations.

The first F_4 yield trial in this study was conducted in 1977, and the one season result is encouraging. Estimating the stomatal aperture (the size of pores in the leaves) with a mass-flow porometer on the F_2 plants gave a more accurate estimate of yield in the F_4 generation than did the breeders' visual assessment. Tests will be made of this as a selection criteria in 1978.

Drought studies

A drought trial was conducted on 29 bread wheats, three durums, and four triticales at three levels of moisture.

Plots under "early drought" received one irrigation at sowing, a second at 67 days, and a third at 97 days. Plots exposed to "late drought" received one irrigation at sowing and a second at 35 days. Rainfall was 35 mm for the season. Control plots received the normal 6 irrigations considered necessary for full expression of yield potential in northwest Mexico.

Some of the newer bread wheat lines showed better yield under drought stress than the older varieties. The highest yielding line under late drought, Nacozari "S" yielded 4.3 t/ha with two irrigations, and one Pavon "S" yielded 6.9 t/ha with three irrigations, whereas the highest yield in the control plots with six irrigations was 7.3 t/ha.

Some early barley lines yielded extremely well in a trial with only a planting irrigation (about 150 mm of irrigation plus 24 mm of rainfall). The best line, Mona Arivat, yielded 3.9 t/ha under these extreme drought conditions and matured in 88 days. This is a yield of over 44 kg/ha for each day in the ground, whereas the highest yielding variety in any physiology plot in 1977, under full irrigation, gave 59 kg/ha per day.

In reading these results, caution is needed: these trials are useful in identifying parents for the breeding program, but the results of drought studies in Mexico cannot be extrapolated to other parts of the world where different types of drought, or different soils or different temperature regimes prevail.

Leaf angle

CIMMYT physiologists have conducted a series of studies to determine whether leaf angle of the wheat plant is a factor in yield potential. These studies were prompted in part by the high yielding rice varieties bred by the International Rice Research Institute with upright flagleaf. Similar wheat varieties can be developed if leaf angle were found to be a significant factor in yield potential.

Physiologists work on the frontier between applied science and the basic biological sciences; studying plant characters that may limit yields and screening materials for drought tolerance.

In 1977 well watered, high fertility trials were conducted on bread wheat lines exhibiting different leaf angles. Lines with erect leaves were from F_3 populations of crosses between one erect-leafed parent (Erect RAF) and three high yielding Mexican varieties, Siete Cerros 66, Inia 66, and Yecora 70. Disease was controlled. Leaf angle was estimated visually as an angle from the vertical, at three stages before flowering and one stage shortly after flowering.

The conclusions: No obvious correlation was found between leaf angle and yield in these trials under conditions of northwest Mexico.

Under environments with lower radiation than in Mexico, leaf angle may be important, and the trait will continue to be studied in the breeding program.

Factors limiting yield potential

The highest yielding wheat lines under optimum conditions (no moisture or nutrient stress, no weeds, no disease) are normally the highest yielders under poor growing conditions, although under poorest conditions the differences in yield are negligible. Therefore, increasing the yield potential of wheat under optimum conditions is of interest to CIMMYT, since it relates to yields also under sub-optimal conditions (the circumstances under which most of the world's wheat is grown).

Physiologists and agronomists at CIMMYT are conducting studies to determine how yield is limited under optimum conditions.

In 1977, foliar nitrogen applied during the 30 days before flowering gave no significant increase in grain numbers per spike or in yield.

More moisture applied as an extra irrigation at 71 days after sowing, or in the form of aerial misting when temperatures reached 24° C, tended to increase numbers of grains per spike and yields, but only slightly.

Day-length extensions with artificial lights were given to seven populations during the period before flowering, and their response was compared to checks with normal day-length. Day-length extension advanced the date of flowering, and reduced yield in proportion to the number of days that flowering was advanced.

In a shading study with six varieties, yield was markedly reduced by applying 50 percent shade during 14 days immediately before flowering. Yield loss was due to reduction of spike numbers and grains per spike, and the loss varied by variety.

To date, these studies have shown that yield in this environment is limited by the number of grains set per unit area, and that yield could be increased if it were possible to increase either the number of grains per ear or the number of ears per unit area.

Nitrogen trials

Different sources of nitrogen were tested for their agronomic effectiveness. The sources of nitrogen used were urea, ammonium sulfate, ammonium nitrate and sulfur coated urea. Urea, ammonium sulfate and ammonium nitrate always gave similar results although at the higher rates of N application urea gave higher yields than the other two sources, sometimes significantly. All three fertilizers were consistently superior to sulfur coated urea under growing conditions of the trials in Northwest Mexico. In a combination of 24 comparisons sulfur coated urea was significantly inferior 18 times.

Weeds and weed control

Since wild oat (*Avena fatua*) is a major weed problem in many wheat growing areas of the world, its biology and chemical control are being studied.

The effects of varying lengths of weed competition (wild oat) on four crops — triticale, bread wheat, durum and barley — were studied using the varieties Yoreme, Jupateco, Cocorit and Celaya respectively. The effect of wild oat competition began to show between 48 and 59 days postemergence of the crop under these conditions. When weeds were not removed until 111 days postemergence, the crop losses were 4070 kg/ha, 2550 kg/ha, 3190 kg/ha and 520 kg/ha, for Yoreme, Jupateco, Cocorit and Celaya respectively, as compared to their respective checks. The most competitive crop was barley (variety Celaya). This is due to the early seedling vigor of barley and the fact that it covers the ground rapidly to prevent light penetration and the development of weeds. The important factors that emerge from this experiment are (1) the varying ability of crops to compete with weeds and (2) the importance of crop density.

Pathology

A severe epidemic of leaf rust (*Puccinia recondita*) attacked the principal commercial wheat area of northwest Mexico in the winter season 1976-77. Seventy percent of the crop was planted to the variety Jupateco 73, which is susceptible to leaf rust.

The Government of Mexico organized an aggressive program of aerial spraying with fungicides. In fields where no fungicide was applied, Jupateco 73 yielded as low as 800 kg/ha, whereas in fields effectively sprayed, yields were as high as 6 tons/ha.

The circumstances behind this epidemic are described in a report at the back of this Review, together with conclusions.

During the epidemic CIMMYT conducted commercial-sized trials on the use of fungicides as control agents against leaf rust. The results are reported below.

Chemical control of a leaf rust epidemic

In one fungicide trial, a 25-hectare field of Jupateco 73 was divided into blocks of 5 to 6 hectares for fungicide treatment, and a one hectare area was reserved as a check. Yield data were taken by commercial combine. The fungicide Indar was applied from the air at the rate of 800 cc per hectare and gave an average 54 percent yield increase compared to the check. The fungicide Bayleton was applied at 1 kg/ha and gave 32 percent increase in yield. Both treatments were economic (value of crop saved greatly exceeded the cost of treatment).

Bayleton showed excellent eradication ability (it killed rust pustules already formed) whereas Indar served to prevent new pustules from forming after treatment.

In a second trial, Indar was applied to irrigation water 60 days after crop emergence of the variety Jupateco 73, which already showed 10-12 percent leaf rust infection. The fungicide, taken up by the plant roots as a systemic, increased yield by 13 percent 200 meters from the point of application, indicating excellent dispersal, and demonstrating both feasibility and economic payoff of this method.

Gibberella blight or "Scab" disease

Gibberella blight is a fungus disease of wheat, commonly known as "head scab", which took a heavy toll in southern Brazil and Argentina in 1977, and is endemic in Japan and

China. CIMMYT is collecting wheats reportedly resistant to scab to determine whether resistance can be combined into high yielding varieties.

Until now, Japan has had the best resistance to scab but Japanese resistance has been generally associated with wheats of poor agronomic type, high susceptibility to stem rust, and poor baking quality. Argentina has developed one source of resistance in the variety Klein Atlas. In Brazil crosses are being made between Brazilian wheats and Asian varieties which have some resistance to scab, especially Japanese such as Minami Kyuchu, Nibiaka, Nyu Bay and Peking 8. Progress in breeding for resistance to the disease is slow. Chinese breeders say they have no wheats with strong resistance to scab.

The USA eliminated scab as a serious wheat disease during the period 1890-1930. Wheat and maize were then grown in the same areas of the USA and the two crops served as alternate hosts to the fungus, winter and summer, until the wheat crop moved farther west into drier areas and the chain of continuous infection was broken. This solution is not feasible in some countries where the disease is now endemic. Hence genetic resistance is sought.

Preparing plots for planting at El Batan.

International Wheat Testing

In 1977 collaborating scientists in 96 nations planted over 1700 trials of wheat, triticale, and barley nurseries distributed by CIMMYT. A nursery consists of a set of varieties or lines, sometimes as many as 470. Identical sets are sent to scientists at numerous locations. The results reveal the adaptability and comparative yield of each entry under dozens of different ecological conditions as well as the breadth of disease resistance of the entry. The information derived from 1 year of testing at so many locations could not be equalled by decades of testing at one location.

