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BIOTECHNOLOGY AND DEVELOPING COUNTRY AGRICULTURE: MAIZE IN MEXICO

by

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RÉSUMÉ

Aliment de base au Mexique avant la conquête espagnole, le maïs reste une importante source de calories et de protéines dans l'alimentation quotidienne, surtout pour les familles pauvres. Ses modes d'utilisation évoluent cependant, caractérisés par le déclin de la consommation humaine et l'augmentation de son emploi pour l'élevage. Les conditions agro-climatiques de la culture du maïs sont extrêmement diverses, avec de considérables différences de rendement. Les zones de culture pluviale représentent la majorité des terres ensemencées en maïs et fournissent la plus grande partie de la récolte. Le Mexique est devenu un importateur conséquent de maïs en grains et de semences. De ce fait, les priorités politiques portent sur une réduction de ces hauts niveaux d'importation de grains et sur la croissance de la production domestique.

A peine 20 % de l'ensemble des terres, mais la moitié des surfaces irriguées, bénéficient de semences améliorées. Et malgré la grande variabilité génétique du maïs mexicain, plus de la moitié des graines utilisées pendant la saison favorable (printemps-été) appartiennent à seulement cinq variétés améliorées. Il existe donc au Mexique un besoin pressant de diversification des variétés améliorées et des variétés particulièrement adaptées à une localisation précise, si l'on veut augmenter sensiblement la productivité. Les petits exploitants pauvres ont également besoin de semences améliorées, performantes dans leurs conditions de culture.

Les ressources allouées à l'effort public de recherche, y compris les biotechnologies, sont sans commune mesure avec l'ampleur des besoins. La recherche en biotechnologie pourrait contribuer à la caractérisation de lignées de maïs utiles et à l'efficacité des programmes de multiplication. Mais, comme la recherche porte surtout son effort sur la résistance à la sécheresse et aux parasites, les biotechnologies n'ont guère d'effets directs sur les rendements.

SUMMARY

Maize has been a staple food in Mexico since pre-Hispanic times and is still an important source of calories and protein in daily consumption, especially for poor families. The pattern of consumption is nevertheless changing; with the share of food consumption declining and feed utilisation expanding. The agro-climatic conditions of production are highly diverse, with wide ranges in yields and rainfed areas accounting for the major share of total maize area and of total production. Mexico has become an important importer of both maize grain and seed. Reduction of these high levels of grain imports and growth in domestic production are priority policy objectives.

Improved seeds are sown in only one-fifth of the total area cultivated, but half the irrigated area. Despite the wide genetic variability of maize in Mexico only five improved varieties accounted for almost half the improved seed used during the spring/summer

growing season. There is a pressing need in Mexico for a wider diversity of improved varieties and for more location-specific varieties if productivity is to be significantly improved: there is also a pressing need to make improved seed available to small, poor producers.

The resources devoted to the public research effort, including biotechnology, are clearly not commensurate with the magnitude of the task. Biotechnology research could facilitate identifications of maize lines with useful characteristics and improve the efficiency of breeding programmes. However, as the focus of research is essentially on resistance to drought and pests, biotechnology may not have significant direct impact on yields.

PREFACE

This case study of Mexico has been undertaken as part of a research project on "Biotechnology and Developing Country Agriculture: the Case of Maize", carried out in the context of the Development Centre's research programme on "Changing Comparative Advantages in Food and Agriculture". The project, which assesses the prospects for selected developing countries of incorporating new biological techniques in maize production and, by implication, enhancing their competitiveness in maize, focuses on the institutional aspects of technological change in developing countries.

Maize was selected as an eminently suitable subject for examining how new technological developments in industrialised countries "interact" with the situation in developing countries. One of the world's major cereal crops, in many developing countries maize is an important food and/or feed crop for which demand continues to expand; particularly for use as livestock feed; maize is also a crop on which major biological research effort has been focused. This effort resulted in the innovation of hybridization in the 1930s and shows promise with respect to new biotechnologies.

Drs. Jaime Matus, Arturo Puente and Cristina López have contributed this case study of Mexico, which has become an important importer of maize. It traces production and consumption trends, examines Mexico's maize research, technology development and diffusion system and highlights the constraints to appreciable productivity gains in the short-term. In addition to the case of Mexico, the project includes case studies of Brazil, Indonesia and Thailand. It also analyses trends in research on the emerging maize biotechnologies and in the supply, demand and trade of maize internationally. The conclusions and policy implications to be drawn from the project will be published by the OECD in a separate volume by Carliene Brenner.

Louis Emmerij
President
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I. INTRODUCTION

For 15 years, there has been a growing surplus of agricultural products in developed countries, and in most developing countries an increasing deficit in agricultural food products, mainly grains. In Mexico, demand for maize has grown faster than domestic supply and the country has became a net importer. Since maize is a staple food for Mexicans, government policy aims to cut costly imports.

But it has not been possible to reduce imports over the last 10 years, even though production has grown. Can Mexico ever become self-sufficient in maize or ever again a net exporter of it?

The future of maize production in Mexico depends on technology. So agricultural research is crucial to increased productivity. Technologies can transform a country's international standing, so it is important to define present and future conventional and biotechnical maize research in Mexico.

1. Objectives

This paper aims to:

-- determine the relevance of maize in the Mexican diet.

-- analyse the production structure and assess farmers' potential for adopting new technologies.

-- assess the contributions of conventional research and the availability of suitable seed to producers.

-- determine the state of biotechnological research, specifically concerning maize, and its contribution to production and productivity in Mexico. Public and private participants and private property rights are considered.

2. Background on Maize

Botanists, agronomists and archeologists are still debating where maize first appeared. There is evidence that maize was grown in Mexico in about 5000 B.C.

Maize has become very much part of everyday life in Mexico and the country probably contains the greatest genetic variety of the crop. Hernández Xolocotzi **(78)** recognizes 25 varieties in Mexico. Four factors explain such diversity:

-- continued existence of primitive varieties.

-- the influence of exotic varieties from South America.

-- some inbreeding of teocintle and maize in Mexico and Guatemala.

-- Mexico's topography, which favors maize differentiation among regions.

Mexican maizes have been important in development of modern high yield varieties in the Americas, especially in the US Corn Belt.

The growth of civilization in Central and South America shows great interdependence between its people and maize -- first in its domestication and later its cultivation. Today maize is a staple food and this interdependence persists for the indigenous people of Latin America. It is not the same everywhere because other crops are grown along with maize. Several sources of carbohydrates exist and their relationship with maize affects its importance **(26)**.

In temperate rainfed areas of Mesoamerica, there is a dearth of other carbohydrate generating crops which can be produced as efficiently as maize. So various uses of maize have developed. This leads to varietal selection of maize just as many varieties of chile were selected and used together with maize.

About 90 per cent of maize produced in Mexico is white maize **(21)**. The other 10 per cent comprises yellows, blues, purples and other types. Most maize is the flint type. The tuxpeño varieties are dent maize.

3. Relevance of Maize

3.1 Consumption

Maize is rich in calories and protein. A hundred grams of maize has 356 kilocalories. Wheat has 330 and rice 362. Maize has an average 8.1 grams of protein, while wheat has 10.2 and rice 7.4. In Mexico, maize is transformed into many things -- flour, starch, nixtamal[i], and tortillas[ii]. When made into nixtamal, its calorie content rises to 377 kilocalories. Its protein content falls to 7.1 grams, but there is a rise in protein quality.

Most Mexicans eat maize, but the quantity depends on income levels and geographical region. More is consumed in the Central and Southern regions than in the North, and the grain is more important in the diet of poor people.

A national survey in 1976/1977 **(12)** showed that out of 1 300 grams of daily food consumption per capita, maize accounted for 326, wheat 103 and rice 22. Fresh milk provided only 174 grams and all meats and poultry 74 grams. Out of 43 grams of protein consumed, maize accounted for 60 per cent, wheat 10 and rice 0.7 per cent, while all meats and poultry were 16 per cent and fresh milk 14 per cent. Out of 2,289 calories of daily percapita consumption, maize supplied 46 per cent, wheat 13, and rice 2 per cent. All meats and poultry supplied 9 per cent and fresh milk 4 per cent.

3.2 Production

Maize is grown by all types of producers all over Mexico. Agricultural policy has been shaped taking into account the effects on maize production, but farm policy has always been subordinate to industrial policy, so agricultural surpluses have been chanelled to the industrial sector.

The annual average harvested area of maize was 6.8 million hectares from 1977 to 1987. This was 34 per cent of the country's 20m ha. of farmland. Maize averages 54 per cent of the 12.5m ha. devoted to the 10 main crops: maize, sorghum, drybeans, wheat, rice, soybeans, cardamon, cotton, sesame, and barley. Out of a total 5m irrigated harvested hectares, 20 per cent was used for maize.

Sorghum, used as animal feed, has increased in area from 10.9 per cent (1.5m ha) in 1977 to 13.5 per cent (1.9m ha) in 1988. This has been partly at the expense of maize because of sorghum's higher profitability to farmers and its lower risk in rainfed areas. The maize areas first substituted were areas under irrigation and good rainfed areas.

4. Institutional Framework and Governmental Policies

Agricultural policy is devised and carried out by five ministries -- Agriculture (SARH), Treasury (SHCP), Planning and Programing (SPP), Commerce (SECOFI) and Agrarian Affairs (SRA). Along with the state agency for marketing basic products (CONASUPO) and the government's rural bank (BANRURAL), they form the Agricultural Cabinet, chaired by Mexico's president. The most important agricultural policy decisions, such as the level of support prices and imports of key staples, are taken by this body. Crops involved are maize, wheat, drybeans, rice, soybeans, cardamon, sesame, cotton seed and sorghum **(24)**.

The fertilizer industry is a government monopoly, with the Mexican Fertilizer Company (FERTIMEX), producing nearly all fertilizer used in Mexico. Its production capacity is 5.4 million tonnes (mt) of finished products (equivalent to 2.1 mt of nutrients) and 5.6 m/t of intermediate products. FERTIMEX also markets its products and imports a small amount of fertilizer.

To stimulate fertilizer use, the government partly subsidizes farmers. Several programs to increase maize production have been based on subsidized fertilizers for small farmers. The ratio between fertilizer (urea) price and the guaranteed price has declined from 1.75 in 1970 to 0.30 in 1987, which means the producer has needed less and less product per unit of fertilizer.

Private and public sectors participate in production and marketing of seeds. The total average annual 1984/1986 certified seed production was 257 208 metric tons. The public sector, through its parastatal seed company, PRONASE, accounted for 45.7 per cent of the total. PRONASE specializes in drybeans (92.2 per cent of total improved seed produced in Mexico), maize (63 per cent), rice (90) and wheat (63).

The private companies produced 97 per cent of sorghum seed and 75 per cent of cotton seed produced in Mexico. Farmers' organisations produce mainly wheat seed. About 49 per cent of PRONASE's production is wheat seed, 11 per cent maize, 9 per cent each drybeans and soybeans and 13 per cent rice.

Irrigated areas use about 90 per cent of improved seeds and private companies sell to these areas. In rainfed areas, only 15-20 per cent of seed is improved seed, mainly maize and drybeans.

PRONASE is in charge of seed multiplication and the National Seed Certification Service Agency (SNICS) is in charge of quality control. The SNICS also certifies the quality of seed produced by private companies and seed that is imported. The National Research Institute (INIFAP) provides basic and registered seed to PRONASE.

INIFAP is officially responsible for agricultural, livestock, and forestry research in Mexico and currently has 32 research programs. It maintains 20 research centers all over Mexico and 85 experimental stations. The biggest research area is agriculture. Irrigated and good rainfed areas get most attention. They account for 40 per cent of total cultivated area, 67 per cent of agricultural production and 33 per cent of all farms.

The Department of Agriculture (SARH) had an office of rural extension services from 1952 to 1977 in charge of technological diffusion at the farm level. After 1977, this responsibility was taken over by different branches of SARH. So its effect has not been as beneficial as if it were under a single authority. Farmers in Northwestern Mexico usually hire their own agricultural technicians. They can afford to because most of their farms are irrigated.

Nearly two-thirds of Mexico's farmland needs irrigation to be profitable (2). Sixty-three percent of the total area is arid, 31 per cent semi-arid, 5 per cent semi-humid and 1 per cent is classified as humid. Irrigated land was 27 per cent of all cultivated land from 1983 to 1985. Almost all the 5.2 million irrigated hectares were put under irrigation with public funds. Subsidies for water, electricity and fertilizers have been the subject of major government policies in modernizing the agricultural sector in Mexico.

The support price policy is carried out by CONASUPO. This parastatal company is in charge of buying crops at the support price, and then selling to its own and private millers and at its own stores at the retail level. CONASUPO owns several grain and oil seed mills. The processed products are also sold at their own and other government retail stores.

The percentage of total domestic production CONASUPO buys varies with the product and the year. From 1980 to 1988, it bought an annual average of 17 per cent of the maize, 23 per cent of the rice, 23 per cent of the wheat and 21 per cent of the sorgum.

To regulate the domestic market, it imports products in short supply. Over the last decade, these have included maize, sorghum, soybean and its derivatives, and powdered milk. Up to 1985, it had an import monopoly. Later the government allowed mills to import them through CONASUPO, except for maize, drybeans and powdered milk.

The government, through the Department of Commerce (SECOFI), sets maximum prices to consumers for several items, including maize and its industrialized products. Producer support prices and the buying prices CONASUPO pays are mostly set above CONASUPO'S selling prices so mills and retailers can supply products to consumers at maximum official prices. This implies large subsidies to producers and consumers. These policies have allowed producers to use modern technology in wheat and sorghum production, but not in production of maize **(69)**.

5. Public and Private Maize Research and Certified Seed Production Systems

Maize research and seed production systems are the work of public and private institutions. Some of the private ones are international. Some farmers' organizations produce their own seeds. One INIFAP function is to supply basic seeds to the government seed company, PRONASE. By law INIFAP cannot provide seeds to private companies.

The Consultative Group on International Agricultural Research has based a center in Mexico -- the International Maize and Wheat Improvement Center (CIMMYT). CIMMYT's main aim is to produce superior germplasm and distribute it to national research systems and private companies that ask for it.

Four main universities do agricultural research -- Postgraduate College (CP), Chapingo University (UACH), Antonio Narro University (UAAN) and the Technological Institute of Monterrey (ITESM). Their programs are geared toward methodologies and results later incorporated into their courses.

PRONASE gets basic seed from INIFAP in order to multiply and certify it. The private companies started their seed production programs in the 1970s. As mentioned, both public and private seed producers have to certify their products with SNICS.

Mexico has no well-integrated seed research and production system because there is no strong relationship between the research institution and the seed production companies (public and private). This has been an obstacle to significant development of the Mexican seed industry. Another limitation has been the almost complete lack of ties between public and private companies. So research and technological information are not shared **(18)**.

Analysis of production, consumption and trade is based on official information. The analysis of conventional research comes mainly from the National Research Institute and CIMMYT. Data on seed production is from PRONASE and private seed companies. The information on biotechnology comes from documents and interviews.

II. MAIZE PRODUCTION AND CONSUMPTION

1. Production

1.1 Recent Trends in Maize Production

From 1978 to 1987, total maize production was around 12 million metric tons (m/t) a year, grown on 6.8m harvested hectares, with average annual yields of 1.7 tons/ha. Average annual growth of production was 0.7 per cent, area growth rate was -0.47 per cent, and yields growth rate 1.17 per cent. Maize cropped in rainfed areas accounted for 86.2 per cent of total maize area, with yields of 1.55 tons/ha. Maize produced in irrigated areas yielded 3.01 tons/ha. So rainfed areas accounted for 75.8 per cent of total maize production.

Mexico has two crop seasons. Maize grown in the spring/summer (May to October) season accounts for 92 per cent of total production. Rainfed area accounts for 89 per cent of the area cropped in this season. The other growing period is the fall/winter one.

In the 1978-87 period maize production was pushed out to areas with higher failure rates. Total annual losses of area under maize cultivation amounted to one millon hectares. One factor was the rapid area growth of sorghum (an average 4.7 per cent a year), with an annual production of some 5.1 m/t. Sixty four percent of this is grown in rainfed areas -- 995 000 out of 1.6m ha., with yields of 2.6 tons/ha. The area annual average growth rate was 3.3 per cent, mainly in former maize areas.

1.2 Geographical Distribution of Maize

Of Mexico's 32 states, 10 account for 73 per cent of the total area under maize. These are in the north-central, central, west-central and southeastern parts of the country (Figure 1). Their agroclimatic conditions mean that maize is grown in areas with adequate rainfall or where there are almost no other crops to grow. One arid state, Zacatecas, has yields of 0.967 tons/ha over 94 per cent of its (rainfed) area. Jalisco state, with more rain, has yields of 2.52 tons/ha over 94 per cent of its (rainfed) area.

Sorghum has a higher concentration of production. Five states have 85 per cent of the total area under sorghum cultivation. Sinaloa, in the northwest, has 8.2 per cent, Tamaulipas (northeast) 39.8, Jalisco, Michoacan and Guanajuato (all in the centre) have 11.9, 8.8, and 16.3 respectively. The last three were mainly maize producers. Guanajuato has the highest sorghum yields (4.8 tons/ha).

1.3 Maize Production Systems

Montañez and Warman **(45)**, using a 1981 national survey that excluded Baja California, Baja California Sur and the Federal District, analysed maize production systems in Mexico. This survey also excludes irrigated maize areas and the fall/winter season. The exclusions are not very important for the analysis.

The survey shows there were two million farm units growing maize. The area under cultivation was 6.9m ha., with average yields of 1.44 tons/ha. Total production was 9.9 m/t and average size was 3.3 ha. per farm.

The analysis shows great diversity in maize production in very different agroclimatic conditions, with very different types of producers. This diversity gives Mexico an extremely dispersed technological pattern and great availability of maize germplasm. The main production systems are called "Annual Rainfed" and "Traditional Arid Zones." We will call them Rainfed and Arid systems. The Rainfed system accounts for 53 per cent of the total area -- 56 per cent of farms and 67 per cent of production. Yields are 1.8 tons/ha. The rainfall in these areas is 600 mm a year and very regular in the rainy season. The Arid system accounts for 24 per cent of the total area, 16 per cent of farms and 13 per cent of production. Yields are 0.8 tons/ha. The rainfall in these areas is below 600 mm a year, and frequently irregular even in the rainy season. The other systems account for 23 per cent of total area, 27 per cent of farms and 20 per cent of production. Yields are 1.2 tons/ha (Table 1).

Most of these farms are relatively small. Average farm size in the rainfed system is 3.1 ha. and annual maize production 5.7 tons per farm. The average size in the arid system is 4.8 ha. and annual maize production 3.8 tons. Average size for the other systems is 2.8 ha. and annual maize production per farm 3.5 tons. Annual average production for all type of farms is 4.7 tons.

So maize farmers' profits are generally low. The agroclimatic conditions of the maize areas and their technological production level is therefore a great challange to maize researchers and policymakers to increase maize production and productivity.

1.4 Maize Technology Levels

Little information about maize technology in Mexico is available. Given the geographical dispersion of maize production and the great variety of production systems, it is hard to speak about national-level technology. But such information is important for improving research and technology policies.

The information sources for this analysis are a production survey for the 1975 spring/summer season **(50)** and national cost surveys between 1985 and 1988 **(65)**. Other technological indicators suggest conditions have not changed much since 1975.

The 1975 survey identifies 18 technology levels. The five main ones account for 70 per cent of total maize production, 71 per cent of farms and 71 per cent of cropped area. Auto-consumption of maize by producers is high -- 53 per cent. Table 2 shows the input characteristics of these five technological levels.

Yields range from 0.54 to 3.4 tons/ha., but the number of farms on the highest level is very small. Forty-eight per cent of farmers have below-average yields (1.08 tons/ha). These farms (groups 1 and 2) are called traditional technology farms in Mexico.

The low productivity of groups 1 and 2 reflect other socioeconomic factors, such as the amount consumed by the producer's family (79.3 per cent). This implies little capacity to adopt new technologies. Farmers in groups 4 and 5 consume only 32.6 per cent themselves. In this situation, it may be possible to consider seed and grain for feed, in addition to direct consumption.

Table 3 shows the average input by each farm on each technological level. Level 1 does not use improved seed, while groups 3 and 4 use 25 per cent improved seed. The survey shows the low level of improved seed and fertilizer use in Mexican maize production.

Production costs depend heavily on labor costs, as shown in Table 4. As the technological level rises, labor costs go down relatively and fertilizer costs go up. Seed costs account for only 2.3 per cent of total costs.

The production cost surveys (1985-88) showed 82.2 per cent of the total maize area used non-improved seed in the main spring/summer production season (Table 5). In the fall/winter season, 51.6 per cent was seeded with improved seed. About 8 per cent of annual production is grown in this season.

Only five improved seeds accounted for 49.5 per cent of the improved seed used in the spring/summer season (Table 5). So despite a great germplasm variability in Mexico, seed improvement research still has a long way to go. More research is needed to produce improved seed to fit the agroclimatic diversity. For the fall/winter season, there is more improved seed diversity. Private seed companies also participate in improved seed production and sales. In this season, most of the area is under irrigation.

The surveys show that at national level, only 20 per cent of the area under maize cultivation uses improved seeds. The seed cost participation is around 2.2 per cent, which is similar to the estimate in the 1975 production survey.

Throughout this analysis, the estimated maize area using improved seed is 15-20 per cent. Apart from 1985-88 production cost survey, there are no other direct estimates of this percentage. An indirect way to estimate it is to divide the quantity of improved seed sold in any year by the maize seed planting density. But there is no information in Mexico about private company sales or about quantities imported and sold.

One way of estimating is to add the improved seed sold by PRONASE to the official reported figure of private companies' seed production, offset one year, to the amount of seed authorized to be imported in a given year. The private seed production has to be offset because seed produced one year is not planted until the next. When this area is divided by the total maize area planted, we get the percentage area planted with improved seed.

Using this method and a planting density of 20 kg/ha., we estimated an average annual percentage of 13.2 from 1978 to 1987 (Table 6). If we take into account that improved open pollinated varieties are reproduced by farmers, the estimated percentage will rise. If the 20 per cent figure of the cost surveys is accepted, then around 7 per cent of improved seed planted in any given year is improved seed produced by farmers themselves.

The highest percentage we estimated was 21.3 per cent for 1982, when there was a very strong government program to increase food crop production (the SAM Program). This program increased support prices of food crops and promoted use of improved seed and fertilizer in maize and dry beans production in rainfed areas.

For these crops, the selling price of fertilizer was reduced 30 per cent and the price of improved seed was cut 75 per cent. The distribution system of these inputs was reinforced by federal and state level institutions and credit was granted to small producers who do not usually qualify for bank loans.

This large government-promoted maize seed demand was met by a greatly increased supply of seed by PRONASE and record seed imports. The SAM program, however, was considered too costly. This and the fact that Mexico was in the midst of an economic crisis caused the program to be discontinued in 1982.

Echeverría **(18)**, using Serrano's **(68)** own estimates of PRONASE and private company maize seed production and estimated imports for 1987, and using an estimate of maize area harvested instead of planted, obtains a figure of 26 per cent of area planted with improved maize seed. His figures are: PRONASE; 1987 production of 25 000 tons; private seed production; 15 000 tons, for a total of 40 000 tons. Echeverría says 37 000 tons were produced in Mexico and 3 000 tons imported from the United States. He uses a figure of 7.8m harvested hectares. The 26 per cent figure implies the farmer uses an average 19.72 kg of seed per hectare.

Comparing Echeverría's figures with the official data in Table 6, we can see he overestimates the area planted with improved maize seed.

In contrast with production systems and technology levels in maize, there were only 81 000 wheat producers in 1970. Only 1.4 per cent of small producers grew wheat, whereas 22 per cent of large commercial units grew it. National average plot size was 8.6 ha., but in the three main wheat-producing states, in the northwest of the country, average field size exceded 20 ha. From 1970 to 1987, more than 80 per cent of land under wheat cultivation was irrigated.

During the Green Revolution in the wheat sector in the 1950s and 1960s, dwarf varieties were introduced and yields more than tripled, to 3.02 t/ha. in 1970. These more favorable conditions were enhanced by a government policy that made wheat a more profitable crop than maize, so wheat had a higher rate of new technology adoption. Average wheat yields have kept growing, averaging 4.15 t/ha. between 1981 and 1985.

In the 1960s, sorghum production began in Mexico, usually in irrigated areas and using hybrid seed and fertilizer. Government price policies seem to have favored production of sorghum over basic food crops **(3)**. The effect was that commercial farmers found it more attractive to grow sorghum than maize. Another advantage of sorghum over maize is its lower labor requirement. It has only 39 per cent of the average per hectare labor requirement of maize **(3)**.

Besides its higher profitability, sorghum's drought resistance makes it a relatively low-risk crop for rainfed areas. Farms of over five hectares account for more than half of total production and machines prepare and harvest over 90 per cent of the area. So sorghum is produced on small mechanized farms with modern technology rather than on large farms, like wheat, and does not require irrigation. About 30 per cent of sorghum land was irrigated in the 1980s. Cost surveys show that in 1984-1987, farmers' net revenue per hectare from maize production was 30 per cent lower than from sorghum.

Government policy favored wheat and sorghum profitability over maize. Maize has greater agroclimatic variability and involves smaller and poorer farms. This helps explain why the adoption rate of new technology (improved seeds, fertilizers, pesticides, credit and insurance services) by maize producers is lower than for wheat and sorghum producers. It also explains why most maize farmers need strong government programs to increase improved seed and fertilizer use.

1.5 Employment

Maize is also important because a lot of people are employed in its production. There are an estimated 3.3m agricultural producers **(37)**, two million of whom produce maize by itself or intercropped with other products, mainly drybeans **(45)**. So three out of five producers are involved in maize production.

2. Consumption

2.1 Food consumption in Mexico

Income is very unequally distributed in Mexico. Surveys on income and food expenditure show food consumption is also unequally distributed. In 1977, the lowest 10 per cent of the population had just over one percent of total income. The top 10 per cent had 38 per cent and the bottom 50 per cent only 16.7 per cent (Table 7). These extremes are typical of poorer countries. One consequence is that while the lowest 10 per cent spent most of their income (62 per cent) on food, they only accounted for 1.55 per cent of national food expenditure. The top 10 per cent spent only 22 per cent of their income but accounted for 25 per cent of national food expenditure.

Twenty percent of the population consumes 80 per cent of the food value. The lower income population's diet is mainly maize and drybeans. So income distribution mostly determines who consumes how much maize, drybeans and rice on the one hand, and the by-products of wheat and sorghum on the other hand.

2.2 National Maize Consumption

Total maize consumption (production plus imports less exports) has grown considerably in the past 20 years. Consumption was 7.4 m/t in 1967 and 15.2 m/t in 1987. The average annual consumption growth rate (3.7 per cent) was higher than the population growth rate (2.8 per cent). Population grew from 46.4m to 81.1m in this period.

There are two sharply different sub-periods in the last 20 years. From 1967 to 1972, domestic production kept pace with total consumption. From 1973 to 1987, consumption grew faster than production, so more and more maize was imported. The per capita consumption trend has also changed. It grew an average 5 per cent a year from 1967-77, while the population grew 3.2 per cent. In the second period (1977-87), consumption growth fell to 2.2 per cent and population growth fell to 2.4 per cent.

Per capita consumption grew from 163.3 kg in 1967 to 190.3 kg in 1977. Since then, it has stabilised around 195 kg. This may mean that from the late 1960s and early 1970s, maize consumption was diversified into feed grain and industrial uses.

2.3 Structure of Maize Consumption

Total maize supply averaged 15.4 m/t a year between 1984 and 1986. Domestic production accounted for 87 per cent, imports for 13 per cent. Some estimates indicate 33 per cent was for auto-consumption and that the rest was channeled into the market. Of this 67 per cent, CONASUPO bought about 26 per cent and the other 41 per cent was sold on the open market (27).

Maize has been used mainly for direct human consumption. The importance of this has been diminishing and maize is being increasingly used as feed grain. Higher incomes have meant more demand for meat, poultry, milk and milk derivatives, so demand for maize as a feed grain has increased.

Table 8 shows that human consumption declined from 73 per cent of total production in 1967 to 62 per cent in 1986, while maize as feed grain grew from 12 to 23 per cent. Seed uses fell from 1.9 to 1 per cent **(27)**.

As noted, sorghum has been substituted for maize in production and has a faster annual growth rate. On the consumption side, in 1980-87 sorghum consumption averaged 7.5 m/t -- a more than 11-fold increase over the 1960-1967 average (680 000 mt).

In the sorghum sector, there has been a demand pull effect:

-- increases in national herd sizes of cattle, hogs, and chickens to which it is principally fed.

-- changes in production practices of hogs and chickens, which account for 70 to 80 per cent of sorghum consumption.

-- replacement of maize and wheat as the principal feed grain.

So even though consumption of maize as feed grain has increased, it has not been as large as might have been expected had sorghum not replaced it as a feed grain.

The main livestock in Mexico are cattle, hogs and chickens (meat and eggs). They comprise 90 per cent of the livestock production value. Between 1972 and 1987, there are two periods of animal stock trends. From 1972 to 1983, hog and chicken stocks grew five and 4.7 per cent a year respectively. Cattle stocks grew 2.9 per cent.

In the second period (1983-87), Mexico's economic crisis reduced stocks of hogs and chickens by 5.1 per cent and 2.6 per cent respectively. In 1983, the government stopped subsidising the CONASUPO selling price of sorghum, while other livestock input prices rose. This and falling demand for animal products explains the livestock sector's contraction **(51)**.

2.4 Maize Trade and Future Trends[iii]

Mexican grain imports were low in the 1960s and the country was a net exporter. As a result of rural-urban migration, higher incomes and food subsidies, demand grew faster than supply in the 1970s, and Mexico and other less developed countries became net importers of grains. Imports of maize, soybeans and sorghum have been the most significant.

The growth in demand for maize outstripped the supply growth rate in the 1970s. This was mainly because the population grew faster than maize production. Other factors were increased per capita income and rural-urban migration. Mexico now became a net importer of maize to the tune of 1.3 m/t annually between 1970 and 1979. This was 12.2 per cent of annual disappearances (production plus imports less exports) in this period. Annual average maize imports were 2.6 m/t from 1980 to 1987. This was 20.7 per cent of annual disappearances. In value terms, these imports accounted for 25 and 22 per cent of total agricultural and livestock imports value from 1970 to 1979 and from 1980 to 1987 respectively. In the consumption year 1989/1990, this may be surpassed (Table 9).

Since 1970, the United States has been Mexico's main maize supplier, averaging between 53 and 100 per cent of Mexico's imports. Argentina has been a secondary supplier. The US government encourages imports by Mexico with easy credit terms under the GSM-102 program, with promises to help obtain basic commodities, permits for use of USDA facilities to hold public tenders, and by working jointly to resolve transportation problems **(58)**. Mexico has tried to diversify its import sources for geopolitical reasons, but has had little success because of higher prices and costs elsewhere.

Sorghum imports were minimal until 1974, but then grew steadily, reaching a high of 3.3 m/t in 1983 before falling because of increased domestic production, to 750 000 mt in 1986. Average imports during 1980-1986 were just over 2 m/t a year.

The United States has consistently dominated sorghum exports to Mexico, with 38 to 99 per cent of annual market share since 1970 (an average of 78 per cent). Argentina is the second biggest supplier, providing 577 000 mt in 1981.