CIMMYT's international testing program evolved from cooperative wheat testing in North and South America in the late 1950's. When the Mexico program received its first trainees from outside the Americas in the early 1960's the idea of worldwide tests was a logical expansion. The First International Spring Wheat Yield Nursery in 1964/65 was the beginning. Other types of nurseries followed. Nurseries are sent out annually in triticales, durums and barleys as well as bread wheats. Some nurseries consist of F_2 seed, others contain advanced generations, still others released varieties. Certain nursery trials are replicated, others are not.

The nurseries are a mechanism for distributing germ plasm. Any entry in any nursery can be used as the local breeder sees fit. He may use an entry as a parent for making crosses with local varieties, or make selections from the entry, or multiply the entry for direct release to farmers with appropriate recognition to originating institution and country.

A significant benefit of the nurseries is that they foster contact and cooperation among scientists in nations with wide social and political differences.

In 1977, 96 countries received nurseries (see Table). The total weight of the nurseries, shipped by air, was 4.5 metric tons.

As rapidly as test data are received from each nursery, CIMMYT summarizes and publishes the results for distribution to all collaborators and other interested scientists.

Bread Wheat, Durum, Triticale and Barley Nurseries Distributed by The International Nurseries Program 1977.

Latin America	Bread wheat	Durum	Triti-cale	Barley
Argentina	27	14	18	3
Bolivia	9	6	6	8
Brazil	34	4	29	7
Chile	18	11	15	9
Colombia	8	—	6	3
Costa Rica	3	1	1	1
Cuba	1	—	1	—
Dominican Republic	4	—	2	—
Ecuador	14	5	12	9
El Salvador	1	—	—	—
Guatemala	7	1	3	2
Guyana	3	—	2	—
Honduras	2	—	1	1
Jamaica	2	—	1	—
Mexico	43	21	15	16
Nicaragua	5	—	2	—
Paraguay	6	—	2	1
Peru	14	12	8	11
Trinidad	2	—	—	—
Uruguay	5	2	4	3
Venezuela	2	—	3	—
	210	77	131	74
Africa				
Algeria	10	14	8	4
Cameroon	3	2	2	—
Egypt	10	6	5	5
Ethiopia	5	8	8	5
Ghana	3	1	2	1
Kenya	8	6	12	5
Lesotho	1	—	2	—
Libya	4	5	4	4
Malawi	1	—	1	—
Mali	2	1	—	—
Morocco	1	6	1	1
Nigeria	9	2	4	6
Rhodesia	2	—	—	—
Senegal	2	—	1	1
Somalia	3	1	2	2
South Africa	10	8	12	8
Sudan	12	10	4	7
Tanzania	2	1	—	—
Tchad	2	—	—	1
Tunisia	5	7	3	4
Uganda	1	—	1	—
Zaire	2	—	1	—
Zambia	9	1	4	1
	107	79	77	55
Mideast				
Cyprus	3	4	1	4
Iran	5	2	2	4
Iraq	5	3	4	4
Israel	16	10	12	3
Jordan	6	8	5	4
Saudi Arabia	2	1	1	1
Syria	22	20	23	13
Turkey	14	14	10	10
N. Yemen	2	1	1	—
S. Yemen	1	2	3	2
	76	65	61	45

East Asia	Bread wheat	Durum	Triti-cale	Barley
Afghanistan	9	1	3	2
Bangladesh	5	2	3	4
China	9	1	5	4
India	24	27	30	10
Indonesia	3	—	—	1
Japan	3	—	7	1
Korea	6	—	5	6
Nepal	10	2	9	5
Pakistan	22	18	23	13
Philippines	3	1	5	—
Sri-Lanka	2	—	1	—
Thialand	3	—	1	1
Vietnam	1	—	—	—
	100	52	92	47
Oceania				
Australia	7	4	7	3
New Caledonia	3	—	—	—
New Zealand	3	3	2	1
Tahiti	1	—	1	—
	14	7	10	4
Europe				
Albania	1	3	1	1
Austria	1	4	1	—
Belgium	2	—	—	1
Bulgaria	4	6	3	2
Czechoslovakia	3	—	1	—
England	3	1	1	1
Finland	1	—	—	—
France	4	6	5	—
Germany	6	1	6	1
Greece	5	4	3	—
Hungary	2	1	4	—
Italy	1	7	3	—
Malta	—	1	—	1
Netherlands	5	1	1	1
Norway	3	—	2	—
Poland	4	2	4	2
Portugal	2	3	2	2
Romania	3	5	2	—
Russia	3	2	2	3
Spain	10	8	3	3
Sweden	3	1	5	—
Switzerland	—	—	3	—
Yugoslavia	4	5	2	2
	70	61	54	20
North America				
Canada	14	—	14	8
U S A	35	13	31	12
	49	13	45	20
TOTALS:				
Countries	94	62	82	61
Locations	626	354	470	265

Milling and Baking Laboratory

The milling and baking laboratory evaluates the grain of bread wheat, durum, and triticale lines for their suitability in making bread, tortillas, chapatis, cookies, spaghetti, and other products.

In 1977 the laboratory tested 30,000 samples from early generation bread wheat lines (F_3 and F_4) for gluten strength by the use of the micro-Pelshenke test, after being selected for seed type. By screening in early generations, it has been observed that advanced materials have increased in test weight (weight of grain per unit volume), and very few advanced lines are now discarded because of low grain test weight. Test weight influences flour yield. Among advanced lines and varieties of bread wheat, some 1900 were evaluated in 1977 for milling, protein percent, mixogram, alveogram, sedimentation and baking.

In durum wheats the laboratory screened 7000 individual plants for pigment content, and 250 advanced lines were evaluated for spaghetti-making quality. Several advanced durum lines were found with better spaghetti cooking quality than Mexicali, Mexico's leading durum.

In 1977, 9500 triticale lines from segregating generations were screened for alpha-amylase activity by the use of the "falling-number" method. A direct correlation between alpha-amylase activity and sprouted grain has been observed, lines with the highest activity exhibiting the highest sprouting in the field. With the use of this test, the lines with tendency to sprout will be discarded from the program.

In triticale, 497 high yielding lines that have good yield and high test weight were evaluated for milling and baking and for quality in cookie-making.

Almost all the triticale lines tested had a flour yield higher than 60 percent, and some higher than 70. Good bread wheats have flour yields of 70 percent. Baking tests were conducted with triticale flour using low fermentation period, and a high number of triticale lines had loaf bread volumes above 700 cc. compared to Yecora a good bread wheat, which has a loaf volume of 765 cc. Many triticale lines provide flour that is better for cookies than the soft bread wheat normally used for making this product.

Wheat Training

Since 1966 over 400 wheat scientists have received in-service training in Mexico. During 1977, 41 young scientists from 21 nations were trained.

The training program lasts 3 to 7 months. It aims to develop skill in field and laboratory techniques, to give experience working in an interdisciplinary team, and to improve understanding of agricultural development and the role of wheat production.

The number of training fellows by country in 1977 carries no program significance, because availability of candidates in a particular year depends upon the ability of each government to approve study leaves for young scientists. (See table.)

Over a 10-year period the number of trainees per country can indicate several cropping situations. For example, countries where CIMMYT has participated in major wheat improvement campaigns have sent the largest number of candidates: Algeria, Brazil, Mexico, Pakistan, Tunisia, and Turkey. Some smaller wheat producers are trying to expand their crop, and these countries are active participants in CIMMYT wheat training: Bangladesh, Ecuador, Nigeria, and Peru.

Farm trials

Starting in 1975 the course for wheat agronomists has provided experience in laying out on-farm testing of wheat, barley, and triticale, from which recommendations to farmers can be drawn. The trainees have installed, managed, and harvested trials, and prepared recommendations. The principles and techniques learned in these trials should help the trainees develop programs in their home countries that will produce information useful to policy makers in formulating recommendations.

Training in national programs

The CIMMYT training staff have helped a number of governments to set up training courses within national wheat programs. In past years such courses have been organized in Turkey, Tunisia, Algeria and Ecuador.

In 1977 the head of the wheat training staff in Mexico spent several weeks in Tunisia and Algeria, helping lay plans for additional training programs to be carried out in 1978.

Origin of Wheat in-service trainees, 1966-77.

	1966-1977	1977
Latin America	118	10
Argentina	12	0
Bolivia	5	3
Brazil	17	0
Chile	6	0
Colombia	4	0
Dominican Republic	1	0
Ecuador	10	1
Guatemala	5	0
Honduras	1	0
Mexico	40	2
Panama	1	0
Paraguay	4	1
Peru	11	3
Uruguay	1	0
North Africa & Mideast	159	14
Algeria	42	4
Cyprus	1	0
Egypt	9	2
Iran	6	0
Iraq	5	1
Jordan	3	0
Lebanon	4	0
Libya	4	0
Morocco	18	1
Saudi Arabia	1	0
Sudan	3	0
Syria	5	1
Tunisia	23	1
Turkey	30	4
Yemen	3	0

	1966-1977	1977
Africa, South of the Sahara	40	7
Ethiopia	11	2
Kenya	7	1
Malagasy	1	0
Nigeria	14	3
Somalia	1	0
Tanzania	3	0
Zaire	1	0
Zambia	2	1
South, Southeast & East Asia	83	10
Afghanistan	13	0
Bangladesh	17	3
India	6	1
Korea, South	7	1
Nepal	7	3
Pakistan	33	2
Other countries	17	0
France	1	0
Hungary	1	0
Poland	3	0
Portugal	1	0
Romania	2	0
Spain	2	0
USA	4	0
USSR	3	0
Total:		
Countries	51	21
Individuals	417	41

Wheat Cooperative Projects Outside Mexico

During 1977 CIMMYT had posted four wheat scientists to work with regional wheat programs outside Mexico and five to work with national wheat programs.

In three regions of the world wheat growing countries have entered into cooperative arrangements to improve their wheat crop. Regional groupings generally comprise neighboring countries in which wheat is a major crop, grown under similar climatic conditions, exposed to similar diseases, and benefiting from continuous exchange of technology. Typically a regional program will sponsor: (1) an annual workshop among wheat scientists, (2) circulation of uniform nursery trials, (3) visits by local scientists to observe wheat research in neighboring countries, (4) more training in the region, and (5) consultation by CIMMYT scientists.

At the close of 1977 CIMMYT wheat scientists were stationed in the following regional programs:

Wheat region & headquarters	Number of cooperating countries	1978 population (millions)	Wheat crop (tons)	CIMMYT assigned staff 1977	Donor of restricted core funds	Year regional arrangement began
Mediterranean, Mideast & South Asia (Egypt & Turkey)	22	1040	69,000,000	2	Netherlands	1973
East Africa (Kenya)	14	106	1,000,000	1	Canada	1976
Andean Region (Ecuador)	5	69	330,000	1	Canada	1976

A fourth regional program is expected to commence during 1978 in the Southern Cone countries of South America (Argentina, Brazil, Chile, Paraguay, Uruguay); and a fifth is projected to begin during 1979 in North and West Africa (Tunisia, Algeria, Libya, and Morocco) with services extending to Sub-Sahara Africa).

In addition to the regions, national wheat programs typically served to improve wheat research in local experiment stations, to test experimental varieties on local farmers' fields, to multiply seed for improved varieties, and to provide additional training for local scientists. CIMMYT's assigned staff in national programs share these activities.

The following countries participated in cooperative arrangements during 1977:

Country	Start of CIMMYT arrangement	CIMMYT assigned staff 1977	Approximate wheat crop (tons)	Donor*
Pakistan	1965	1	7,000,000	USAID/Ford
Tunisia	1968	1	1,400,000	Ford
Algeria	1971	2	2,900,000	Ford
Nepal	1976	1	300,000	USAID

*CIMMYT requires 'extra core funds' for support of each national arrangement.

Participation by CIMMYT in each national program may continue 10 years or more, subject to mutual agreement among the cooperating country, the donor, and CIMMYT.

Mediterranean and Mideast Region

Since 1973, a unique disease warning system has been operating with cooperation of cereal growing countries stretching from Morocco in the west to the Indian sub-continent in the east. North-South the region extends from southern Europe to East Africa.

Two CIMMYT pathologists are assigned to the project, one headquartered in Egypt, the other in Turkey, both able to make regular trips to monitor epidemic levels of wheat-barley diseases and to cooperate with the International Center for Agricultural Research in Dry Areas (ICARDA) at Aleppo, Syria, and Tabriz, Iran. The Project operates as follows:

International wheat-barley trials are distributed each year as (1) a trap nursery, and (2) a disease and insect screening nursery and other trials.

A trap nursery consists of small plots of the principal commercial varieties of wheat-barley grown in the region. This trial is grown by cooperators in most countries of the region, permitting observation by the pathologists of the diseases which attack each variety, the extent of damage, and virulence of the pathogen involved. If an existing commercial variety is seriously damaged in the trial, early warnings can be issued to the governments concerned that this variety will need replacement in future years.

A disease screening nursery consists of small plots of experimental lines of wheat-barley, gathered from national programs of the region and CIMMYT. These trials are likewise exposed to the prevailing wheat-barley diseases. By monitoring when the diseases strike, and the intensity of attack, the pathologists are able to identify breeding materials which carry strong resistance to each disease. This information is distributed to cooperating governments. By selecting resistant wheats in the "hot spots" (locations with virulent forms of pathogen), the pathologists are probably identifying multiple-gene resistance, and may thus help produce future varieties with effective commercial life longer than 5 years.

Testing is so widespread that it is possible to map the movement of epidemics and even the newer races of pathogens, as they cross national boundaries. Ultimately, it may be possible to predict when a new race of rust will reach certain countries of the region and thus warn the governments when substitute varieties are urgently needed. More information on weather systems is needed before prediction is possible.

Laboratory identification of the races and virulence of rust is performed for this project by collaborators in Netherlands, Yugoslavia, and Egypt.

Pathologists of this region work closely with the East African program (below).

East African regional wheat program

Starting in 1976 CIMMYT assigned one wheat breeder to the East African highlands. This operation is headquartered at the Kenya National Plant Breeding Station, Njoro, elevation 2300 meters, about 200 kilometers northwest of Nairobi, near Nakuru.

Fourteen countries of this region together produce more than 1 million tons of wheat: Botswana, Burundi, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Rwanda, Somalia, Swaziland, Tanzania, Uganda, Zambia.

In 1977 this regional program held its first workshop at Njoro for 23 wheat scientists from 12 African countries. The workshop focused on the potential for triticale in the region.

In 1977 the first African Cooperative Wheat Yield Trial was grown in replicated plots in 11 countries. A second trial will be distributed in 1978.

The high altitude summer wheat nursery was grown at Njoro station in 1977, approximately June-October, and the opportunity to gain an extra generation in research was utilized by 10 nations; Cyprus, Egypt, Ethiopia, Greece, Iraq, Lebanon, Pakistan, Spain, Tunisia, and Turkey. ICARDA also sent many entries.

Thousands of cereal introductions were screened at Njoro in 1977 for stripe rust and stem rust resistance. The screening activity is conducted two cycles a year and results are notified to CIMMYT, ICARDA, and national collaborators.

Visits by CIMMYT wheat scientists to national programs in East Africa have speeded the reporting of data on the nurseries, thus increasing the timeliness and usefulness of the information to breeders.

Andean regional wheat program

Five countries of the Andean region (Bolivia, Colombia, Ecuador, Peru, and Venezuela) produce 300,000 tons of wheat a year, but import 2,000,000 tons of wheat and flour *(FAO Yearbooks, 1970-76)*.

These circumstances led CIMMYT to post one wheat breeder to Ecuador in 1976 to work with national wheat programs of the region. The Andean countries also produce 400,000 tons of barley per year, and import another 100,000 tons. Research on wheat and barley is generally conducted by the same scientists.

In 1977 the Andean wheat program included: (1) an annual workshop among wheat scientists of the region; (2) regional nurseries grown by collaborators of the region, including a regional disease and insect nursery similar to the early warning system around the Mediterranean; (3) arranging additional training for wheat scientists; and (4) consulting by CIMMYT scientists.

During the decade 1966-77 CIMMYT provided one season of training in Mexico to 25 young scientists from the Andean countries, and 5 more were sent to Mexico in 1977.

Pakistan national wheat program

A CIMMYT wheat scientist was first posted to Pakistan in 1965, and other staff members have served their intermittently, including a wheat agronomist in 1978.

Wheat is the number 1 cereal crop in Pakistan, where the population of 76.6 million (1978) is increasing 2.9 percent a year.

The CIMMYT training program has brought 33 young Pakistani scientists to Mexico for one cropping season including 3 in 1977. More than a dozen Pakistan wheat scientists were sent to U.S. universities for advanced academic studies. This body of trained manpower was the foundation of subsequent progress.

The wheat program in Pakistan has released more than a dozen new varieties during the past decade.

During this decade of collaboration, the average yield of wheat in farmers' fields has risen by 50 percent.

High yielding wheat varieties are now sown on 63 percent of Pakistan's wheat land and produce 78 percent of the wheat grain. The amount of fertilizer applied to wheat has doubled in the 1970's. Despite these gains Pakistan still imports almost one million tons of wheat this year.

Mike Prescott, CIMMYT pathologist, discussing the harvest with a Turkish farmer.

Tunisia national wheat program

Tunisia imported as much as 400,000 tons of grain a year during the first half of the 1970's, but reached approximate self-sufficiency in 1976 and 1977.

National population will pass 6.2 millions in 1978, increasing at 2.5 percent a year.

CIMMYT wheat scientists were posted to Tunisia starting in 1968, and during the past 10 years 23 young Tunisian scientists have spent a cropping season in the Mexico training program. Several Tunisians were sent to U.S. universities for advanced degrees. From this young staff has come the following progress:

(1) Several new bread wheat and durum varieties have been released, together with recommended practices. The production of bread wheat has doubled. The new varieties of durum now cover 50 percent of durum land.

(2) A 2-year rotation of wheat and medicago (forage legume) has been introduced from Australia and proven adapted under local conditions, providing more grazing to sheep than the previous 'weed fallow' between wheat crops.

(3) Limited work has been completed on barley and triticale. More can be expected from these crops.

(4) These activities led to cereal crops of about 1.4 million tons in 1976 and 1977, compared with 800,000 tons a decade earlier. The gain can be credited partly to weather, partly to national policies, and partly to excellent research. Tunisia was the bread basket of the Roman Empire and it is again exporting to Rome.