The implication of these growing imports is summarized in Table 10. Several grain production and consumption forecasts for the year 2000 indicate large annual grain imports, bigger than the annual average for the last five years. Different assumptions are made by the authors about consumption and production growth, so the forecasts vary. The biggest maize import forecast is 5.5 m/t , and for sorghum 13 m/t .

The marketing implications are different for each grain. Sorghum has to be milled and there is some regional concentration of mills. Maize has to be distributed all over the country, so larger imports mean larger marketing costs.

All the authors assume positive growth rates for production. This implies that new investment for infrastructure, direct support programs to producers, and putting special emphasis on rain-fed areas will be essential.

Total maize consumption estimated by CESPA for the year 2000 is 16.9 m/t. They estimated 4.6 m/t would be used for animal feed -- 27.6 per cent of total maize utilization. Rodriguez (60) estimates total maize demand that year at 15.5 m/t. He estimates animal feed use will be 3 m/t -- 19.3 per cent of total demand. When the

CESPA forecasts were made (1981-1982), hog and chicken growth rates were high, so Rodriguez' estimates (1988) seem to be more appropriate given the fall in livestock production since 1983.

III. MAIZE RESEARCH, TECHNOLOGY DEVELOPMENT AND DIFFUSION

1. Agricultural Research in Mexico

1.1 Research in Mexico: Institutions, Objectives and Priorities

Institutions

The Mexican government established a first experimental research station in 1907. By 1932, there were nine. The Agricultural Research Institute (IIA) was founded in 1947. Priorities were wheat, maize, drybeans, cotton, rice, rubber, coffee and cocoa **(46)**.

The government and the Rockefeller Foundation together set up the Office of Special Studies (OEE) in 1943. Its aims were yield-enhancing activities and IIA personnel training. Priorities were first wheat and maize. Later drybeans, potatoes, vegetables, sorghum, barley, and feed legumes were incorporated.

With the merger of IIA and OEE, the government created the National Agricultural Research Institute (INIA) in 1960 to organize, coordinate and develop agricultural research. The National Livestock Research Institute (INIP) and National Forestry Research Institute (INIF) were set up by the government in 1952 and 1958 respectively. The three institutes were integrated in the National Research Institute on Livestock, Agriculture and Forestry (INIFAP) in 1985.

The most important agricultural research institutions in Mexico are in the Department of Agriculture and the universities. Research by private firms is minor. The biggest research institution is INIFAP. The most relevant universities are the Postgraduate College (CP), Chapingo Autonomous University (UACH), Antonio Narro Agricultural Autonomous University (UAAAN), and more recently the private Technological Institute of Superior Education in Monterrey (ITESM).

An international institution works with the Mexican institutions -- the International Maize and Wheat Improvement Center (CIMMYT), established in Mexico in 1966 **(14)**. The Ford and Rockefeller foundations, together with the Mexican government, were the center's initial supporters and CIMMYT is now backed by the World Bank's Consultative Group on International Agricultural Research (CGIAR).

Several private companies do seed research in Mexico. In general, they do not claim to create new varieties but mainly test foreign basic and registered seed. In recent years, applied research for improving seed has been done. The companies apply for marketing licenses in Mexico for seeds with good performance. These firms include Semillas Híbridas (Dekalb), Asgrow, Northrup King and Semillas Master de Mexico. Semillas y Fertilizantes de Mexico does adaptive research on oil seeds.

Aims and Priorities

INIFAP's mandate is broad. Its main aim is to generate technology to increase production and productivity at farm level. This is done through research, validation and technology transfer and development of a scientific staff. It is the largest agricultural research institution in Mexico **(44)**, with an annual budget of 24 306 million pesos in 1986. The country's most important research area is agriculture. The agriculture budget was 18 256 million pesos, to livestock's 3,158 and forestry's 2 892 million pesos (Table 11).

The government budget for INIFAP from 1975 to 1982, in real terms, shows strong support for agricultural research. This was partly the time of the Mexican oil boom. However, the 1986 budget for INIFAP was 53 per cent of the 1981 budget, which was the highest ever. The effects of this reduction were research cuts, understaffed inter-disciplinary research teams, less operational funds per research worker and a young and inexperienced scientific staff due to high attrition **(23)**. There are no figures for INIFAP's maize research budget. A rough estimate can be based on the proportion of research experiments concerning maize. In 1981, there were 9 841 agricultural experiments, of which 1 697 were on maize. So maize research was 17.24 per cent of the total research effort in terms of experiments. In number of scientists involved, the figure was 14 per cent in 1986.

The INIFAP budget, as a percentage of agricultural gross national product seems small. It was 0.11 per cent in the 1960s, 0.42 per cent in the 1970s and 0.96 per cent in 1980-82. It was 0.55 per cent of the agricutural, livestock and forestry gross national product from 1980-86. The Institute has 1,800 research staff **(31)**, a decline from 1 872 scientists in 1988. In the agricultural program, there were 1 100 to 1 300 researchers from 1982-86 **(44)**. In 1986 **(5)**, 179 researchers worked in maize, 67 of them in maize genetic improvement, out of a total 1 317 in the agricultural program.

These figures reflect the extent of government commitment to agricultural research via the Department of Agriculture's Research Institute. One former head of INIA **(44)** believes government agriculture research efforts are not enough in view of Mexico's food and agricultural problems. Some government officials agree. The country's agro-ecological diversity and dualistic agricultural sector are a great challenge to research institutions in setting priorities. INIA figures show that about 44 per cent of 7,737 crop experiments in 1981 were committed to irrigated crops[lv]. Another 44 per cent involved rainfed crops. As private investment in agricultural research before the 1970s was almost nil, these figures show the government effort to support research for commercial farmers and for small farmers in rainfed areas. Of the budget, 32 per cent went on research for irrigated areas and 68 per cent for rainfed areas.

INIFAP research priorities have been on food crops, four of which (maize, wheat, rice and dry beans) accounted for 43.4 per cent of all crop experiments in 1981. Sorghum and forage crops amounted to 15 per cent. The remaining experiments were on 43 other crops. Maize is by far the most favored, with 1 697 experiments. This is 22 per cent of all crop experiments and half of those on basic foods.

Non-crop research -- on production systems, soil fertility, entomology, phytopathology etc. -- involved 2 104 research activities in 1981 out of a total of 9,841. Lack of money cut the number of total research activities (crop experiments and other activities) to 7 471 in 1985 **(23)**. In 1989, the program called for 4,100 agricultural experiments, 900 in livestock and 750 in forestry, for a total 5,750.

Main results

One way to measure research results is by the number of improved seed varieties produced. Moncada **(44)** reports 667 improved varieties released by INIFAP and its predecessors up to 1988. From 1960-82, four basic grains account for 54.6 per cent of improved varieties: wheat with 88 improved varieties, drybeans 79, maize 73, and rice 19. Oilseeds account for 11 per cent and sorghum 8.6 per cent.

Maize research tries to generate seeds suitable for different agroclimatic and economic growing conditions. In Mexico, this has led to the following seed classifications: native or local, improved open pollinated varieties, synthetic varieties and hybrids.

Improved open pollinated varieties can be created from local or introduced germplasm by mass or recombinant selection. Synthetic is an open pollinated variety made by combining selected self pollinated lines, the good combining ability of which has been spotted by testing several of them in all possible first generation (F1) combinations. Hybrid is a single, double or triple cross of selected inbred lines, normally with very different genetic backgrounds, that tries to enhance predetermined characteristics such as yield, insect or disease resistance, stalk strength etc., and attain hybrid vigor or heterosis.

Synthetic varieties are generally developed for adverse or marginal maize-growing conditions or where technology, infrastructure and demand for maize seed is not enough to make hybrid seed production viable **(70)**.

Different seed types grown in the same place have different productivities, ranging from the lowest -- local varieties -- through improved open pollinated and synthetic varieties to double cross hybrids, three-way cross hybrids and single cross hybrids. Hybrids predictably yield much more in favorable environments.

The cost of growing different seed types depends on their seed yields and the many stages of commercial seed production from the farm and seed enterprise to marketing and distribution channels. It costs more to grow commercial maize seed than commercial maize. It also costs more per hectare to grow hybrids than commercial seed of improved varieties, since the former need more complicated field layout, planting and harvesting, more supervision, additional training of growers, extra labor for detasseling and roughing, and greater quality control **(15)**. So hybrid seed costs more than improved varieties seed.

Farmers are unlikely to get full benefit from hybrids unless they buy new seed for each crop cycle, since the yield of hybrid seed harvested by the farmer may drop 15-25 per cent. Open pollinated and synthetic variety seed harvested by the farmer will, with proper care, not show these dramatic drops in yields and farmers can use their own seed for years before replacing it.

Because hybrid seed has to be bought every crop cycle and hybrids are like a trade secret (only the breeder who knows the crossing patterns can replicate a particular hybrid), private companies have an incentive to invest in research and produce and sell hybrid seeds. Once an open pollinated variety is released however, it can be spread among farmers without benefitting the inventor.

The advantages of improved open pollinated varieties are:

-- seed production costs are relatively low, seed quantities of open pollinated varieties can be built up rapidly and commercial grain production is only two generations away from the breeder's seed.

-- open pollinated varieties have a distinct advantage where seed distribution is dificult and costly.

-- seed of open pollinated varieties can move from farmer to farmer and be saved from year to year. This expands the area covered.

-- exchange of germplasm among national research programs is easier than with some closed pedigree maize materials that involve proprietary rights **(16)**.

In Mexico, INIFAP and its predecessors have been working on these three seed types and generated 128 hybrid and improved maize seed varieties from 1941 to 1985 **(61)**. Improved open pollinated varieties account for 36.7 per cent, synthetic for 14.3 per cent and hybrids for 48.8 per cent **(5)**

In 1943, the Mexican government and the Rockefeller Foundation began a joint food crops project. One research aim was to increase maize production. This and the fact that maize research was focused on generating hybrid seed led to production of 30 hybrids between 1946 to 1960 -- 58 per cent of 52 materials produced. Improved open pollinated varieties accounted for 27 per cent and synthetic varieties 17 per cent. This shows most research was directed toward better maize-growing areas where farmers had better conditions.

When the National Agricultural Research Institute (INIA) was created in 1960, the official aim was to emphasise synthetic and improved open pollinated varieties to provide farmers in rainfed areas with better seeds. From 1961 to 1985, 74 materials were produced (43 per cent hybrid seeds, 42 per cent improved open pollinated and 15 per cent synthetic varieties). Marquez **(41)** says that at the time most scientists were trained in hybrid seed research. This caused some resistance to change at INIA and the proportion of synthetic seed produced stayed the same, even though the share of open pollinated varieties increased.

INIFAP and CIMMYT have together developed improved experimental germplasm and research procedures. CIMMYT research has focused on open pollinated maize varieties so as to produce improved synthetic materials and populations. INIFAP is the official distributor of CIMMYT's germplasm in Mexico generated through its international network of trials. Mexico has been a major contributor of maize and wheat germplasm, with Mexican scientists playing an important role in germplasm development.

Over the past two decades, almost all wheat varieties released by Mexico have been developed under the CIMMYT-INIFAP improvement program and have occupied more than 90 per cent of Mexico's wheat-growing area during that time.

In 1980, closer ties were established between CIMMYT and the INIFAP maize research program, starting with extensive yield trials around Mexico to evaluate the best experimental materials. INIFAP has benefitted from using 10 materials produced by CIMMYT between 1970 and 1985. These included eight improved open pollinated varieties, one synthetic variety and one hybrid. A hybrid maize program began in 1985 at CIMMYT aimed at releasing earlier generations of inbred lines **(70)**.

CIMMYT and its predecessor, the Office of Special Studies (OEE), have greatly contributed by training personnel and with financial support from, or arranged by, CIMMYT. An improved seed has a useful life of 10-15 years, but a person has a longer productive life and can help train others.

Maize research at the universities has resulted in ITESM releasing five synthetic varieties and a hybrid, UAAAN releasing three improved varieties, and the Postgraduate College releasing three synthetic varieties **(61)**.

Mexican seed law says INIFAP's improved seed passed for commercial reproduction has to be handed over to the parastatal seed company PRONASE. This firm is turning out 41 improved maize seed varieties **(41)**. Hybrids account for 63.4 per cent, open pollinated 28.8 per cent and synthetic 9.7 per cent. In volume, it works out as 58.5 per cent hybrid, 36.5 per cent pollinated and 5 per cent synthetic. These figures show the type of farmers benefitting from government research and seed production.

To analyse seed availability and requirements, Angeles **(5)** considers three groups of maize farmers classified according to moisture availability. Group A is for irrigated maize production. He estimates 0.9m ha. in this category -- 13 per cent of 6.9m ha. under maize cultivation. He recommends hybrids for this type of producers. Group B is for efficient rainfed areas with precipitation above 600 mm. He estimates 3.5m ha. (50.7 per cent) in this condition and recommends hybrid and synthetic varieties for this group. Group C is for inefficient rainfed areas, with rainfall under 600 mm. and irregular distribution over time. He estimates 2.5m ha. (36.3 per cent) in this category and recommends open pollinated varieties.

Marquez (41), who uses Angeles' maize producer groups and relates them to PRONASE seed production, he finds that the percentage area in group A plus B (63.7) corresponds to the percentage of hybrid plus synthetic type seed production (63.5). Group C percentage area (36.3) corresponds to open pollinated seed production (36.5). Marquez concludes that this correlation between seed requirements and seed production may indicate PRONASE is producing the appropriate type of seed materials. But he qualifies this.

First, he says that in group B synthetic varieties may be more in demand than hybrids, but hybrid seed production accounts for 92.1 per cent of both types of seeds, so there is an unmet demand for synthetic varieties. Secondly, he points out that only an estimated 20 per cent of total maize land uses improved seed varieties. He says there are no estimates of private firms' sales by type of seed. So a national group classification has to be based on a sample of less than 20 per cent of land under maize. Thirdly, Marquez observes that open pollinated seeds produced by PRONASE do not exactly match group C's adverse agroclimatic conditions.

Marquez concludes that if no factors disturb the percentage correlation found, seed produced by PRONASE tends towards meeting Mexico's economic and agroclimatic maize seed requirements. This does not mean specific seed requirements are met or that total domestic demand for that type of seed is satisfied by PRONASE seed production. It indicates that more research is needed on synthetic varieties for Groups A and B and on improved open pollinated varieties for Group C.

1.2 Relevance of Maize Research

As stated, maize is Mexico's main crop and very important as food for many Mexicans. Agroclimatic, technological and economic factors affect its production and productivity. It is grown in almost all types of weather and soil conditions, so the most limiting factors are frost and drought, poor soil and steeply sloping terrain, disease, low-productivity local varieties and the use of traditional technology. Other factors reducing productivity are monocultivation, minimal use of improved seeds, low use of modern imputs, reduced financing and technical assistance, and unfavorable relative prices.

The challenge to research institutions is to raise yields in 7m ha. under maize cultivation, of which 85 per cent is in rainfed areas, half of it with good levels of moisture and half with bad or marginal moisture levels and with problems of frost and drought.

Another challenge for researchers is the high location specificity of maize seeds. A seed that has good yields in one valley may not perform as well in an adjacent one. About 30 000 valleys in Mexico are used to produce maize. Even if hybrid seeds perform well in some, most are not large enough to create a big demand for hybrid seed, so there is no incentive to produce them for these areas and private firms do not get involved. Public research institutions should therefore make more effort to generate improved open pollinated and synthetic varieties for these valleys.

INIFAP generated 128 improved maizes (hybrids, improved and synthetic varieties) up to 1985, as well as crop technologies in fertilization practices, planting densities, pest controls, planting dates etc. But only 15-20 per cent of the maize area uses improved seed and not all the available technology is used. In some cases it is not known to the farmers **(48)**.