CIMMYT's 5 scientists posted in Tunisia in the late 1960's were gradually reduced and the last resident scientist was withdrawn in 1977.

CIMMYT staff will continue to pay short visits.

Algerian national cereals program

Algeria's population of 18.3 millions (1978) has been increasing by 3.2 percent a year. Algeria experienced a decade of food deficits prior to the mid-1970's; during this period grain imports ranged from 0.7 to 1.7 million tons a year and the cost of imported food rose as high as US$250 millions in one year.

In 1976 Algeria achieved an all-time record harvest estimated at 2.9 million tons, partly attributable to good weather, partly to good government policies, partly to good research. In 1977 grain production was only about 1.5 million tons. This was mainly due to severe drought and freezing during critical crop phases.

Starting in 1971 CIMMYT assigned a team of wheat scientists to collaborate with the Algerian national cereals program. FAO and Caisse Centrale of France also lent technical staff.

An ambitious training program during 1971-77 sent more than 60 Algerians abroad, including 42 for in-service training at CIMMYT-Mexico, and others for advanced academic study in France, Australia, USA, UK, Yugoslavia, and Canada. By 1980 a core of 15 postgraduate scientists are expected to be in place, leading the research activities. The program emphasis is on development of new high yielding varieties for durums and bread wheats, and new production technology.

By 1977 the Algerian Government considered its biggest problem to be the yield gap between the research station and the farmers' fields — yields of three to six tons in experimental plots compared to 0.8 to 1.8 tons in production fields. A workshop between Algerian and CIMMYT scientists recommended on-farm demonstrations to display to farmers the needed production practices for seed bed preparation, weed control, fertilizer strategies, and choice of variety. This program is now underway in 1978.

Another workshop dealing with the role of pathology in varietal improvement was held at Algiers in March 1977, attended by 25 Algerian wheat scientists.

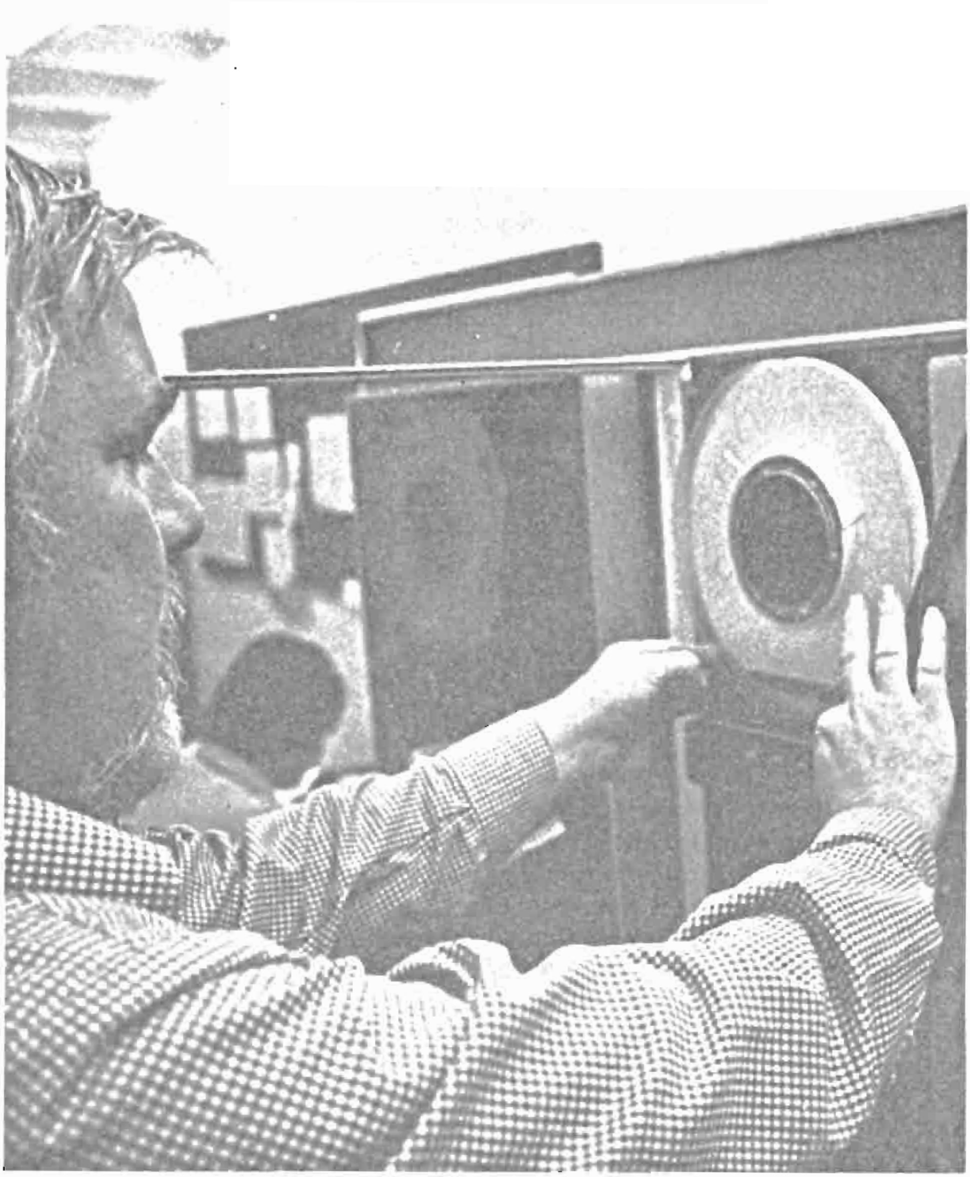
Nepal national wheat-maize program

CIMMYT assigned a wheat agronomist to Nepal for the period 1976-77. (Background information on Nepal's grain production is given in the maize section of this report).

CIMMYT gave training in Mexico to seven young Nepali wheat scientists during 1971-77, who now work on the staff which tests the annual wheat and barley nurseries from Mexico, conducts local breeding, and places trials on private farmers' fields.

The CIMMYT wheat scientist in Nepal concluded his assignment during 1977.

supporting services



Economic Studies

The Economics Group at CIMMYT participate in CIMMYT's central objective — to help nations develop and disseminate improved technology for maize and wheat. The economist does this by working with biological scientists and policy makers to make technology and policy more consistent with the circumstances of farmers, by joining with CIMMYT maize and wheat staff in their training programs, and by collaborating with maize and wheat staff on special projects.

Technology adapted to farmers

Economists at CIMMYT believe that farmers' decisions are dominated by three sets of forces — physical, biological and economic. Other factors may impinge on farmers' decisions, but their influence is usually minor compared with that of the three dominant factors. It follows, therefore, that a knowledge of these three influences at the farmers' level must orient the research of agricultural scientists, if the resulting technologies are to be made acceptable to farmers. Given this concept, economists at CIMMYT encourage collaborative research between biological scientists and economists on the circumstances of farmers and on markets which serve them.

The aim is to bring about close cooperation between the biological scientists working on crops in national programs, and indigenous economists in the same country. The biologist can contribute his knowledge of agro-climatic factors interacting with the crops at critical stages in plant development. The economist can bring his sensitivity to farmers' goals and constraints, his awareness of alternative uses for farmers resources, and his concern for markets. The economist also supplies knowledge of survey techniques, of data analysis, and of policy issues important to national programs.

The economist helps to organize surveys which are designed to obtain information about why farmers manage their enterprises the way they do, what compromises are forced on farmers by their circumstances, and what are their perceptions of factors limiting production. This information helps identify major needs and opportunities within the farming system.

Several studies of this kind have been completed and others are underway. In Egypt, for example, a survey showed that few farmers use the planting practices recommended by scientists. New trials have now been designed for use on farmers' fields, to test side-by-side the farmers' planting practices and those recommended by the scientists, to see the effects of each upon yields and upon returns from other practices being recommended.

Similarly in Ecuador, revised trials on private farm land combine improved practices proposed by scientists with representative practices used by farmers. Farmers, biological scientists, and economists review the resulting crop. These reviews guide future research on experiment stations and serve to improve the practices chosen for testing.

Participating biologists have used the completed studies to reshape their research, sometimes changing the thrust of their earlier work, sometimes finding new opportunities for collaboration with farmers. The findings of these studies have been incorporated into new technologies, and have been referred to agricultural decision makers when policies are brought into question.

Initially all CIMMYT economists working on these studies were based in Mexico and travelled to developing countries. As the number of studies increased, some economists were posted to maize and wheat production regions outside Mexico, where they are closer to national institutions.

Regional economists

The concept of regional economists was approved by CIMMYT Trustees in 1975. By 1978 economists had been posted to four regions.

The first regional economist went to eastern Africa in 1976 with funding from UNDP. His work concentrated initially in Kenya and Tanzania, where seven surveys combining national crop staff and local economists had been undertaken through 1977. Studies in other countries of eastern Africa are being discussed.

A second regional economist was posted in the Andean Region in 1977 for cooperative work in Columbia, Ecuador, Peru, and Bolivia. His initial work concentrated on floury maize production systems, a dominant food crop in the highlands, and on wheat, a secondary crop in that area. Six surveys were completed by 1977. In one study the importance of the maize-potato rotation led to a joint CIMMYT/CIP study.

A third regional economist began work in Central America in 1977 from his base at CIMMYT-Mexico. The first joint study in this region was centered on Honduras. Other studies in this region will follow.

The fourth regional economist is stationed in Asia, starting in 1978, and is focusing his work on Pakistan, northern India, Nepal, Bangladesh, and Thailand.

In each regional program, the CIMMYT economist finds biological collaborators in the national crop programs, while collaborating economists are found in a variety of institutions, mostly schools of agriculture. One national crop program in East Africa decided to add a substantial economics section to its crop work, after a year's experience with collaborative research.

CIMMYT is preparing a manual to assist those engaged in joint efforts between crop scientist and economists.

Training

The Economics Group participates in the training of agriculturalists in three ways — by working with CIMMYT wheat and maize training programs in Mexico, by helping regional programs in their special training sessions, and, more generally, by preparing materials of special interest to agronomists. The aim is to bring to the attention of agriculturalists the dominant forces in farmers' decision making. These forces — physical, biological, and economic — can then be integrated into the research plans and into recommendations and demonstrations for farmers.

Training also demonstrates how to gather data on what farmers are doing, on what is happening in the markets, and evaluating data from the farmer's view point. We take the trainee to grain markets, to fertilizer supply centers, to credit agencies. The emphasis is on learning more about the environment in which the farmer makes his decisions.

National program reviews

In 1977 national officials of Algeria and Tunisia invited CIMMYT to offer suggestions on ways in which their wheat production could be expanded faster. CIMMYT scientists had been collaborating in Algeria for seven years and in Tunisia for nine years, concentrating on varietal improvement and agronomic practices. National officials asked CIMMYT to examine their entire wheat economy.

CIMMYT biological scientists and economists jointly prepared background papers, participated in a workshop on each country, and prepared recommendations to national officials.

The experience suggested new ways for collaboration with national programs and for collaboration within CIMMYT.

Seminars involving senior agricultural policy makers

During 1977 CIMMYT Trustees asked the staff to begin a new activity — organizing a series of seminars among agricultural policy makers from developing countries.

The reasoning behind this initiative was: (1) improved technology for maize and wheat has proved to be only one factor in raising food production; (2) sound agricultural policies are equally important in assisting farmers; (3) policy makers can exchange experiences on decision making if given opportunity to meet together; and (4) CIMMYT is an appropriate institution to sponsor gatherings among policy makers.

Following this thought, the Trustees approved a 3-year project in which the first year (1978) would be devoted to the preparation of case studies, and the remaining two years to seminars bringing together senior agricultural policy makers — about three seminars a year, each lasting 2-3 weeks, each with 30-35 participants. Major themes of the seminars would be the critical importance of farmer circumstances and of technical relationships in policies relating to the development and diffusion of new technology.

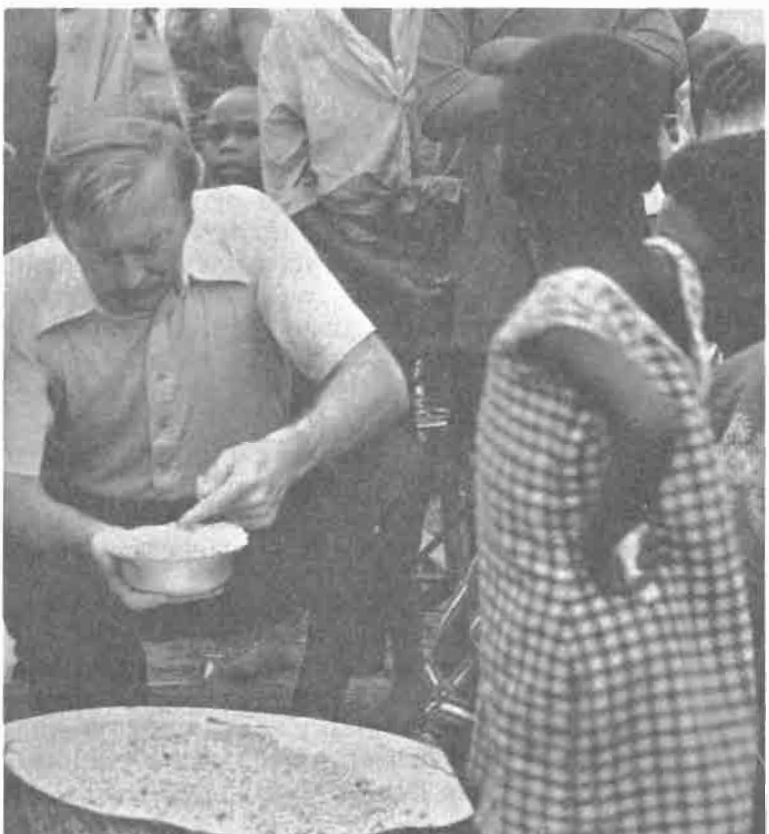
For purposes of these seminars agricultural policy makers are described as public officials below the rank of vice-minister and in positions of leadership for crop research, agricultural extension, agricultural credit, input supply and subsidy, price support and storage programs, and other public policy areas which influence the diffusion of new agricultural technology. Since many of these decisions are made outside of Ministries of Agriculture, participants will come from a broad range of Ministries.

CIMMYT Economics Group was asked to provide leadership in this project, to enlist the skills of outside specialists in case studies, and to involve the CIMMYT maize and wheat staffs as appropriate. Other centers have been asked to share in the planning and presentation of the seminars.

At the end of three years the Trustees will evaluate whether the seminars should continue in their initial form, and whether CIMMYT is still the appropriate sponsor for the seminars.

Predoctoral fellows in economics

During 1977 two doctoral candidates working at CIMMYT completed dissertations. One thesis concentrated on yield losses in maize caused by diseases and pests and indicated how these losses might influence the strategy of the maize breeder. The second dealt with farmer response to alternative maize markets in the lowland tropics of Mexico. Two additional thesis efforts are being sponsored in 1978.



Don Winklemann, head of CIMMYT's Economics group, examines maize quality in Zairian market.

Laboratory Services

CIMMYT maintains laboratories which perform central services for all crop programs.

Protein quality laboratory

The Protein Quality Laboratory analyzed approximately 23,000 samples of grain in 1977, of which about 75% were maize, 15% triticale, 6% wheat and 4% barley.

In maize, the laboratory analyzes most samples for total protein and for the amino acid tryptophan. Micro-Kjeldahl and colorimetric procedures are employed to obtain these two measurements in the endosperm protein. Since lysine content is highly correlated with tryptophan level, lysine levels are measured only for the samples which have already been found to have outstanding tryptophan content. This saves time and cost.

In 1977 the dye binding capacity method (DBC) was used to measure protein quality in 900 whole kernel maize samples from advanced lines.

For floury maize from the Andean region, the ninhydrin (chemical) test is used to determine the level of free amino acids as a means of selecting those with higher lysine content.

In samples of triticale, wheat, and barley, total protein (nitrogen content) and protein quality (DBC procedure) are analyzed. For the most promising 1450 of these, lysine was measured more accurately by the ion exchange chromatography procedure.

Complete amino acid analysis was performed on only 24 outstanding samples from all the programs.

The above work assists the crop scientists in selecting the best seeds for further crossing, and in rejecting inferior materials.

Biological evaluation

CIMMYT no longer maintains an animal feeding laboratory but contracts with outside organizations for biological feeding trials. In 1977 the most promising six triticales and seven corns were tested using animals at the Mexican National Institute of Animal Research and the Danish Agricultural Experimental Laboratory.

Training and consulting

During 1977 protein laboratory technicians from five countries received training in the CIMMYT protein laboratory in Mexico (Ecuador 1, Pakistan 1, Peru 1, Philippines 1, and Thailand 1). CIMMYT biochemists visited protein laboratories in three developing countries (Egypt, Ecuador, and Guatemala) to advise on testing procedures and equipment. In this way CIMMYT keeps in touch with a network of laboratories.

Soil and plant nutrition laboratory

This laboratory ran tests in 1977 on more than 10,000 samples of soil, water and plant materials submitted by CIMMYT program units.

Included were 3458 soil samples studied for pH, organic matter, nitrogen, calcium, magnesium, potassium, phosphorus, micro-elements, nitrates, electric conductivity or cation exchange capacity. Most of the studies served as background for fertilizer trials. The work was requested by CIMMYT program units in Agronomy, Physiology, Experiment Stations, and Training.

Thirteen samples of irrigation water were analyzed for soluble salts, sodium, and boron.

The plant nutrition side of the laboratory studied 6802 samples of vegetal tissue and grain. Most measurements were for nitrogen, to determine the uptake of fertilizer; or for sugars, to determine the yield limiting factors in crop varieties.