Nevertheless, maize productivity from 1943 to 1988 increased 192 per cent, which is good in view of the problems of maize-growing in Mexico. Maize yield in the United States from 1915 to 1965 only grew 114 per cent under more favorable agroclimatic and soil conditions.

There is always a gap between productivity at experimental level, semi-commercial level and the actual farm results. In the early 1980s, the Department of Agriculture made several studies on productivity potential. They showed that by using the technology then available to producers, it was possible to produce 20 m/t of maize, increasing average national yields by half **(58)**. Development of the third generation of single cross hybrids makes it possible to produce 25 m/t of maize **(47,49)**.

1.3 Maize Improvement Research

Specific improved varieties have been developed to solve specific problems. Varieties such as VS-201, Cafime, H-504 and H-32 are good in areas of frequent drought or frost. The dwarf corn H-507 is good where rain and wind beat down the plants. The hybrid H-366 is resistant to ear rust and good for grain forage. CIMMYT's scientists are convinced the beneficial effects of the opaque-2 gene can be combined with superior yield to develop quality protein maize which can be commercially exploited.

What most maize scientists want from research is higher yields. Sometimes the yield increase over the existing seed is not very great, but if the new seed is more resistant to local diseases, then it becomes a better seed. This is the case of the hybrid H-135 which is more resistant to corn rust than H-133 and gives an 11 per cent higher yield equal to 0.98 tons/ha. and an increase relative to local seed of 1.86 tons/ha. A new seed soon to be released by INIFAP is the hybrid H-149E. Its yields are 8.9 per cent higher than H-135 **(3)**. The average expected yield at field level is 9.5 tons/ha. and the maximum experimental yield 19 tons/ha.

Under good research conditions, hybrid seeds require 11 cycles (seasons) for their development. The hybrid H-149E took 40 years from local seed selection to inscription in the National Register of Plant Varieties (CCVP). But the time and money invested will have a high social pay-off.

1.4 Profitability of Maize Research

The aims, efforts and results of INIFAP research can be evaluated to find out if the investment had a positive return or if the projects cost more than the benefits.

Research investment can enhance yields, reduce unit cost of production or input use and enhance quality. Lack of data has focused most evaluation on the nature of yield increases. The analyst makes assumptions about research investment allocation and yield increases attributable to it and obtains benefit/cost ratios and rates **of return.**

Mexico's public investment in agricultural research has a high rate of return -- some 26-58 per cent between 1943 and 1970 (Table 12). This is very high compared to the 4-8 per cent elsewhere for that period. Ruvalcaba **(61)** estimated an internal rate of return of 81 per cent from 1960-72 and 78 per cent from 1973-86.

Rational behavior indicates that investment is efficient when the rate of return is equal to the opportunity cost of money. With the international lending prime rate or LIBOR rate (around 10 per cent in 1985) as a proxy for opportunity cost, there is ample margin for government maize research investment in Mexico. There has been under-investment in maize research and agricultural research in general, even though it is very profitable.

Ardito **(6)** estimated an internal rate of return for wheat investment of 69-104 per cent, much higher than for maize. He points out that benefits from wheat outstrip those from maize. The difference is explained by the lower rate of adoption of new maize varieties compared with wheat varieties, and by the lower level of adoption of new maize seeds.

Ardito says the causes are biological and geographic. Useful applicability of each maize variety was very localized, whereas wheat seed was used more extensively in several latitudes, altitudes and climates. Maize areas are all over the country, while wheat is only in a few areas, so distribution of improved maize seeds was more expensive than for wheat. Since the 1970s, wheat areas have been more concentrated and more land has opened up to maize production. So the negative factors for rate and level of adoption of improved maize seed remain.

The higher rates of return for the last two periods can be explained by more use of improved seed by farmers. Ruvalcaba attributes the lower internal rate of return of maize research in the last period to the overall bad state of agriculture at the time, in particular the plight of small producers in rainfed areas. But without maize research, the relative profitability of maize would be much less.

The profitability of INIA's maize research investment, calculated as the net benefit cost ratio, is presented in Table 12. The implications of a benefit-cost ratio of 24.3 for the period 1961-86 are better appreciated when the actual net value added (the flow streams of benefits) by INIA research investment is calculated **(61)**. In 1988 pesos, this is 22.6 trillion pesos -- 5.2 times the total INIA budget from 1961-85 and

3.6 times the combined budget of the three national research institutes in the same period. In 1985 pesos, it is 1.35 times the total agricultural production value in 1985 and 75 per cent of the agricultural, livestock and forestry gross national product in 1985. So government maize research investment has a substantial pay-off.

1.5 Future Research Orientation

Given the agroclimatic diversity of maize areas and the socio-economic diversity of farmers, specific variety improvement is required. As Mexico is a net importer of maize, the government's National Development Plan (1988-94) gives high priority to increases in basic food crops. So the main research aim for maize is to increase yields.

The priority maize research areas for INIFAP are[v]:

-- to obtain improved open pollinated varieties and synthetics with high yield potential and wide adaptability to rainfed areas (80 per cent of the maize area under cultivation).

-- to obtain single cross hybrids from parents that make them easily and economically reproducible and which have good yields and early maturity characteristics.

-- improvement in drought resistance

-- improvement in resistance to disease, mainly leaf blight, stalk rot, rust, corn stunt and downy mildew.

-- improvement of nixtamal quality and protein content.

INIFAP has launched a National Program for High Technology Maize (PRONAMAT), aimed at maximising the potential of existing improved varieties, synthetics and hybrid seeds. INIFAP has found that its own seed used in farmers' fields has yields 30-40 per cent higher than PRONASE seed, even though they use the same materials. Some difference is expected between small and large scale seed production, but this gap shows PRONASE seed reproduction and handling is not up to standards expected in the seed industry **(72)**.

PRONAMAT strategy calls for creation of new improved seed varieties for six groups of maize-producing areas INIFAP has defined. These are classified by their production potential and associated production risk (Table 13). The program adds to the resources for creating double and single cross hybrids for areas I and II, which have the best agroclimatic conditions (2.5m ha), improved open pollinated and synthetic varieties for areas III and IV and open pollinated varieties and selection of local seed for areas V and VI. Since some materials are already specific for these areas, the strategy is to increase adaptability trials in farmers plots to accelerate choice of better materials. INIFAP expects that with PRONAMAT's action, farmers in each of the six areas will have more options in five years.

INIFAP current and medium term strategy does not include maize biotechnology programs. INIFAP officials hold that this is still at a rudimentary stage in Mexico and that research must be done in universities. They say programs such as those at the Postgraduate College should be expanded and given more money.

PRONAMAT is based on a better diagnosis of the farmer's technology requirements and calls for their greater involvement in INIFAP research. It is expected that participation of farmers in testing materials will mean more diffusion of INIFAP research results. The aim is to make researchers more aware of farmers' circumstances and to develop more cost-effective technology. In this, CIMMYT is collaborating with INIFAP in five regional projects.

Private companies started seed production in Mexico in the mid-1960s. Most private firms, national and international, were dependent on imports of basic seed to multiply their varieties and hybrids. Two things caused this:

-- by law INIFAP has to hand over its production to PRONASE, and in some cases to farmers' organizations that produce their own seeds. This was the case of wheat.

-- a great range of materials was needed for the different agroclimatic conditions, diseases and production seasons. This greatly increased production costs, so it was cheaper to import seeds.

Private firms later began adaptive research in Mexico. International companies have spent more on this. Until seven years ago, private firms were not allowed to do more than basic research. This law did not benefit Mexican farmers. The country's agroclimatic conditions mean private companies' efforts are directed towards creation of hybrid seeds more resistant to environmental stresses, disease and insect pests. They seek higher yields under those conditions rather than simple yield genes only expressed under ideal growing conditions. Their parent companies are following this strategy and the sum of these genetic improvements will probably allow new hybrids to outyield older ones.

Some international private firms have benefitted from materials provided by CIMMYT to their parent companies. By law, CIMMYT has to deliver its materials through INIFAP and INIFAP has to give its seeds to PRONASE. INIFAP has proposed changes to the Mexican Seed Law to enable it to deliver materials to farmers' organizations, and in return receive some economic compensation from them.

Private companies too would like the seed law changed so they could get materials from public research institutions and directly from CIMMYT, so benefitting from the new CIMMYT hybrid seed production program and the INIFAP seed improvement programs.

Private firms do not see INIFAP's hybrid seed production as a commercial threat. The argument is that more research is needed to obtain the new hybrids they are looking for, in addition to the fact that hybrids and improved seeds are vulnerable to new pests and diseases and so need to be replaced. The firms think INIFAP and PRONASE should release more improved open pollinated and synthetic varieties. They say the commercial market will expand once more farmers are using improved varieties.

Two things guide private sector research: market size and public sector activities and policies. Recently both factors have favored development of private sector research. Local seed sales and remittances from parent companies abroad are the source of research funds.

Net revenues from total private company maize seed sales are estimated at $3.2m for 1987. About half that was spent on all types of research that year. This investment reflects the high payoff of agricultural research in Mexico. This high rate of investment means Mexico will have a powerful private seed industry in 5-10 years time **(18)**.

CIMMYT research emphasizes development of open pollinated varieties as its goal. In Mexico, as in other developing countries, some materials are used to create hybrids, so at CIMMYT information is collected and made available to national programmes on the heterotic response among various populations for development of hybrids.

CIMMYT's strategic plan up to the year 2000 states that "the Maize Program will slightly increase its emphasis on lowland tropical products as opposed to subtropical materials, primarily in response to the growing interest of private companies in subtropical maize. We will support such public/private sector complementarities in germplasm improvement in line with our desire to strengthen national systems" **(14)**.

2. The Mexican Seed Industry

2.1 Legal Framework

The seed law (Production, Certification and Marketing of Seeds Law) was enacted in 1961, creating a National System for seeds. Public and private seed firms are part of this system, along with INIFAP, SNICS, the Plant Varieties Certification Committee (CCVP) and the National Register of Plants (RNVP).

All materials the seed industry wants to release onto the Mexican market first have to be tested in INIFAP experimental fields for 3 consecutive years and show yields higher than local seeds. The quality of imported materials must be approved by SNICS before being allowed into the country. These aspects of the law sometimes make domestic seed production more difficult than importing the same seed.

2.2 Seed Industry Participants

PRONASE has 37 seed plants with an annual installed capacity of 323 000 tons working at 60 per cent capacity. Private firms have 30 seed plants with an annual installed capacity of 150 000 tons. Of 31 companies, 22 are 100 per cent Mexican. There are 28 associations of farmer seed producers. They produce mainly wheat seed -- 64 per cent of their total annual production, which is around 100 000 tons.

PRONASE sells 60 per cent of its seed via the government rural bank (BANRURAL), 25 per cent via its authorized dealers and 15 per cent in its own plants. There is a strong link between agricultural government financing and use of improved materials. BANRURAL has been a promoter of improved seeds, since part of its credit was given in kind (improved seed). One problem with this "modernization" scheme was that farmers did not have the chance to choose the seed they wanted and so became a captive market for PRONASE seed. In recent years, this has changed and farmers now have more chance to pick the seed they want. Private companies also sell some seed through BANRURAL.

2.3 Seed Production

From 1977 to 1981, total seed production grew from 165 000 to 364 000 tons. Then it fell from 352 000 tons in 1982 to 243 000 tons in 1986 (Table 14). This reflected a decline in crop production and so less profitability for most crops and was part of the agricultural and economic crisis of the 1980s.

Seed production of maize, wheat, drybeans, and rice grew 25 per cent annually from 1977 to 1982, and declined 17.3 per cent a year from 1982 to 1986. In constrast, sorghum grew an average of 28.6 per cent annually from 1982 to 1986. This corresponded to increased area under sorghum cultivation in response to increased demand for sorghum in hog and chicken production.

Public sector participation in total seed production grew from 36.8 per cent in 1977-79 to 45.7 per cent in the period 1982-86. The main seeds produced were wheat, maize, rice, soybeans and drybeans. Private companies are oriented toward more commercial crops such as sorghum, wheat, barley, and soybeans.

2.4 Maize and Sorghum Seed Production

Maize and sorghum seed production had very different development patterns in the last 12 years. Strong government support for maize production from 1977-81 led to growing demand for maize seed. This demand was created by the government's programs to subsidize use of improved seed and fertilizers (one of them was the Mexican Food System). These programs tapered off after 1983, when oil prices fell and the general economy had a inflationary recession. Sorghum did not have the same kind of government support as maize, but increasing demand for sorghum and its greater profitability led to an increase in area and use of improved seeds. This higher profitability is shown by farmers' 30 per cent lower net revenue per hectare from maize than from sorghum between 1984 and 1987.

As stated, the maize seed industry was mainly in the hands of the public sector due to the fewer growing areas under good rainfed conditions or under irrigation. Also the government was promoting use of improved seed with price subsidies. But there was some room for private seed companies.

Table 14 shows the decline in maize seed production of PRONASE and some increases in private company production. The ratios of PRONASE seed production to private companies' output indicate virtual elimination of the maize seed production "monopoly" that PRONASE had for several years. But the quantity of seed sold by PRONASE has remainded at around 10 000 tons since 1985. This means the area planted with PRONASE seed has been above half a million hectares for that period. The difference between quantity produced and sold means PRONASE was not selling all its annual production. This in part reflects market fluctuations (due to weather and other factors) and in part lack of planning by PRONASE.

Almost all sorghum seed is produced by the private sector, even though some seed materials had been given by INIFAP to PRONASE. The latter decided not to reproduce all of them, perhaps because of market conditions (strong competition from private companies) or because its priorities were elsewhere, or both.

International companies have always imported maize and sorghum seed. Average annual maize seed imports from 1977 to 1979 were 12.4 per cent of total demand. They increased to 26 per cent from 1984 to 1986, partly because of adaptive research by private companies. Sorghum seed imports however fell, from 39.5 per cent to 16.3 per cent between 1977 and 1986. The increased demand has been met by increased domestic production.

2.5 Maize Seed Prices

CIMMYT reports ratios of maize seed prices to grain prices. The average price of single crosses was less than five times the price of grain in Colombia, while in the United States it was 30 times higher. For Mexico, the ratio of typical hybrid maize seed to grain price was six in 1985/86 and of commercial seed of improved varieties to grain price 2.4 for the same year **(15)**.

PRONASE seed prices are much lower than private company prices. The average PRONASE maize seed price ratio with respect to the maize support price was 4.5 in 1978. A lower support price saw this rise to 5.2 in 1983 (Table 9). From 1983-87, there was no big increase in real support prices, but the ratio fell to 2.4 in 1987, reflecting the strong government price subsidies to farmers via PRONASE seed sales programs. This is a major reason why private firms have almost no participation in non-hybrid seeds and have not won a larger share of the hybrid seed market.

CIMMYT says "Mexico is typical of many developing countries where both public and private seed industries produce hybrids and the prices of seed from the private sector are generally well above those of seed from the public sector. Under those circumstances farmers will not purchase private industry's hybrids unless they show a much more dramatic increase in yield over local varieties than those of the public sector. For that reason, the private sector has generally concentrated its seed marketing in the country's better maize-growing regions and has penetrated the poorer areas to a much smaller degree. For those lower yielding and more risky areas in Mexico, it appears that improved varieties and lower cost hybrids are more appropriate" **(43)**.

CIMMYT also states that "the magnitude of yield increase required to motivate farmers to choose purchased seed of improved varieties over their own seed of local varieties depends very much on the average yield of the local variety. If that average is only about 1 ton/ha., then the improved variety would have to yield 8 per cent more than the local variety to compensate farmers for the extra cost of the seed purchased, plus the margin for capital costs and risk (a 100 per cent margin). The yield difference drops to 3 per cent, however, if the average yield of the local variety is 3 tons/ha. The difference is smaller because at this higher average yield, the extra cost of purchased seed represents a smaller proportion of the extra income per hectare that is gained from the yield increment." **(35)**.

2.6 Future for the Seed Industry

The governments of De la Madrid (1982-88) and the current President Salinas (1988-94) have privatized or eliminated parastatals considered non-strategic for Mexico's economic development. Reports say the size and role of PRONASE will be reduced or even sold to farmers' organizations and/or private companies. Seed import licenses are to be eliminated and imports will only have sanitary and quality controls. Any of these changes will increase the private sector's role and Mexico's rural development will be changed substantially.

Even though the seed law has not been changed since it was enacted, its regulations have changed. In the last five years, controls over marketing and research have been partly lifted. This and the contraction of PRONASE seed production have spurred private firms to expand and increase research investment. In 5-10 years time, the private seed industry will probably contribute more to the maize yield increases so needed in Mexico. Government subsidies to farmers may be switched from larger farmers in irrigated areas to small farmers in rainfed areas who are then more in need of such help to increase productivity. There will be some complementarity between public and private enterprises.

3. Technological Diffusion

The analysis of returns from research investment show that the higher the level and the faster the rate of adoption of improved seed, the higher the internal rate of return. So more effort is needed to validate and transfer the technology generated by INIFAP. This should be done even if policy and economic environment do not favour a higher rate and level of new technology adoption.

The Department of Agriculture (SARH) had an office of rural extension service from 1957 to 1977 in charge of technological diffusion at the farmers' level. After that, responsibility was split among different sections of SARH and its effectiveness reduced. The government rural bank (BANRURAL) gives some technical aid to farmers who get loans from the bank.

A very effective way of transferring new technology to farmers was through BANRURAL services. Farmers granted loans by the bank were given credit in kind -- fertilizers and seed. BANRURAL has several technological packages for different agroclimatic and farmers' economic conditions. PRONASE has had an almost captive market for its improved seed. Recently this practice by BANRURAL has changed and farmers can now buy the seed they think best for them.

Since the 1960s, the Mexican government has had several programs to promote higher maize yields. The main ones have been the Jalisco Plan (1959-64), the Puebla Plan (since 1967), the Mexican Food System (SAM)(1980-82), which was much broader in scope, the Increased Production of Maize Program (PIPMA) (1983-85) and the Strategic Promotion of Maize Production Project (1987-88) **(69)**.

These have focused on raising yields based on technological improvements, more use of agricultural inputs (seed, fertilizers, pesticides and machinery), more access by farmers to loans and crop insurance, and promotion of farmers' organizations.

The Puebla Plan was launched and managed jointly by CIMMYT and the Postgraduate College at Chapingo from 1967-73 and then by the Postgraduate College alone **(73)**. The project covered 1.1m ha. and 43 000 producers. Most of the area was rainfed and 77 per cent of producers had holdings of less than three hectares. Most of these farmers had little capital and made minimal use of modern inputs.

The aims of the Puebla Plan were:

-- to develop, field test, and refine a strategy for rapidly increasing yields of basic food crops (maize) among small producers.

-- to train technicians from other regions to use this strategy.

Later a third aim was added: to standarize technical and scientific information generated over the years by the operation of the Puebla Plan **(33)**. Since maize yield increases alone do not make farmers richer, the Plan is using a farming system approach.

Maize yields have increased in the Plan area and it has been copied in other areas of Mexico and the world. One Plan feature was the handling of the the political and institutional arrangements the small farmer faces. At the start, researchers realized farmers did not have access to loans and so could not buy fertilizer and improved seeds. Plan staff began publicizing the Plan's results. Eventually local policies and practices obstructing adoption of new technology were lifted. Later, farmers organized and now deal directly with those who provide their goods and services.

The Plan has led to adoption of new technology by farmers. The Department of Agriculture (SARH) and the Postgraduate College have set up joint programs to train SARH technical staff and reproduce the Plan strategy in other parts of the country.

CIMMYT has a research project based on the on-farm research approach and the policy environment in which farmers and researchers make decisions. INIFAP, to participate more in diffusion of its technologies, has a joint research project with CIMMYT. The project has allowed them to identify policy constraints farmers face. With the information farmers and researches now have, they can promote changes in the policy environment to complement technical change (9). This project is being carried out in five lowland regions in two of Mexico's biggest maize-producing states.

Seed companies, through their commercial departments, promote adoption of new inputs by farmers. Improved seeds and hybrids best express their potential under high fertility soil conditions, so seed companies promote "technological packages." Companies educate farmers to use improved seeds and then sell them the seed they require.

The technical staff of private companies and their distributors advise farmers and they also study specific seed characteristics farmers want to have. Technicians and distributors pass this information to company seed production departments, where it is evaluated to establish programs to test and/or develop new seeds. They get a percentage of sales revenues, so have a strong motivation to push farmers to use their seeds.

Some private companies give credit to farmers when they buy seeds. This is a very effective way of promoting technology adoption. It is reinforced by demonstration fields, seminars and other advertising. Private companies also sell through BANRURAL. They have a strong lobby to convince BANRURAL to buy their seeds.

As mentioned, PRONASE distributes a large amount of its seed through BANRURAL. This is more an inter-institutional arrangement than market competition. PRONASE does not pay its personnel a percentage of seed sales revenues, so they are not as motivated to increase the seed market share as private company personnel. These elements give an edge to private companies in the hybrid seed market. The improved seed market has been around 1.1m ha. in Mexico in the last five years.

Private and government efforts to promote use of higher yield seeds in the maize market have faced very heterogeneous agroclimatic and farmers' socio-economic conditions. So after 40 years of maize research, only some 20 per cent of Mexico's total maize area uses hybrid and improved seeds.

IV. BIOTECHNOLOGY IN MEXICO

1. Agricultural Biotechnology

Biotechnology has been defined as "a continuum of technologies ranging from long-established and widely-used technologies, based on the commercial use of microbes and other living organisms, through the more strategic research on genetic engineering of plants and animals" **(52)**. It could also be called the use of methodologies and techniques of different scientific areas applied to living organisms (plants, animals, micro-organisms or cells) in order to change or improve them with specific aims.

Biotechnology does not seek to transform the role of agriculture but to enhance efficient agricultural production of food, fibres, vegetal oils, woods etc. It aims to complement rather than replace conventional ways to increase agricultural productivity. But substitution may develop in some areas, such as chemical fertilizers and pesticide technologies.

The methodologies in biotechnology range from simple to complex. Describing the gradients of biotechnology, Jones **(36)** comes up with:

-- biotechnological nitrogen fixation: collection, selection, and production of appropriate bacteria strains.

-- plant tissue culture.

-- embryo transfer.

-- monoclonal antibody production.

-- plant protoplast fusion.

-- use of recombinant DNA (rDNA) for diagnosis of plant and animal diseases.

-- genetic engineering of biocontrol agents to combat plant pests and diseases.

-- genetic engineering to develop animal vaccines.

-- genetic engineering to improve rhizobia.

-- genetic engineering of animals.

-- genetic engineering of plants.

With this broad spectrum of methodologies, biotechnology scientists are part of a chain of scientists in all the areas of agriculture: biochemistry, cell biology, molecular biology, genetics, physiology, chemistry, microbiology, phytopathology, bacteriology, ecology, botany, zoology, entomology, virology, bioengineering, agronomy, computing, socio-economy etc. All these areas are related to biotechnology research.

Plant biotechnology, as opposed to animal biotechnology, has grown rapidly in recent years. This may mean plants raise fewer social, moral and legal issues than animals. The rDNA and cell tissue of plant technologies have already made important contributions to agriculture. Robert Herdt makes an international assessment of several plant biotechnology promises and the present state of the art:

-- improve efficiency of conventional breeding: operational now in many crops.

-- insert resistance genes: some examples now exist with "model" systems.

-- improve hybrids: not yet demonstrated.

-- change grain quality: demonstrated.

-- conserve germplasm: not yet demonstrated.

-- nitrogen fixation: highly complex, few ideas on how to proceed.

-- increase photosynthetic efficiency (this would increase biomass production): speculative.

This assessment in no way indicates that biotechnology is the panacea for agricultural development, but it does show it can make important contributions to agricultural production and that some breakthroughs are coming soon.

2. The Economics of Biotechnology

It is too early for a precise economic evaluation of the investment returns of biotechnology or a precise assessment of the effects of biotechnology results on agricultural production and productivity, and on the input and product markets.

For Anderson and Herdt, "the likely economic impact of modern biotechnology on agriculture in developing countries will be modest in this century, given the minimal amount of work in progress that is directly relevant to the Third World, and the probable high degree of location specificity of the acomplishments" **(79)**. So biotechnology research in developing countries still seems to have a long way to go.

There are no figures about the potential economic impact of research being done in Mexico, but Gilliland **(22)** analysed the likely effects of applying nitrogen fixing biotechnologies (NFB) in maize in Mexico. She says that soon genetic engineering can improve the NFB for maize that involve bacteria. Her analysis assumes maize prices are constant and that NFB increase yields by 0.5 tons/ha on 70 per cent of land now under maize. This excludes the driest land under cultivation.

The yield increase is reasonable because, Gilliland says, measured yield responses for fertilizer additions on these types of land range from 1 to 2 tons/ha. A yield increase of 0.5 tons/ha. requires only 35 kg. more nitrogen per hectare, a level believed to be feasible with NFB. The data is for 1985.

Gilliland's results show that increased yield of 0.5 tons/ha. (26 per cent) on 5.2m ha. of small-plot scale maize land increases national maize production 21 per cent. Farmers' income could increase 55 per cent. She says the benefits of implementing NFB in the commercial maize sector are minimal. Yields are unlikely to increase in commercial farms, since NFB is just a substitution for nitrogen fertilizer. Production costs might fall, but only a small amount. If they do, the big farmer benefits more than the small farmer and the division in agriculture worsens.

This kind of experimental analysis shows there are some biotechnology results that will exacerbate the gap between the haves and have-nots in developing countries. But it seems smaller production costs can be expected. Some biotechnology results may not have these effects. NFB and pest control biotechnology may have positive results on yields.

3. Plant Biotechnology in Mexico

3.1 National Biotechnology Research Program

The Mexican government, to make efficient use of its economic resources, created the National Council of Science and Technology (CONACYT) in 1970. Since then, every presidency (1970-76, 1976-82 and 1982-88) has created its own science and technology program. In 1984, the government established the National Scientific and Technological Development Program, 1984-88 (PRONDETYC). In it, the state of science and technology in Mexico and the main government goals in these areas are reported.

The program does not have guidelines for biotechnology development, so there is no explicit national program for biotechnological research and development. This does not preclude the government financing biotechnology research.

The World Bank says about 0.5 per cent of Mexico's gross national product has been devoted to science and technology in recent years. One estimate of biotechnology expenditure in 1988-89, in nominal US dollars, is 3 million. The largest amount is channeled through CONACYT ($1.4m). The Departments of Education and Agriculture have $820 000 and $780 000 respectively. There is also an undeterminated amount in biotechnology fellowships, mainly supported by CONACYT. About $750 000 a year comes from external sources.

Scientists and public officials regret the lack of a national biotechnology program and a formal institution where they can meet to discuss and analyse biotechnology and recent information. Several professional organizations hold conferences, seminars, workshops etc. that help fill the gap. Most can get government support (CONACYT) and/or support from universities and ministries.

At the most recent national meeting on biotechnology (September 1989), the head of CONACYT said Mexican institutions should set their priorities in the light of the National Development Plan (1989-94) and the National Science and Technology Program. He said institutional arrangements for science and technology should be used by scientists and administrators in biotechnology to interact with each other. CONACYT, he said, would no longer support individual research projects, especially in biotechnology, so scientists and institutions should focus on getting finance for joint projects. Multi-disciplinary projects would get preference, he added.

The general director for scientific and technology support at the Ministry of Education (SEP), and the head of CONACYT, said that from 1989-94 more funds would go to training in biotechnology. So institutions getting public funds for biotechnology research have to set their own agendas and priorities. Scientists and heads of research institutions in Mexico have a clear idea of the different levels of research (basic and applied) and its uses and scope. Basic research solves problems of lack of knowledge, while applied research tries to solve specific problems. The research balance institutions devise depends on their overall aims, but which areas should have priority in biotechnology research in Mexico?

The National Development Program (1989-94) says Mexico's main problems stem from present socio-economic conditions. The government has given high priority to solving problems of low income and food consumption, but macro-economic policies are geared to solve two crucial problems -- inflation and external debt. Inflation must be cut quite quickly and stabilised at a low level. In the medium and long term, foreign debt (about $100 billion) and its servicing must be slowly reduced to direct more public money to priority areas, including domestic food production. This means domestic farm production must increase. But only some products will have the highest priority: maize, wheat, drybeans and rice. To generate foreign exchange, policies holding back production of exportable products -- vegetables, fruits, coffee, cotton, sugar cane and recently flowers -- must end. These sets of products indicate crop research priorities. Some will solve a food shortage and perhaps cut foreign exchange expenditure. The others will increase foreign exchange needed to repay the external debt.

The private sector, concerned with profit, adjusts its research according to present and future market conditions. It looks for agricultural products in increasing demand and with a broad market.

One private US firm representative, Carlson, asked to state four things which made a difference for an agricultural/biotechnology company, cited a breakthrough technology, a high (profit) margin product, a large market and repeat sales. Carlson stressed the last point: "To have real business, you have to sell the same product to the same customer year after year after year. I think that law, that iron law, is the dividing line between the activities of the private sector and the public sector in agricultural biotechnology" **(10)**. These four points seems to be the driving force behind research in the private seed industry.

3.2 Biotechnology Research Institutions

This section is based on reports and interviews with people working in biotechnology research[vi].

The World Bank Summary of Country Reports in Biotechnology **(80)** has about 40 institutions in Mexico doing biotechnology research: 17 public sector institutions, 13 universities and about 10 corporations. Another report, not strictly comparable, says 36 research units in institutions were, in 1987-88, doing or had done some plant biotechnology research **(80)**.

Our own assessment indicates 18 leading institutions doing plant biotechnology. Table 15 shows that 10 of them are universities. So in most, scientists spent some time doing research and some time teaching. Five of the universities have graduate programs. They are the Center for Research and Advanced Studies (CINVESTAV), the Center of Scientific Research of Yucatan (CICY), the National Autonomous University of Mexico (UNAM) and the Postgraduate College (CP) at Chapingo.

Arroyo and Waissbluth **(7)** report that in 1987, 16 000 persons were doing research and experiments in Mexico. They say that by 1984, they were concentrated in three states (out of 31) and Mexico City and accounted for 52.7 per cent of the institutions and 88.4 per cent of persons doing research and development. The three states were Mexico, Nuevo Léon and Jalisco.

The World Bank report puts the number of people in biotechnology research at around 50 in 1984, 100 in 1986 and 400 in 1989. Half of all researchers are in only five institutions (Table 16), more or less equally divided among doctoral (PhD), master of science (MSc) and bachelor of science (BSc) levels. So it is urgent to increase the number of people in this area to avoid a shortage of top biotechnology researchers in the near future.

3.3 Biotechnology Research Areas

The World Bank report divides biotechnology research into three parts: plant biotechnology, industrial-agricultural applications and animal biotechnology (Table 17). They found that 80 per cent of all activities are in plant biotechnology, and that micropropagation (tissue culture) takes up half the activities in this and genetic improvement and basic studies supporting biotechnology 10 per cent each.

Arroyo and Waissbluth report that of 30 institutions involved in plant biotechnology, 24 (80 per cent) are in micropropagation. Fifteen of the 24 only do micropropagation. Our own assessment is that 14 institutions do research in micropropagation. These figures indicate the resource base for handling new knowledge in plant biotechnology. They also show Mexico's efforts are at the lower end of the Jones gradient of biotechnology, but the World Bank report, however, says basic biotechnology studies at CINVESTAV in Guanajuato and at the Center for Nitrogen Fixation (CEFINI) in Morelos merit special mention because their work matches the highest standards of industrialized countries. Apart from these two institutions, eight others do basic studies (7).