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Experiment Station Management

CIMMYT has conducted research at seven stations in Mexico during 1977 and 1978. Three are under Mexico's National Agricultural Research Institute (INIA), and four under CIMMYT. Some characteristics of these stations:

Station	Elevation	Latitude	Hectares used by CIMMYT
CIANO-INIA	39 m	27° N	165
Los Mochis-INIA	40 m	26° N	2
Rio Bravo-INIA	30 m	26° N	1
El Batan-CIMMYT	2240 m	19° N	66
Toluca-CIMMYT	2640 m	19° N	69
Poza Rica-CIMMYT	60 m	20° N	42 (twice a year)
Tlaltizapan-CIMMYT	940 m	18° N	31 (twice a year)

The four stations operated by CIMMYT are fully developed, with land fenced, levelled, provided with field roads, equipped with drainage and irrigation facilities, and crop buildings.

El Batan station is testing new herbicides to identify chemicals compatible with both maize and wheat, because some herbicides previously applied to maize do not allow rotation of land with wheat.

At Toluca station a shortage of irrigation water has been corrected with a deep well. A new drainage and irrigation scheme is being implemented.

At Poza Rica station, a flood control wall along the Poza Rica river was build after a flood in 1975, and further reinforced during 1977.

Training and consulting

Since 1973, persons interested in experiment stations management from 24 countries have received training at CIMMYT's stations in Mexico for periods of two weeks to six months. During 1977, 43 training participants came from: Bangladesh 1, Costa Rica 2, Egypt 2, Kenya 1, Tunis 1, Pakistan 3, Yemen 1, Honduras 3, Mexico 7, Syria 4, Colombia 4, Zaire 2, Tanzania 2, India 1, Guatemala 2, Caribbean countries 7.

The Head of CIMMYT's experiment stations spends a period each year as consultant to national programs, which in 1977 included a month and a half in Egypt, Honduras, Kenya, and Tanzania. Training and consultation in station management has so increased in volume that CIMMYT added a Training Officer for this purpose at El Batan in 1977.

Statistical Services

Services of the statistical unit expanded greatly in 1977-78.

For the first time the international yield nurseries of the wheat program were analyzed within CIMMYT on its own computer equipment, using computer programs developed at the University of Colorado. With minor alterations, these nurseries can now be handled satisfactorily.

CIMMYT staff developed a series of computer programs for summarizing the wheat screening nurseries, which are unreplicated observation trials with more than 300 entries, and scores of testing sites.

Maize international trials have been analyzed in-house for several years and continued to be printed directly from the computer in 1977. An improved "filter" system now examines maize field data for improbable values.

An inventory of the seed in CIMMYT's maize germ plasm bank has been placed on the Nova computer, and is undergoing trial. In operation, this will simplify the task of managing the bank, preparing invoices for seed shipments, and preparing reports.

The Statistical Unit found more time in 1977 to give service to a wide range of users in design and analysis of field experiments. Many wheat variety trials and maize protein trials were analyzed by machine for the first time. Several trials from CIMMYT outreach program were also processed by the statisticians at El Batan.

Information Services

Fifteen new titles were published during 1977. In addition, the general information booklet, This is CIMMYT, was revised and reissued. Most bulletins. reports, and reprints were published in two languages (English and Spanish).

Publications Issued by CIMMYT 1977

Title	Language	Pages	Press Run
Wheat			
Results of the 7th International Durum Screening Nursery	E-S-F *	16	1,000
Field manual of common wheat diseases and pests	English	68	7,500
	Spanish	68	7,500
Grain production potentials in developing countries: World implications	English	68	500
A second look at the Green Revolution	English	76	500
Genealogies of 14,000 wheat varieties	English	119	2,000
Maize			
Maize training in the International Maize and Wheat Improvement Center	English	4	517
CIMMYT 1975 Maize Improvement	English	64	2,000
Maize improvement: A multi-disciplinary approach	English	4	500
	Spanish	4	1,100
Current status of plant resources and utilization	Spanish	5	1,000
Economics			
Maize production patterns in southern Zaire	English	12	1,000
Notes on the role of rural Pakistani women in farming in the northwest frontier province	English	4	1,000
Administration			
This is CIMMYT	English	32	10,000
	Spanish	32	5,000
CIMMYT Review 1977	English	99	6,240
CIMMYT Today: Turkey's wheat research and training project	English	20	5,250
	Spanish	20	4,800
Miscellaneous			
Soils derived from Volcanic Ash in Japan	English	102	2,000

* English, Spanish and French

The serial, CIMMYT Today, continued with one issue published during the year. Articles in CIMMYT Today treat broad aspects of CIMMYT's activities for the informed layman.

The Commonwealth Agricultural Bureau (UK) issued on behalf of CIMMYT, Volume 3 of the Maize Quality Protein Abstracts, and Volume 3 of Triticale Abstracts. About 650 maize scientists receive MQPA and about 400 scientists receive TA.

Mailing list

CIMMYT's general mailing list for publications now contains 4600 addresses classified by interest: 25 percent wheat specialists, 25 percent maize specialists, 38 percent general agriculturalists and 12 percent libraries; by language: half English and half Spanish; by geographic area: 8 percent Europe, 42 percent Latin America, 25 percent North America, 8 percent Africa, 27 percent Asia and Oceania.

A separate mailing list is maintained for economics publications.

Audio visuals

The permanent exhibit in the administration building continues to grow; new displays were added in 1977. The exhibit depicts CIMMYT's activities in increasing world food supply. The audiovisual section continued its support of the crop programs with art work, photography, and a film archive.

Visitors service

In 1977 over 9,000 visitors from 60 countries were registered at CIMMYT headquarters, individually or in groups. Many others visited CIMMYT research stations away from El Batan, where no records are kept. A number of busloads of visitors were sent to El Batan by agribusiness in the U.S. The Visitors Service gives these tour groups a slide lecture and brief walking tour of the headquarters.

Library services

CIMMYT's small working library (3360 volumes, 762 serials) continued to offer services to the headquarters staff, postdoctoral fellows, and 100 training fellows. There were 4600 individual visits to the library in 1977. The library also serves as liaison with Mexico's National Agricultural Library (73,000 volumes, 1,400 serials) which is located 10 km from CIMMYT.

Special Report:
Leaf Rust Epidemic in Mexico 1977

A severe epidemic of leaf rust (*Puccinia recondita*) affected commercial fields of the bread wheat variety Jupateco 73 in northwestern Mexico during the winter season 1976-1977. This was the first severe rust epidemic in Mexico since the 1950's, and provided some lessons on rust control both for the Government of Mexico and for CIMMYT.

Leaf rust is endemic in the Mexican northwest states where about 70% of the Mexican wheat crop is produced on 350,000 hectares of irrigated land.

In most years first symptoms of leaf rust appear on susceptible varieties in early March and the peak of the infection is reached 4 to 5 weeks later, about the first week of April. Crop losses from leaf rust were slight during years preceding the 1977 epidemic.

In 1977 leaf rust appeared in January in Sonora State. CIMMYT pathologists were invited by the Mexican Ministry of Agriculture and Water Resources to participate in an emergency rust survey of the northwest. All commercial fields of the variety Jupateco 73 were found to be attacked by leaf rust, whereas fields of the variety Torim 73, interspersed among the fields of Jupateco, were resistant. Both Jupateco 73 and Torim 73 are varieties bred by CIMMYT-INIA.

Around Huatabampo, a town in Sonora State 50 kilometers south of Cd. Obregon, the infection on Jupateco 73 reached an infection rate of 70S over large planted areas (the rating 70S means that fungus covered 70% of the leaf area of the plant which it is possible to cover with susceptible pustules). Around Cd. Obregon and toward the coast, 20 kilometers from Obregon, the infection level varied according to the planting date of the crop. But invariably Jupateco 73 was infected.

In the valley of El Carrizo, 200 kilometers south of Cd. Obregon, the infection was even worse, because of the earlier planting of wheat and more humid environment. The attack at El Carrizo indicated that rust was widely present in December 1976, and had increased massively on the early commercial crops. Leaf rust may cause 80-100 percent loss of yield when young plants are attacked before the boot stage.

The survey concluded that a series of interacting factors in 1976-77 had caused the epidemic:

(1) 70% of the wheat area was planted with a single variety, Jupateco 73. Since its release in 1973 Jupateco showed resistant reactions in most plants, segregating to rare plants which had susceptible reactions. Thus, virulent biotypes of the fungus were known to be present as early as 1973 and increased their prevalence in subsequent years. New races of a fungus do not "explode" from one season to the next, but build up gradually.

(2) Because water in the nearby irrigation reservoirs was at a record low level in 1976-77 due to several years of drought, the cropping area in the summer of 1976 had been reduced to a minimum. Land preparation after the wheat harvest in the spring of 1976 was postponed or done poorly, and numerous volunteer wheat plants grew from residual moisture. These "wild" wheats carried active inoculum throughout the 1976 summer within the commercial cropping area.

(3) Farmers in Huatabampo and along the coast took advantage of the rains of hurricane Liza (September 1976) and planted wheat immediately. The gap between the wheat harvest in May 1976 and the normal recommended dates for planting (November 15 to December 15) was thus reduced by almost 2 months. These early plantings received inoculum from the volunteer plants and developed severe rust symptoms at tillering.

(4) Late plantings, up until January 20, 1977 were also common in the area as a consequence of problems in land tenure at the end of 1976. The potential damage of the epidemic increased with these late plantings, in view of the massive amounts of inoculum already present, and the heightened susceptibility of Jupateco 73 at tillering stage and earlier.