Research on plant micropropagation is a mix of basic and applied research and technological development. There are already some commercial applications. Major emphasis has been put on cut flowers and ornamentals. Other favored products are coffee and fruit (strawberry and pineapple), which are also exportable.

Five of the 24 institutions involved in micropropagation are also doing basic research. If these institutions interact in research, their potential for rapid development is very high. The other institutions risk soon becoming obsolete, carrying out repetitive research, unless they do joint research with institutions with basic research projects.

One institution working in micropropagation, doing basic and applied research and having joint projects with another institution that puts most of its resources into basic research, is the Postgraduate). The CP was the pioneer institution doing *in vitro* culture (plant cell, tissue and organs. In 1970, the Japanese and Mexican governments established a joint program in micropropagation research. Japanese scientists helped set up a laboratory at the CP and launch a human resources development program. Later, with the Department of Vegetal Biochemistry of the Chemistry Department of the UNAM, the CP began a program to identify biochemical characteristics of sexual embryos and measure biochemical parameters during the embryogenesis process. This gave the Postgraduate College an edge over other universities doing biotechnology research.

Six institutions do genetic improvement research. This area shows the links between conventional research and biotechnology. Persley (52) presents the areas with potential biotechnical applications that can be integrated with crop improvement programs. She also gives the time required between germplasm acquisition and seed distribution. Table 18 summarizes the links between biotechnology and conventional research in crop improvement programs.

Some research is also being done in Mexico into pathogenically free materials, secondary metabolites and preservation of germplasm.

4. Maize Biotechnology in Mexico

The main problem with most strategies to apply biotechnology in plant breeding is regeneration of plants from genetically altered cells. In many cases, the regulatory mechanisms of the physiological and biochemical processes in cultivated plants need to be understood. But this knowledge is scarce and basic research in the field limited, so research is needed using economically important crop plants like maize as biological models. Maize is the most important crop in Mexico as part of everyday diet and the centre of productive activity for many Mexicans.

A list of the organizations working in maize biotechnology, with a brief description of their main activity in this field is given in Table 19.

Using restriction fragment length polymorphisms (RFLP) techniques, CIMMYT has been looking for heterotic patterns in elite populations of tropical maize, for genes providing resistance to pests and pathogens, and other screening techniques for better utilization of the thousands of entries in their maize germplasm bank **(34)**.

The Biochemistry Department of the Chemistry Faculty of UNAM has been working on maize for 10 years. Research has been done on the biochemistry of embryo culture in maize and the culturing in vitro of mature embryos of 17 maize varieties. This showed clearly the effect of 2.4-D and Mecoprop, the latter being the best, with its capacity for callus generation under all experimental conditions. Based on these studies, research has been done on nitrogen metabolism to understand both embryogenesis and organogenesis. Some research has also been carried out by UNAM on use of biochemical markers during embryoid formation and use of photosynthetic markers to examine chloroplast biogenesis.

At Postgraduate College, maize has been studied for four years through in vitro tissue culture techniques. One line of research has been study of morphogenesis in maize to properly characterize events involved through either organogenesis or embryogenesis. This study included 18 maize genotypes and enabled identification of best conditions for aseptic culture of different types of explants and best hormonal treatments and physical conditions for incubation. On these results, studies are being made of germination and development of embryoids up to a complete plantule and of some histological, anatomical and biochemical aspects. Both embryogenic and friable calli have been obtained. Recovery of plants from embryoids is still low and little is known about the biochemistry of the processes involved.

A joint project has been set up with the UNAM Biochemistry Department aiming to:

-- identify biochemical characteristics of mature and immature sexual embryos.

-- establish an *in vitro* culture system for maize cell suspensions in a search for viable somatic embryogenesis.

-- measure biochemical parameters during embryogenesis and other processes.

The purpose of all these studies is to identify well-defined biochemical markers that, properly used in *in vitro* cultures of mature and inmature embryos, could lead to more information on how to obtain biochemically "competent" embryoids capable of germinating and forming a complete plant.

The second main project at Postgraduate College has been selection of cell lines tolerant to environmental stress, disease, soil salinity etc. in order to develop germplasm useful in maize breeding programs. Cell cultures have been established and response to stress measured. This and the studies on morphogenesis would enable development of plantules from cell clones selected under stress conditions.

Another line of research is *in vitro* regulation of growth and development of reproductive structures in maize. The aim is to define the technology for the maintenance, *in vitro*, of live reproductive structures of maize and determine the nutritional requirements for lengthening their growth and development up to complete development. The aim is also to get more floral structures and eventually more mature seeds. The technique for *in vitro* culture of these structures has been worked out and some factors inhibiting or inducing growth identified.

CIMMYT has become increasingly aware of what the new gene technologies can offer their breeding programs **(34)**. They have been involved in some areas of biotechnology, such as wide crosses and embryo rescue, for over 15 years and recently have been using monoclonal antibodies. The new technologies holding most promise for beneficial utilization at CIMMYT are related to diagnosis. The Elisa technique in disease diagnosis, breeding and seed health, together with use of restriction fragment length polymorphisms (RFLPs) and DNA probes to increase efficiency of breeding programs, are the basis of CIMMYT's use of new technology.

Molecular genetic markers have many advantages over traditional phenotypic markers such as plant or seed color, chlorophyll alterations and male sterility. One of the more important is the considerable molecular variation in the strains of interest. Especially for maize, variation at DNA level is tremendous. DNA polymorphisms can readily be found among lines. This and the number of RFLP markers makes their use more attractive than isozymic markers.

Further advantages of RFLPs include the fact that DNA polymorphisms are not affected by environment, that one marker does not interfere with the scoring of the next, that all polymorphisms are detected by a single relatively rapid technique, that the public genetic map is approaching saturation, and finally that they can be detected as either homozygous or heterozygous. Measures of allelic frequencies are forthcoming from several procedures and will be useful in assessing relatedness and potential variety performance.

Research on heterozygosity and variety performance has been initiated in a joint project between CIMMYT and CINVESTAV-Irapuato. This institution is eager to apply its basic and strategic research capacities in molecular biology to back the applied maize breeding program at CIMMYT. The project has support from the Rockefeller Foundation. Proof of a relationship between yield performance and heterozygosity, using molecular probes, will allow breeders to directly screen for heterozygosity before variety formation, procedure which has so far been impractical.

An important feature of the biotechnology program is that CIMMYT will not try to develop biotechnology techniques. Its role will be to test and adapt existing techniques and applications and possibly incorporate them into breeding programs and help transfer this technology to developing countries. CIMMYT will also encourage joint research in developing and testing new gene technologies. For CIMMYT to be a meaningful participant in collaboration and use of these new techniques, it will have to be directly involved in the research. It is expected that the biotechnology program will be a joint one and networked with other biotechnology centers in both developing and developed countries. It will enable these countries to work with their national program collaborators on identification and adoption of appropriate technology.

So some research on new maize biotechnology is being done. Officials and researchers think efforts and resources limited and that more cash should go to this emerging area of knowledge and technology from public, private and international institutions. People in biotechnology are optimistic, even though results in maize cannot be expected in the near future. Maize research efforts have so far focused on stress resistance, so new technology may not have direct significant effect on yields.

The need for interdisciplinary work in biotechnology to speed up progress has been accepted. Researchers are optimistic about short-term results in those areas under research (micropropagation, secondary metabolites). But with maize, research is mostly basic and, as noted, its application is not expected very soon.

Biotechnologists and breeders must be better informed about the complementarity of most biotechnology techniques and traditional breeding methods. They should also be aware of the rapid advances they can make with them.

The need to speed up training is recognised so as to intensify and direct biotechnology work toward the most pressing national needs, and also to encourage liaison among public and private sectors in this field.

5. Intellectual Property Rights

Several countries have laws protecting Intellectual Property Rights (IPR) of persons, industries and institutions. The IPR protect new products and processes. Inventors and producers want their rights protected and if possible to make a profit out of it. Users of inventions and consumers want to pay less for what they get and IPR is considered an extra cost. So the IPR issue is at the heart of the sellers and buyers controversy, the market place and the laws that regulate the market.

Old laws are being changed or reinterpreted in line with advances in biotechnology. In the United States, patent protection can be got for biological processes and for living microbial, plant and animal materials produced using recombinant DNA technology **(52)**.

Evenson and Putman (19) listed eight ways to protect inventions or IPR:

-- seed and breed certificates

-- plant patent and variety protection

-- invention patents

-- petty patents (utility models)

-- inventors' certificates

-- industrial design patents

-- copyrights

-- trade secrecy.

These protections are enforced at national level by national laws and at international level by international agreement.

Mexico's biotechnology research and technology advances make the country an importer of biotechnology results and products. So it is in its interest not to have IPR, or minimally. At the same time, it is in Mexico's best interest to develop its biotechnology capacities rapidly. The country can then get maximum knowledge from abroad and be in a better position for technology transfer. Technology-exporting countries do not want this. Their governments try to enforce international agreements on IPR.

To meet pressures from developed countries, Mexico recently changed its patent law giving more protection in the area of agriculture, particularly biotechnology. The new law (January 1987) does not allow patenting of plants, animals or food for human use. But from 1997, it allows patenting of:

-- biotechnology processes of all kinds

-- genetic processes for generating plant and animal products

-- chemical products and pharmaceuticals

-- animal feeds

-- fertilizer, agrochemicals and biologically active products.

This means Mexico will have to step up biotechnology research to be in a better competitive position by 1997.

To discourage patent holders using a patent as a way of preventing use of a product or process by others, Mexican law says "granting a patent implies the obligation to use it in the national territory. The patent use should be over three years starting from the date of its grant."

There is disagreement among scientists about the desirability of IPR protection. However most prefer some degree of IPR protection, since it can increase their income. This goes for those -- plant breeders or biotechnologists -- in the private or public sector.

VI. CONCLUSIONS

Since 1945, Mexican governments have aimed to industrialize the country. This called for cheap food and raw materials, so food subsidies were introduced. It led to domestic deficits of some products, chiefly maize. Later the government encouraged production by subsidies, but imports of maize and other agricultural items kept growing.

Maize is grown by all types of producers all over the country. Mexico's climate means nearly two thirds of the cultivated area needs irrigation to produce profitable crops. Of 6.8m ha. of maize, 85.3 per cent was cropped on rainfed areas and produced 75.8 per cent of total maize production. Between 1978 and 1987, maize production was pushed out to areas with higher failure rates. One reason was the rapid area growth of sorghum, which reflects the higher profitability of sorghum compared with maize.

Farms producing maize average 3.3 ha. This is smaller than those growing wheat. The average maize yield for these farmers is 1.4 m t/ha. These small yields and relatively low prices they get mean net earnings are low. For the biggest commercial farmers, their higher productivity translates into higher profitability. So most maize farmers have little incentive to spend more on new technology, since expected yield increases have to pay for the new technology.

Only an estimated 20 per cent of the total area under maize uses improved seeds. In irrigated areas (some one million hectares), the adoption rate is 52 per cent. It is here and in areas with good rainfed conditions (a total of 2.5m ha.) that there is potential for adoption of new improved seeds. With the breakthrough on wheat with dwarf and semi-dwarf varieties in irrigated areas, yield increases have to pay for use of improved seed and greater use of fertilizer. More than 90 per cent of the area planted with wheat uses improved seed.

With existing technology and the same area under cultivation, it is thought possible to raise maize yields by half and boost production from 12 to 20 m/t of maize. But to achieve this higher productivity, better market conditions have to be created for producers. This means more protection for Mexican maize against foreign competition.

So agroclimatic conditions and technological production levels are a great challenge to maize researchers and policymakers to raise production and productivity through adoption of new technology.

The diversity of agroclimatic conditions where maize is grown calls for greater diversity of seed. This is an opportunity for conventional and new technology research. Private seed companies have concentrated on production of hybrid seed for irrigated areas and areas with good rainfed conditions. The public seed company PRONASE produces hybrids (58.8 per cent of total volume), improved open pollinated varieties (36.5 per cent) and synthetic varieties (5 per cent). Some researchers think PRONASE should produce more open pollinated and synthetic varieties (which also are open pollinated varieties) for rainfed areas.

The government research institute, INIFAP, generated 128 hybrid and improved varieties from 1941 to 1985. Hybrids account for 48.8 per cent, open pollinated for 36.7 per cent and synthetic varieties for 14.3 per cent. INIFAP has benefitted by using 10 materials developed by CIMMYT between 1970 and 1985.

INIFAP says more research is being directed toward generation of open pollinated and synthetic varieties. But some work will be done to produce hybrid seed to replace seed now on the market. The international institution based in Mexico (CIMMYT) has focused on generating open pollinated and synthetic materials. In 1985, it launched a program for hybrid seeds. Mexican public universities also have favored generation of open pollinated and synthetic materials. Private companies however have concentrated on hybrid seeds, first with adaptive research, and recently some of them (mainly international firms) with more basic research.

Hybrid seed cannot be reproduced by farmers, who are thus a source of revenue for seed companies. With the decline of PRONASE market participation and new private sector research investment, any increased profitability of maize production in Mexico or scientific breakthrough in maize will be due to the private companies, unless new technology comes up with improved open pollinated and synthetic varieties or causes increased use of these types of seeds.

Agroclimatic conditions, production systems and markets have prevented farmers using more improved seeds. However public research investment has had high internal rates of return and high benefit-cost ratios. This means the government has under-invested in maize research. Public investment in agricultural research has been falling in Mexico, which does not bode well for maize producers in rainfed areas (85.3 per cent of total maize area). So to head off a widening rural income gap, more attention should be paid to the rainfed production areas.

To increase maize production, a better national distribution system is needed. Also, more location-specific research on producing improved seeds and adoption of new technology by farmers is required. The price policy that favours expansion of sorghum in maize areas must also be taken into account.

New technology research, in the form of biotechnology, is being done in Mexico. Most research is on plant micropropagation. There is some interaction between basic research and more applied research, as with restriction fragment length polymorphism (RFLP) techniques.

Most research institutions aim for new knowledge of biological and physiological processes of maize. Another goal is to facilitate identification of maize lines with resistance to stress factors (drought, pests and disease). Results of this research are expected to improve efficiency of breeding programs. Some cooperation exists between institutions doing basic research and others doing more applied research (CINVESTAV-CIMMYT, Biochemistry Department of UNAM-Postgraduate College). Joint projects are expected to yield quicker results and better allocation of resources to each institution.

International transfer of new technology and joint projects have raised the issue of intellectual property rights. The granting of patents by developed countries to micro-organisms, plants and procedures concerns Mexicans in private and public sectors. Scientists say this hinders the flow of information. Government officials say domestic laws and international agreements will raise the cost of obtaining new technology (products and processes).

The Mexican government has however enacted a law that will allow from 1997 patenting of biotechnology processes of all kinds; genetic processes for generating plant and animal products; chemical products and pharmaceuticals; animal feeds; and fertilizer, agrochemicals and biologically-active products. This is expected to facilitate transfer of new technology.

Current advances in maize biotechnology in Mexico allow us to predict that first results will be on plants with resistance to adverse factors. They may not have higher yields, so big production increases are not expected. First applied results are expected in 5-10 years.

Mexico is expected to remain a net importer of maize. As long as domestic maize production does not increase, Mexico's maize deficit in international trade will not change. Even though a National Program in Science and Technology exists, there is no program for research and development in biotechnology. Private and public institutions advocate a national biotechnology program, in which research priorities should be set and funding sources identified.

People involved in biotechnology think a body dealing with biotechnology should be created, with public and private sector participation. The main aim would be to analyse research priorities, intellectual property rights, rules and regulations for release of new organisms and genetically-modified micro-organisms. On the last point, most officials think Mexico should adopt international standards set by the OECD unless evidence supported special treatment for Mexico **(44)**.

Private firms have concentrated on plant micropropagation (cut flowers and ornamentals) and fermentation processes. This points to the need for a biotechnology body where public and private institutions interact. The integration can be stimulated through shared-risk funds and tax incentives for biotechnological research and production of biotechnological products.

Some applicable results of biotechnology research are expected in 5-10 years time. To help this on its way, more people must be trained and more attention paid to the multi-disciplinary nature of biotechnology.

People and institutions in Mexico have the capacity to conduct biotechnology. Most of this capacity is in universities. But not enough money is available for research and development in biotechnology to meet the pressing demand for improved productivity of maize and other products. Officials and researchers say efforts and resources are limited and that more cash should go to this emerging area of knowledge and technology from public, private and international institutions. People in biotechnology are optimistic about results, even though maize results are not for the near future. As noted, maize research has so far focused on stress resistance, so new technology may not have a direct significant effect on yields.

There is some support from international agencies and foundations. This should complement national funds invested in biotechnology. More joint projects among institutions (public and private) and foreign institutions are needed to expand Mexico's research base.

NOTES

i. Nixtamal is prepared by boiling maize kernels in a lime solution, then ground.

ii. Corn-flour dough is shaped into tortillas, a traditional staple.

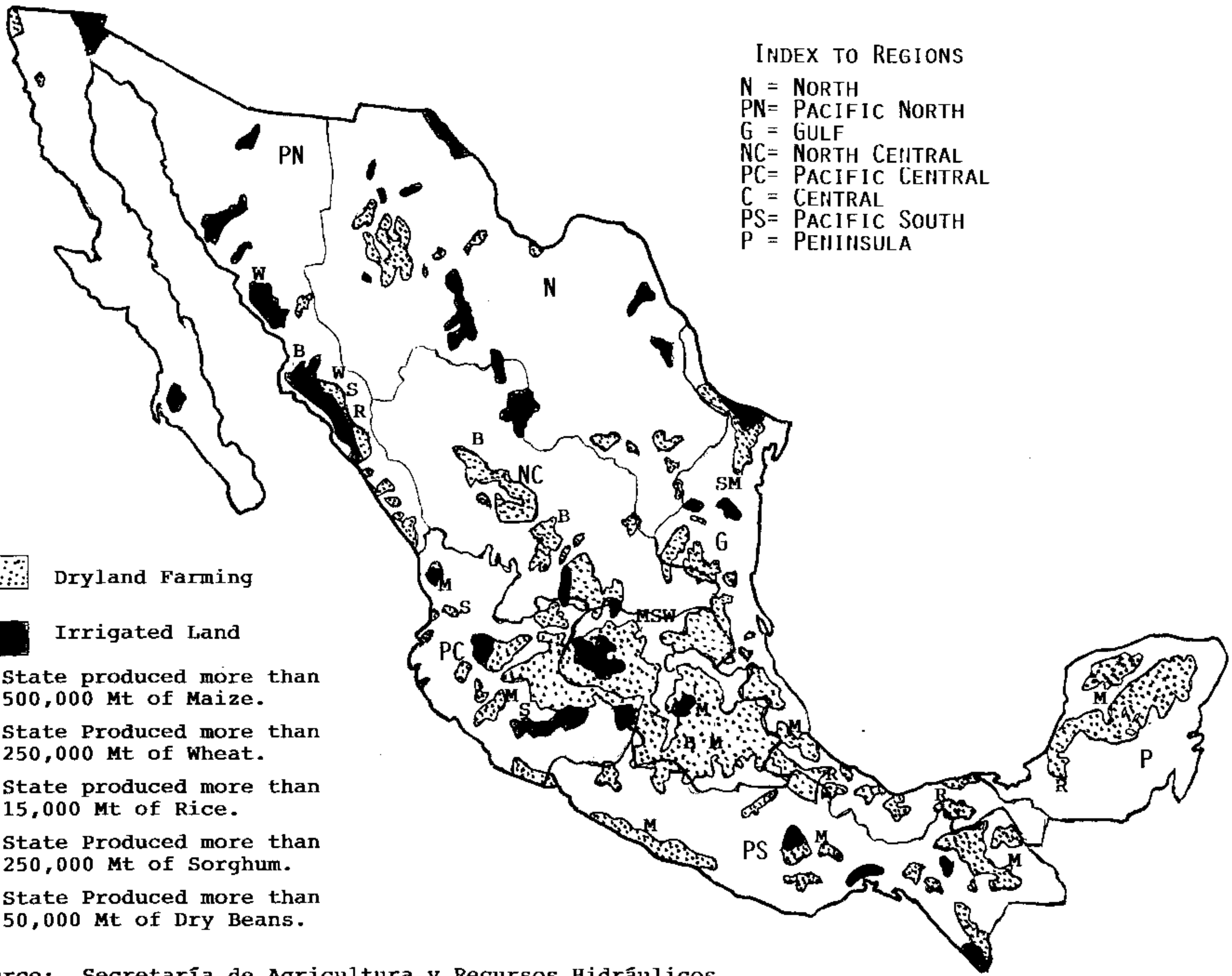
iii. This section relies heavily on "A Review of the Mexican Grain Situation," by J.A. Matus G. and R.W. Bierlen, **(43)**.

iv. These figures were calculated from Diagnostico de la Investigacion Realizada por el INIA en 1981 **(27)**.

v. For more information on INIFAP programs see references **46, 47, 48** and **49**.

vi. For more information see references **1, 17, 32, 33, 64, 66, 67, 74, 75, 76** and **77**.

FIGURE 1



INDEX TO REGIONS

N = NORTH
PN= PACIFIC NORTH
G = GULF
NC= NORTH CENTRAL
PC= PACIFIC CENTRAL
C = CENTRAL
PS= PACIFIC SOUTH
P = PENINSULA

Dryland Farming

Irrigated Land

M= State produced more than 500,000 Mt of Maize.

W= State Produced more than 250,000 Mt of Wheat.

R= State produced more than 15,000 Mt of Rice.

S= State Produced more than 250,000 Mt of Sorghum.

B= State Produced more than 50,000 Mt of Dry Beans.

Source: Secretaría de Agricultura y Recursos Hidráulicos.

TABLE No. 1 MAIZE PRODUCTION SYSTEMS

SYSTEMS AND VARIANTS	AREA (HA)	PRODUCTION UNITS	PRODUCTION (MT)
Rainfed Annual	3651772	1155526	6588807
- Human force	28725	11015	47183
- Animal traction	1537436	566179	2077798
- Mixed traction	1391691	435177	2808272
- Mechanic traction	693920	143155	1655554
Traditional of Arid Regions	1629369	335707	1299350
- Animal traction	460387	115367	275363
- Mixed traction	609840	139052	448256
- Mechanic traction	559143	81288	575731
Other Systems	1613141	564314	2009987
Total of the Systems	6894282	2055547	9898144

Source: Carlos Montañez y Arturo Warman, "Los Productores de Maīz en México: Restricciones y Alternativas" (45).

TABLE No. 2 TECHNOLOGICAL COMBINATIONS IN MAIZE PRODUCTION

TECHNOLOGICAL COMBINATIONS	INDICATORS						
	Relative Participation (%)			Kilograms per Hectare	Average Size Per Farm (ha)	Utilización (%)	
	Production Units	Cultivated Area	Production			Auto consuption	Sales
1. Rainfed, yoke and low utilization of inputs and services.	28.0	28.0	14.0	540.0	2.7	79.3	20.7
2. Rainfed, yoke and regular utilization of inputs and services.	20.0	16.0	14.0	1000.0	2.2	69.3	30.7
3. Rainfed, yoke and high utilization of inputs and services.	15.0	12.0	15.0	1349.0	2.1	52.8	47.2
4. Rainfed, machinery and high utilization of input and services.	6.0	13.0	21.0	1733.0	4.0	32.4	67.6
5. Irrigation, machinery and high utilization of input and services.	2.0	2.0	6.0	3375.0	3.5	33.3	66.7
T O T A L	71.0	71.0	70.0	1079.0	2.8	52.9	47.1

Source: Pereira, et. al., "Análisis Económico del Cultivo del Maíz en México, en el Ciclo Primavera-Verano" (50)

TABLE No. 3 LABOR AND INPUTS UTILIZATION FOR THE FIVE DIFFERENT TECHNOLOGICAL COMBINATIONS

	1	2	3	4	5
Labor (days/ha)	48	58	58	29	41
Seed (kg/ha)	20	20	20	20	20
- native	20	16	15	15	8
- Improved	0	4	5	5	12
Fertilizer (kg/ha)					
- simple superphosphate	0	0	250	0	0
- triple superphosphate	0	13	0	76	52
- ammonium sulfate	0	117	385	416	512
- potassium chloride	0	0	0	0	17
Insecticide (kg/ha)					
- Sevin 5%	0	1	1	3	4

Source: Pereira, et. al., op. cit (50).

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- simple superphosphate	0	0	250	0	0
- triple superphosphate	0	13	0	76	52
- ammonium sulfate	0	117	385	416	512
- potassium chloride	0	0	0	0	17
Insecticide (kg/ha)					
- Sevin 5%	0	1	1	3	4

Source: Pereira, et. al., op. cit (50).

TABLE No. 4 INPUT PARTICIPATION IN THE PRODUCTION COSTS OF DIFFERENT TECHNOLOGICAL COMBINATIONS FOR MAIZE

TECHNOLOGICAL COMBINATION	LABOR %	FERTILIZER (%)	SEED (%)	INSECT. (%)	OTHER (%)
1.	92.9	0.0	2.5	0.0	4.6
2.	85.8	3.8	2.3	0.3	7.8
3.	66.8	14.0	2.1	0.3	16.8
4.	68.5	15.6	2.5	0.9	12.5
5.	69.4	12.3	2.3	0.9	15.1

Source: Pereira, et. al., op cit. (50) .

TABLE No. 5 SEED UTILIZATION IN MAIZE PRODUCTION

CYCLE AND VARIETY	AREA PROPORTION (%)	SEEDING DENSITY (KG/HA)
SPRING-SUMMER		
Native	82.2	20.6
Improved	17.8	
- H-507	3.2	13.1
- Tuxpeno	2.5	19.1
- H-503	1.4	16.6
- Tacea b4	1.2	21.3
- Celaya 2	0.5	20.3
- Others	9.0	
AUTUMN-WINTER		
Native	48.4	20.6
Improved	51.6	
- Pioner 3147	7.8	20.9
- Growers 2340	6.1	20.6
- Growers f-6	5.1	21.6
- H-422	3.3	17.8
- Asgrow 132	3.1	22.3
- Asgrow 405	2.9	20.2
- Breve Padilla	2.5	15.5
- Tuxpeno	1.9	19.6
- H-507	1.3	16.9
- Llera 3	1.0	19.6
- Others	16.6	

Source: SARH, Encuesta de Costos de Producción (65).

TABLE NO. 6 MAIZE AREA PLANTED WITH IMPROVED SEED AND TOTAL NATIONAL AREA PLANTED
MEXICO 1978-1988 (hectares)

YEAR	PRONASE[1] PLANTED	PRIVATE[2] PLANTED	IMPORTS[3] PLANTED	IMPROVED[4] PLANTED	NATIONAL[5] PLANTED	RATIO[6] IMPR/NAT	RATIO[7] IMP/NAT
1977	492567		81200		7600000		1.07
1978	384383	96000	90800	571183	7450300	7.67	1.22
1979	335074	219950	81100	636124	7045900	9.03	1.15
1980	707506	223350	182450	1113306	7606400	14.64	2.40
1981	1006586	168400	52250	1227236	8759100	14.01	0.60
1982	1000264	155950	669900	1826114	8589300	21.26	7.80
1983	628818	256550	260700	1146068	8635600	13.27	3.02
1984	429027	196850	371400	997277	8021700	12.43	4.63
1985	522406	300400	203950	1026756	8354700	12.29	2.44
1986	535501	415300	229700	1180501	8164300	14.46	2.81
1987	525900	431650	150000	1097550	8400300	13.07	1.79
1988	513400	363950			8169800		

1/ Seed sold by PRONASE (20 Kg seed per hectare). Source: PRONASE.
2/ Seed produce by private companies/(20), lagged one year. Source: PRONASE.
3/ Seed imported/(20) Source: Serrano (68).
4/ Sum of PRONASE plus Privates plus Imports.
5/ National maize area planted; Source: Quinto Informe de Gobierno de Miguel de la Madrid. Estadístico 1987 (39).
6/ Ratio of Improved area planted to National area planted.
7/ Ratio of area planted with imported seed to national area planted.

TABLE No. 7 FAMILY INCOME DISTRIBUTION: 1963, 1968 AND 1977: PERCENTAGE OF TOTAL EXPENDITURE AS FOOD EXPENDITURE AND DISTRIBUTION OF FOOD EXPENDITURES: 1977
(Percentiles)

P'tile	%Y(63)	%Y(68)	%Y(77)	Fd/TOTAL	Fd Dist
I	1.69	1.21	1.08	61.58	1.55
II	1.97	2.21	2.21	58.31	3.27
III	3.42	3.04	3.23	59.74	4.75
IV	3.42	4.23	4.42	57.66	6.16
V	5.14	5.07	5.73	54.45	7.80
VI	6.08	6.46	7.15	50.44	9.48
VII	7.85	8.28	9.11	44.86	11.40
VIII	12.38	11.39	11.98	42.42	13.78
IX	16.45	16.06	17.09	34.94	17.02
X	41.60	42.05	37.99	22.00	24.79

Source: E. Hernández L. and J. Cordoba Ch., "Estructura de la Distribución del ingreso en México". Comercio Exterior, May 1979, P. 507 (25).

TABLE No. 8 DIFFERENT USES OF THE AVAILABLE SUPPLY OF MAIZE

CONCEPT	UTILIZATION (%) 1967 (1)	1977 (1)	1985 (1)	1986 (2)
Human consumption	72.7	70.6	58.1	62.2
Animal consumption	12.3	13.8	21.7	23.1
Industrial consumption	4.5	5.7	11.4	3.6
Seeds	1.9	1.3	1.0	1.1
Shrinkage	8.6	8.6	7.8	10.0

Source: (1) F.A. O. Bandas mageneticas.
(2) INEGI (27).

TABLE No. 9 MAIZE BASIC STATISTICS

YEAR	PRODUCTION MAIZE (TON)	AREA MAIZE (HAS)	YIELD MAIZE (TON/HA)	APARENT CONSUMP. MAIZE (TON)	IMPORTS MAIZE (TON)	EXPORTS MAIZE (TON)
1970	8879384	7439684	1.194	9638581	761791	2594
1971	9785734	7691656	1.272	9529631	18308	274411
1972	9223000	7292180	1.265	8994000	204213	425896
1973	8609132	7606341	1.132	9723000	1145184	31589
1974	7848000	6717234	1.168	9124000	1282132	1603
1975	8449000	6694267	1.262	11070000	2660839	6289
1976	8017294	6783184	1.182	8929000	913786	4151
1977	10138000	7470000	1.357	19123000	1985619	1383
1978	10930077	7191128	1.520	12347000	1418423	1702
1979	8458000	5581158	1.515	9203000	746278	1497
1980	12374400	6766000	1.829	16561043	4187072	429
1981	14550000	7669000	1.812	17504000	2954574	1024
1982	10129000	5643000	1.779	10378000	252784	1205
1983	13061208	7421000	1.760	17693000	4632448	1300
1984	12932000	7076494	1.828	15377000	2444756	325
1985	13957000	7498000	1.859	15680000	1724221	9111
1986	11721000	6417000	1.827	13387000	1666000	1000
1987	14100000	8513000	1.706	15850000	1750000	0

CONTINUES...