(5) Mild temperatures and abundant moisture through the autumn of 1976 favored the production of several generations of infective spores. Thereafter inoculum increased rapidly on the early wheat plantings.

To minimize losses from leaf rust, the Agency for Agriculture in Cd. Obregon adopted several measures of control in 1977:

(a) A prompt survey of farmers fields was made to assess the extent of the epidemic and the stage of development of wheat plantings.

(b) Fields with advanced rust at boot stage, or earlier, were plowed under and planted to safflower. Some 15,000 hectares of wheat were destroyed for this reason at Huatabampo.

(c) In mid-February, fungicidal spraying of the epidemic area was carried out, with emphasis on protecting late plantings. Two fungicides were recommended in spite of the limited experimental evidence for their effectiveness in the northwest area: Indar 70LC and Bayleton 25WP. Both are systemic fungicides and offer some eradicative properties. They protect the plants up to approximately 40 and 25 days respectively. Indar is highly specific against leaf rust, and Bayleton controls a wider spectrum of pathogens including leaf rust.

Some observations can be drawn from the results of this spray campaign:

Farmers in El Carrizo, where no fungicides were applied, obtained low yields of 800 kg/ha or less of poorly filled grain.

In Yaqui Valley the sprayed plots yielded over 5 tons/ha which is significantly higher than the non-sprayed plots in 1977 experiments performed on a semi-commercial scale. It was generally observed that protected younger crops offered higher yields than those which were planted earlier, hence were more advanced and more rusted at the time of spraying.

Exact figures on grain saved as a result of the spraying campaign will be difficult to obtain due to the diverse dates of planting, but there is no doubt that systemic chemical fungicides were successful in controlling the epidemic of leaf rust. "Control" here means diminished yield losses, not eradication of the disease.

Looking ahead, measures other than fungicides were suggested to avoid repetition of the 1977 epidemic: timely plantings, control of volunteer wheats, intensive studies on the fungus virulence, ensuring availability of seed of new varieties, and some sort of legislation to restrict the planting of a single genotype.

Santiago Fuentes

Impact of High Yielding Wheat Package In Less Developed Countries During The Crop Year 1976-77

The U.S. Department of Agriculture is publishing in 1978 the sixth edition of its widely quoted publication, "Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations." This study is the work of Dr. Dana G. Dalrymple, economic researcher for the U.S. Government and long-time analyst of agricultural changes in developing countries. Darlymple made available to CIMMYT the wheat data in his latest study, and CIMMYT is able to summarize here some findings based upon Dalrymple's work, supplemented by previously published information concerning the short wheats.

Word of caution:

In his introduction Dalrymple asks the reader to treat the data on high yielding varieties as approximate, because not all the information is based upon the same definitions, or the same precise time period, or the same quality of crop reporting. The study, nevertheless, offers the most comprehensive data available, and provides a useful measure of the impact of the semi-dwarf grain varieties in one crop year: 1976-77.

How widely are the new wheats grown?

Dalrymple received reports indicating that 29.4 million hectares of the HYV wheats were harvested in 24 developing countries in the crop year 1976-77 (July-June). Other developing countries are known to be planting HYV wheats but have been omitted from the summary for lack of firm information. The report also omits all communist countries, plus Taiwan and Isarel.

The last previous edition of this study (1976) found 19.3 million hectares of HYV wheats in 15 countries in crop year 1974-75. The countries surveyed in 1976 and 1978 are not identical, hence the increased spread of the short wheats from 19.3 million hectares (1976) to 29.4 million hectares (1978) did not occur only in the two-year period.

High-yielding varieties now cover 48 per cent of total wheat area in the 24 countries reported by Dalrymple.

Table 1. Estimated area of high yielding wheat varieties grown in 24 developing countries, 1976-77 (July-June).

Region and country	1976-77 Hectares in HYV Wheat [1]	1976-77 Total Hectares in wheat	1976-77 Percentage of hectares in HYV wheat
South Asia			
Bangladesh	116,600	160,000	73%
India	14,696,000	20,454,000	72%
Nepal	254,200	348,000	73%
Pakistan	4,606,000	6,111,000	75%
Sub-total, 4 countries	19,672,800	27,073,000	73%
Mideast			
Afghanistan	770,000	3,000,000	26%
Algeria	400,000	2,150,000	19%
Cyprus	29,000	65,000	45%
Egypt	125,500	586,000	21%
Iran	150,000	5,000,000	3%
Lebonon	25,000	60,000	41%
Morocco	300,000	1,921,000	15%
Saudi Arabia	33,400	57,000	59%
Tunisia	228,400	1,050,000	22%
Turkey	1,300,000	8,600,000	15%
Sub-total, 10 countries	4,400,000 (rounded)[2]	22,489,000	20%
Tropical Africa			
Kenya	23,300	120,000	19%
Nigeria	3,200	5,000	64%
Rhodesia	15,000	28,000	54%
Sudan	150,500	200,000	75%
Sub-total, 4 countries	225,000 (rounded)[2]	353,000	64%
Latin America			
Argentina	2,900,000	6,428,000	45%
Brazil	650,000	3,624,000	18%
Chile	193,000	628,000	31%
Guatemala	35,000	48,000	73%
Mexico	785,000	885,000	89%
Peru	1,000	140,000	1%
Sub-total, 6 countries	5,100,000 (rounded)[2]	11,753,000	43%
Total, 24 countries	29,397,000	61,668,000	48%

Sources:
(1) Hectares of HYV wheat from Dalrymple.
(2) Total wheat hectares from USDA Circular FG 8-78, May 17, 1978.
(3) Percentages extrapolated.

Footnotes:
1/ Although hectares of HYV wheat for crop year 1976-77 are used when available, data from nearest available year are substituted when necessary.
2/ Sub-totals for Mideast, Tropical Africa and Latin America under column for HYV hectares were rounded by author to adjust for uncertain data.

Table 1 summarizes HYV wheat performance in 1976-77 as reported to Dalrymple. Seven nations are identified as now using HYV to plant more than 70 per cent of their total wheat crop; these are: Mexico 89 percent, Pakistan 75 percent, Sudan 75 percent, Bangladesh 73 percent, Nepal 73 percent, Guatemala 73 percent, India 72 percent.

If comparison is made for greatest number of hectares, India and Pakistan lead the world with 14.7 and 4.6 million hectares, respectively.

The 12-year adoption pattern:

The year-by-year increase since 1965 of the HYV of wheat cannot be measured for all 24 countries. Data are not adequate. But such a record is complete for the four South Asian countries in the survey, and the Asian experience may be indicative for other countries.

Table 2 shows the 12-year adoption record for wheat in four Asian countries. The HYV continued to spread on a straight line projection more or less, through the first decade, then began to slow down.

Table 2. Estimated spreading of high yielding wheats in South Asia 1965-77, as a percengae of total wheat in each country.

	Bangladesh		India		Nepal		Pakistan	
Year	000 ha	%	000 ha	%	000 ha	%	000 ha	%
65-66	–	–	3	*	1	1	5	*
66-67	–	–	540	4	6	5	101	2
67-68	–	–	2942	20	24	13	957	16
68-69	8	7	4792	30	53	26	2387	38
69-70	9	7	5004	30	75	34	1681	43
70-71	13	12	6542	36	98	43	3128	52
71-72	15	12	7868	41	115	52	3286	57
72-73	21	18	10007	51	170	66	3375	56
73-74	29	23	10911	57	206	76	3472	59
74-75	33	23	11778	62	246	85	3682	62
75-76	108	71	13458	70	234	78	4016	69
76-77	116	73	14696	72	254	75	4606	75

Sources: (1) Hectares of HYV from Dalrymple.
(2) Total hectares of wheat from U.S. Department of Agriculture.
(3) Percentage extrapolated.

What is average yield increase from the HYV package?

Average yields of high yielding wheats showed their greatest increase over traditional wheats in the early years of adoption, when some of the best land, best irrigation, and most enterprising farmers were involved. But as the proportion of total wheat land planted to the new varieties increased, average yield increase declined.

For example, in India the high-yielding package outproduced the traditional varieties by 200 percent during 1965-70 (roughly 2400 kg/ha compared to 800 kg/ha). But at the end of eight years, the increase had dropped to 125 percent, and was still declining as the planted area grew. This was predictable.

Another study of both India and Pakistan concluded that national average yields of wheat rose 50 percent in the two countries between 1966 and 1973. This covered both HYV and traditional varieties.

By 1974, Dr. Dana Dalrymple concluded that high yielding wheats were outproducing traditional wheats, across many countries, by a factor of 1.50 (that is, one hectare of HYV package was yielding 1.5 times the yield of traditional wheats).

This conservative figure will be used later in this paper for calculating impact.

What is the impact of HYV wheat package?

Before answering this question it is necessary to restate the process of the agricultural revolution that began with the use of the high yielding cereals in the 1960's.

Impact of a "package" involves not only the wheat varieties themselves but the production practices which have accompanied the varieties, and the improved national services which were stimulated by the varieties. These factors will be examined here as a single impact.

The new wheat varieties, it is now recognized, are more efficient in the use of water and fertilizer, thus making it more profitable for the farmer to install a tubewell or apply fertilizer and herbicide, or expand his hectares of wheat. Similarly it is more productive for a government to provide a larger supply of agricultural chemicals or a support price for wheat.

Therefore, let it be clear that the changes in wheat production, described here, were achieved by 24 national wheat programs, supported by a network of wheat scientists, world-wide, in which CIMMYT played a part, but only one part.

Conceived in this manner, the impact of the high yielding wheat package can be measured in several ways, none of them very precise.

Measuring impact.

(1) The 24 developing countries in the Dalrymple study increased their annual wheat production from 45 to 86 million metric tons during the period covered by the Dalrymple study (see Table 3). This calculation uses 1961-65 average annual wheat production in 24 countries as the base period, and the year 1976-77 as the terminal year. In other words, annual wheat production in the 24 countries had increased by 41 million metric tons at the end of the period.

(2) The 41 million tons of wheat could provide the carbohydrates for a diet to feed 250 million people in developing countries for one year, The calculation is based on three premises: (a) that a kilogram of wheat contains 3300 calories; (b) that people in developing countries now consume 2200 calories per day; and (c) two-thirds of this average diet, or about 1500 calories, consists of cereals or tubers.

(3) Not all the 41 million tons of added wheat can be attributed to the HYV package. We lack precise harvest data on the HYV package, but there are several methods by which we can approximate the production.

(a) First, we can use land areas planted in wheat. Table 1 shows 48 percent of wheat in the 24 countries in 1976-77 was planted with the HYV package, at least 48 percent of the harvest is attributable to the HYV package (48 percent of 41 million tons = 19.9 million tons). That is a very conservative estimate, because it assumes that the yield per hectare of the HYV package and the traditional package were the same.

Table 3. Wheat performance in 24 developing countries which introduced the high-yielding wheat package during the twelve years 1965-77.

Region & Country	Area of wheat (Hectares 1000s) 61-65 (Aver).	76-77	Increase	Yield of wheat (Kilos /hectare) 61-65 (Aver.)	76-77	Increase	Production of wheat (Tons 1000 s) 61-65 (Aver.)	76-77	Increase
South Asia									
Bangladesh	60	160		609	1,630		37	260	
India	13,402	20,464		835	1,410		11,191	28,846	
Nepal	109	348		1,236	1,040		135	362	
Pakistan	4,984	6,111		833	1,420		4,153	8,690	
Sub-total	18,555	27,073	46%	839	1,410	68%	15,516	38,158	146%
Mideast									
Afghanistan	2,321	3,000		951	980		2,202	2,940	
Algeria	1,971	2,150		636	930		1,254	2,000	
Cyprus	69	65		908	1,000		63	65	
Egypt	557	586		2,621	3,360		1,459	1,970	
Iran	3,580	5,000		802	1,100		2,873	5,500	
Lebanon	68	60		939	670		64	40	
Morocco	1,578	1,921		847	1,110		1,336	2,135	
Saudi Arabia	94	57		1,528	3,600		143	205	
Tunisia	1,002	1,050		494	810		495	850	
Turkey	7,959	8,600		1,079	1,510		8,585	13,000	
Sub-total	19,199	22,489	17%	962	1,276	33%	18,494	28,705	55%
Tropical Africa									
Kenya	103	120		1,183	1,500		122	180	
Nigeria	6	5		2,690	1,400		16	7	
Rhodesia	1	28		2,170	3,040		2	85	
Sudan	27	200		1,308	1,510		36	301	
Sub-total	137	353	158%	1,284	1,652	29%	176	573	226%
Latin America									
Argentina	4,916	6,428		1,534	1,710		7,541	11,000	
Brazil	812	3,624		707	830		574	3,000	
Chile	753	628		1,437	1,940		1,082	1,219	
Guatemala	35	48		879	900		31	43	
Mexico	802	885		2,085	3,790		1,672	3,350	
Peru	153	140		982	1,060		150	148	
Sub total	7,471	11,753	57%	1,479	1,590	8%	11,050	18,760	71%
Total, 24 countries	45,362	61,668	37%	968	1,396	44%	45,216	86,196	91%

Sources: (1) Area and production for 1961-65 from FAO Production Yearbook.
(2) Area and production for 1976-77 crop year (JulyJune) from U.S. Department of Agriculture, Foreign Agricultural Circular FG 8-78, May 17, 1978.
(3) Yields extrapolated from area and production.

(b) A second method compares countries which used the HYV package and those that did not. For this tests we chose six developing countries each of which grew an average of 800,000 hectares of wheat in 1976-77, and did not report significant use of the HYV package. These six countries increased their wheat production by 35 percent between 1961-65 (base line) and 1976-77 (test year). We assume that the same 35 percent improvement could have occurred in Dalrymple's 24 countries in the absence of the HYV package. Therefore we attribute the other 65 percent of wheat improvement to the HYV package. That equals 26.7 million tons increase attributable to the HYV package for the test year.

These approaches, (a) and (b), give different answers of ascending magnitude —19.9 million and 26.7 million tons of wheat. Both answers are highly creditable to the HYV package. The average of the answers is about 23.3 million tons.

How much is the increased wheat worth?

If the 24 developing countries had imported the additional wheat instead of producing it with the high yielding package, they would have spent about US$3.3 billions in foreign exchange on additional grain imports in the single year 1976-77. This calculation is based on a price of $140 a ton, the average price of U.S. and Canadian wheats moving in international trade, CIF Amsterdam, during 1976-77.

The estimate of US$3.3 billion is not, of course, a net saving. The farmers in these 24 countries incurred expense for seed, fertilizer and machinery and added their own labor. Nevertheless, the net savings to the 24 countries obviously runs to hundreds of millions of dollars per year.

What about the future?

The number of future adopters for HYV will slow down in India and Pakistan and any country where HYV are already planted on 50-90 percent of total wheat land. This does not mean a slowdown of benefits from the high-yielding package. Benefits will not only continue, but probably grow.

Take Mexico for example. The planting of HYV of wheat in Mexico increased to 90 percent of total wheat land in the 1960s and remained at about 90 percent during the 1970s. Yet Mexico's average yield of wheat per hectare continued to climb in the 1970s as better varieties, better production practices (especially more fertilizer), and better government services were introduced in the 1970s. Here is how the Mexican yields of wheat appear in the FAO Production Yearbook:

Average Yields in Mexico

1961-65	2085 kg/ha
1966-70	2683
1971-75	3246
1976	4202

Mexico doubled its average wheat yield in the 1970s, after already doubling its average yield in the 1960s. Clearly, when a country adopts its first generation of HYV wheat, the process of rising yield is only beginning. It is the aim of each national wheat program and the network of wheat scientists world-wide to ensure that the benefits continue to mount.

1977 CIMMYT INCOME AND EXPENDITURES
(Except from CIMMYT Auditors Report 1977)

	Thousand US$
Core unrestricted income	**8,568**
Canadian International Development Agency	1,048
Denmark	179
Federal Republic of Germany	437
Ford Foundation	350
Inter-American Development Bank	2,620
International Bank for Reconstruction and Development	150
Iran	350
Rockefeller Foundation	400
Saudi Arabia	150
United Kingdom	284
U.S. Agency for International Development	2,600
Core restricted income	**2,734**
Canadian International Development Agency Andean Region and East Africa	533
Federal Republic of Germany Collaborative Research	36
Japan Wheat Pathology	150
Netherlands Wheat Disease Surveillance	219
Switzerland Central American and Caribbean Maize	154
U.N. Development Programme Quality Protein Maize and East Africa Economics	1,490
Unexpended balance from previous year	152
Extra core grants and cooperating projects income	**1,304**
Canadian International Development Agency Peru	18
Federal Republic of Germany Training and other	79
Ford Foundation Projects in North Africa, Pakistan and miscellaneous training	330
Inter-American Development Bank — Training	40
International Development Research Centre Triticale Abstracts and ICRISAT Sorghum Project	42
International Potato Center Regional Research	69
Norwegian Agency for International Development Training	29
Rockefeller Foundation — Turkey	8
U.S. Agency for International Development Projects in Nepal, Pakistan, Guatemala, Tanzania, Zaire and miscellaneous training	441
Zaire Government National Maize Project	151
Training and other miscellanous grants	78
Unexpended balance from previous year	19
Earned Income (not included elsewhere)	100
Total income	**12,706**

	Thousand US$
Core operating expenses	**10,027**
Wheat Program	2,204
Maize Program	1,995
Economics	336
Laboratory services	381
Experiment station operations	1,053
Statistical services	134
Conferences and Training	1,149
Information services	386
Administration	1,020
General operations	1,059
Capital acquisitions	267
TAC review	43
Extra core grant and cooperating project expenses	**1,148**
Additions to working capital and reserves	**462**
TOTAL APPLICATION OF FUNDS, 1977	**11,637**
Funds to be applied to 1978 core restricted expenses	**18**
Other funds retained for future application	**1,051**
TOTAL APPLICATION OF FUNDS	**12,706**

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Location and elevations of experiment stations in Mexico at which CIMMYT conducts research (■ stations of the Instituto Nacional de Investigaciones Agricolas).