Source:
a) Tercero y Sexto Informe de Gobierno de José López Portillo. Anexo 1 Estadístico Histórico 1979 y Sector Agropecuario 1982 (38).
b) Quinto Informe de Gobierno de Miguel de la Madrid H. Estadístico 1987 (39).
c) Dirección General de Economía Agrícola, SARH. "Consumos Aparentes de - Productos Agrícolas 1925-1982". Econotecnia Agrícola Vol. 1 No. 9 México 1984 (63).

TABLE No. 9

... CONTINUATION

YEAR	RURAL PRICE MAIZE (1)	SUPPORT PRICE MAIZE (1)	SEED PRICE MAIZE (1)	NITROGEN FERTILIZER PRICE (2)	PRICE INDEX GNP	EXCHANGE RATE PESO/DLL
1970	905	940	4600	3400	100.00	12.50
1971	900	940	4600	3410	105.90	12.50
1972	902	940	4960	3410	112.46	12.50
1973	1409	1212	5700	3720	126.89	12.50
1974	1463	1500	6500	3720	155.74	12.50
1975	1862	1900	6500	4720	180.00	12.50
1976	2167	2340	6800	4310	215.41	19.95
1977	2837	2900	9000	4590	280.98	22.73
1978	2912	2900	17500	6740	327.87	22.72
1979	3530	3480	20000	6740	394.43	22.80
1980	5019	4450	25000	7010	507.54	23.26
1981	5569	6550	25000	8760	645.57	26.23
1982	9766	8850	37000	12150	1040.98	57.44
1983	20252	17600	100000	26890	2000.33	120.17
1984	34250	29475	116000	35440	3349.18	167.77
1985	52587	48400	140000	59790	5344.92	256.96
1986	91050	96000	265000	109720	8848.52	611.35
1987	210750	245000	600000	473400	22688.52	1366.35

(1) Price per metric ton.
(2) Price per unit of nutrient.

Source: a) Dirección General de Economía Agrícola, SARH. "Consumos Aparentes de Productos Agrícolas 1925-1982" Econotecnia Agrícola. Vol. 1 No. 9 - México 1984 (63).
b) Quinto Informe de Gobierno de Miguel de la Madrid H. Estadístico -- 1987 (39).
c) Productora Nacional de Semillas, SARH.
d) FERTIMEX Gerencia de Planeación y Ventas.

TABLE No. 10 MEXICO GRAINS PRODUCTION AND CONSUMPTION FORECASTS TO 2000
(THOUSAND METRIC TONS)

	MAIZE	WHEAT	RICE	SORGHUM	TOTAL
SRO (1)					
CONSUMPTION	24 407	8 026	783	14 450	47 666
PRODUCTION	19 125	6 500	1 413	11 311	38 349
NET IMPORT**	5 282	1 526	-630	3 139	9 317
FAO (2)					
CONSUMPTION	18 144	9 107	1 566	12 200	41 017
PRODUCTION	14 195	6 500	1 287	11 311	33 293
NET IMPORT**	3 949	2 607	279	889	7 724
CESPA (3)					
CONSUMPTION	16 937	6 431	1 566	18 885	43 819
PRODUCTION	18 938	3 535	1 413	5 847	29 733
NET IMPORT**	-2 001	2 896	153	13 038	14 086
C Y P (4)					
CONSUMPTION	24 574	6 833	707	14 177	46 291
PRODUCTION	19 125	5 010	913	10 327	35 375
NET IMPORT**	5 449	1 823	-206	3 850	10 916

**A NEGATIVE NET IMPORT IMPLIES A SURPLUS.

SOURCES:
(1) REYES O., SERGIO. "PRODUCCION Y CONSUMO DE ALIMENTOS EN MEXICO. UNA IMAGEN AL AÑO 2000", MIMEOGRAPHED (MAY, 1981) (57;. REYES DID NOT FORECAST PRODUCTION. NET IMPORTS ARE CALCULTAED USING THE LARGEST FORECASTED PRODUCTION ESTIMATED BY SOME OF THE OTHER AUTHORS.
(2) NACIONES UNIDAS, FAO,"AGRICULTURA,HORIZONTE 2000",(ROME, 1981) (21).
(3) CENTRO DE ESTUDIOS DE PLANEACION AGROPECUARIA. "EL DESARROLLO AGROPECUARIO DE MEXICO,PASADO Y PERSPECTIVAS" VOL. XIII, S.A.R.H. ONU/CEPAL (1982) (13).
(4) CASAS D., EDUARDO Y PUENTE G.,ARTURO "LA PERSPECTIVA ALIMENTARIA EN MEXICO". COLEGIO DE POSTGRADUADOS, MIMEOGRAPHED (OCTOBER, 1983) (11).

TABLE No. 11 INIFAP PREDECESSORS ANNUAL BUDGET SERIES 1961-1986
(MILLIONS OF PESOS)

	T O T A L		I N I A[1]		I N I P[2]		I N I F[3]	
	CURRENT	CONSTANT 1983=100	CURRENT	CONSTANT 1983=100	CURRENT	CONSTANT 1983=100	CURRENT	CONSTANT 1983=100
1961			24.4	675.3				
1962			27.1	727.3				
1963			26.3	695.3				
1964			28.3	695.9				
1965	29.5	709.0	25.4	610.4	3.0	72.1	1.1	26.5
1966	39.9	722.9	35.2	814.1	3.5	81.0	1.2	27.8
1967	43.6	980.8	34.1	767.1	8.5	191.2	1.0	22.5
1968	50.2	1,109.0	33.1	731.4	16.0	353.3	1.1	24.3
1969	70.0	1,286.2	38.1	817.0	26.0	342.8	5.9	126.4
1970	85.8	1,734.7	39.5	798.3	40.0	809.0	6.3	127.4
1971	107.6	2,073.4	55.9	1,077.6	39.7	764.7	12.0	231.1
1972	140.2	2,520.0	70.7	1,270.6	53.6	963.6	15.9	285.8
1973	212.5	3,386.4	128.5	2,047.6	61.7	983.4	22.3	355.4
1974	246.9	3,204.5	144.7	1,877.8	59.4	771.1	42.8	555.6
1975	438.1	4,914.2	320.0	3,589.5	105.5	1,183.4	12.6	141.3
1976	555.1	5,203.1	342.0	3,204.0	105.5	989.7	107.6	1,009.4
1977	799.0	5,746.8	521.0	3,747.3	111.0	798.4	167.0	1,201.1
1978	972.0	5,989.9	612.0	3,771.4	145.4	896.0	214.6	1,322.5
1979	1,535.5	7,866.2	985.0	5,046.0	248.5	1,273.0	302.0	1,547.1
1980	2,594.1	10,327.9	1,796.0	7,150.4	413.4	1,645.9	384.7	1,531.6
1981	3,553.9	11,168.1	2,647.0	8,318.1	232.4	730.3	674.5	2,119.6
1982	4,865.1	9,442.2	3,181.1	6,173.7	787.4	1,528.2	896.6	1,740.1
1983	6,899.9	6,899.9	4,679.8	4,679.8	1,081.0	1,081.0	1,139.1	1,139.1
1984	12,733.8	8,366.5	9,576.4	6,015.3	1,719.0	1,079.0	1,438.4	903.5
1985	19,153.9	7,349.6	14,198.9	5,548.3	2,638.0	1,012.2	2,317.0	889.1
1986	24,305.8	5,925.4	18,255.6	4,450.4	3,158.1	769.9	2,892.1	705.0

1. Agricultural Activities.
2. Livestock activities.
3. Forestry Activities.

Source: Information compiled by: Coordinación de Diagnóstico Socioeconómico, Zona Centro, INIFAP, as quoted by Moncada (44).

TABLE No. 12 MEXICO's AGRICULTURAL RESEARCH INTERNAL RATES OF RETURN AND NET BENEFIT COST RATIOS

SOURCE	PERIOD	COMMODITY	INTERNAL RATE OF RETURN %	NET BENEFIT COST RATIO
ARDITO	1943-63	CROPS	54-82	
ARDITO	1943-63	WHEAT	60-104	
ARDITO	1943-63	MAIZE	26-59	2.63
MARQUEZ	1951-70	MAIZE	26-58	
RUVALCABA	1960-72	MAIZE	81	29.5
RUVALCABA	1973-86	MAIZE	78	13.5
RUVALCABA	1960-86	MAIZE		24.3
PUENTE	1977-83	MAIZE		13.5

Sources: Ardito (6), Márquez (40), Ruvalcaba (61), and Puente (55).

TABLE No. 13 INIFAP HIGH APPLIED MAIZE TECHNOLOGY PROGRAM: PRONAMAT

AREA TYPE	CHARACTERISTIC	HARVESTED AREA (Million Has)	POTENTIAL YIELDS (Ton/Ha)	POTENTIAL PRODUCTION (Million Tons)
I. Highly Productive.	Irrigated.	0.959	4.82	4.621
II. Very Good Productivity.	Excelent Rainfed Area. Deep Soils.	1.659	3.13	5.191
III. Good Productivity.	Excess of Rains.	1.010	2.74	2.767
IV. Medium Productivity.	Medium Risk of Drought.	2.875	2.52	7.246
V. Low Productivity.	High Risk of Droughts.	0.689	1.63	1.122
VI. Marginal.	Very High Risk of Drought.	0.351	1.07	0.374

Source: Turrent (71).

TABLE No. 14 EVOLUTION IN THE PRODUCTION OF CERTIFIED SEED OF MAIZE AND SORGHUM FOR THE PERIOD 1977-1988 (MT)

YEAR	MAIZE			SORGHUM			PRONASE	PRIVATES	TOTAL (1)
	PRONASE	PRIVATES	TOTAL	PRONASE	PRIVATES	TOTAL	TOTAL	TOTAL	
1977	9879	1920	11799	190	15460	15650	64704	100246	164950
1978	8666	4399	13065	1106	27501	28607	82139	153151	235290
1979	6533	4467	11000	1944	21039	22983	80590	152202	232792
1980	23972	3368	27340	892	15118	16010	133405	169244	302649
1981	32622	3119	35741	1646	20041	21687	187680	176131	363811
1982	17116	5131	22247	1053	17630	18683	215470	136823	352293
1983	26392	3937	30329	2623	21158	23781	139519	138747	278266
1984	13800	6008	19808	2314	34988	37302	133291	118702	251993
1985	10389	8306	18695	233	42165	42398	126178	150802	276980
1986	15047	8333	23380	1427	50664	52091	92862	149788	242650
1987	10763	7279	18042						
1988	8500	7604	16104						

(1) Represents the sum of all seed crops produced by PRONASE and private companies.

Source: Data proportionated by PRONASE.

TABLE No. 15. MAIN FIELDS OF STUDY ON PLANT BIOTECHNOLOGY IN MEXICO

ORGANIZATION [1]	FIELD OF STUDY				
	MICRO-PROPAGATION	GENETIC IMPROVEMENT	BASIC STUDIES	PRESERVATION OF GERMOPLASM	SECONDARY METABOLISM
1. CIATEJ	X				
2. CIB, B.C.S.	X				
3. CICY	X	X	X		X
4. CIFN-UNAM			X		
5. CINVESTAV-IRAPUATO	X	X	X		X
6. CINVESTAV-D.F.	X				X
7. CIMMYT		X	X		
8. CONAFRUT	X				
9. C.P.	X	X	X	X	X
10. ENCB-IPN	X		X		X
11. DEPTO. BIOQ. FAC.			X		
12. INST. BIOL-UNAM	X		X	X	
13. ININ	X				
14. INIFAP-ZACATEPEC	X	X		X	
15. ITAO	X				
16. ITESM		X			
17. UAAAN	X		X		
18. UACH	X				

1. The Complete names are:

1. CIATEJ: Centro de Investigación y Asistencia Técnica del Estado de Jalisco.
2. CIB, B.C.S.: Centro de Investigaciones Biológicas de Baja California Sur, A. C.
3. CICY: Centro de Investigación Científica de Yucatán, A. C. Depto. de Genética y Fisiología.
4. CIFN-UNAM; Centro de Investigación sobre fijación de nitrógeno-Cuernavaca.
5. CINVESTAV-IRAPUATO: Centro de Investigaciones y de Estudios Avanzados del IPN. Unidad Irapuato.
6. CINVESTAV-D.F.: Centro de Investigaciones y de Estudios Avanzados del IPN-Unidad D. F.
7. CIMMYT: Centro Internacional de Mejoramiento de Maíz y Trigo, A. C.
8. CONAFRUT: Comisión Nacional de Fruticultura.
9. C.P.: Colegio de Postgraduados, Centro de Genética, Montecillo, Edo. de Méx.
10. ENCB-IPN: Escuela Nacional de Ciencias Biológicas, I.P.N.
11. DEPTO. BIOL. FAC. QUIM-UNAM: Departamento de Bioquímica de la Facultad de Química, UNAM.
12. INST. BIOL-UNAM. Instituto de Biología. UNAM, Jardín Botánico Exterior.
13. ININ: Instituto Nacional de Investigaciones nucleares.
14. INIFAP-ZACATEPEC: Instituto Nacional de Investigación Forestal Agrícola y Pecuaria. Campo Experimental, Zacapatec.
15. ITAO: Instituto Tecnológico Agropecuario de Oaxaca No. 23.
16. ITESM: Instituto Tecnológico de Estudios Superiores de Monterrey.
17. UAAAN: Universidad Autónoma Agraria, Antonio Narro, Saltillo, Coahuila.
18. UACH. Universidad Autónoma de Chapingo, Depto. de Fitotecnia.

TABLE No. 16 RESEARCH INSTITUTION STAFFING LEVELS, 1989

LAB.	Ph.D.	M.S.	B. S.	TOTAL
CINVESTAV Irapuato	21	12	21	54
UNAM, Chem. Fac.	12	6	3	21
CEFINI, Cuernavaca	26	29	22	77
CICY, Mérida	5	7	20	32
POSTGRAD. COLLEGE CHAPINGO.	4	7	8	19
TOTAL	68	61	74	203

Source: World Bank, et al (1989) "Summaries of Country Reports" (80).

TABLE No. 17 COMPOSITION OF BIOTECH PROGRAMS BY ACTIVITY

ACTIVITY/SUBACTIVITY	PERCENTAGE BY SUB-CATEGORY	PERCENTAGE BY CATEGORY
PLANT BIOTECHNOLOGY		80
Micropropagation/tissue Culture	50	
Genetic Improvement	10	
Basic Studies	10	
Preservation of Germplasm	<5	
Secondary Metabolites	<5	
Pathogen free material	<5	
INDUSTRIAL AG. APPLICATIONS		15
Fermentation of foodstuffs		
Prod. of single cel protein		
ANIMAL BIOTECHNOLOGY		5
Embryo transfer		
Growth hormones		
Vaccines		
TOTAL		100

Sources: World Bank, et al (1989) "Summaries of Country Reports (80).

TABLE No. 18 POTENTIAL APPLICATIONS OF BIOTECHNOLOGY FOR INTEGRATION WITH CROP IMPROVEMENT PROGRAMS

COMPONENTS OF CONVENTIONAL GERMPLASM-BASED TECHNOLOGIES	CONVENTIONAL TIME SPAN	POTENTIAL BIOTECHNOLOGY CONTRIBUTION
GERMPLASM		
A. Acquisition/Exchange	1 year	In vitro culture, disease indexing and eradication, micropropagation
B. Conservation	Ongoing	in vitro conservation genelibraries.
	2 seasons	Molecular diagnostics, RFLPs.
	3-5 seasons	Embryo rescue, molecular diagnostics, somoclonal variation gene transfer
C. Evaluation		
D. Germplasm Enhancement		
	2 years	Embryo rescue, somoclonal variation,anther culture, protoplast fusion.
BREEDING		
A. Selection of Parental Germplasm		Molecular diagnostics, tissue culture derived lines, genetransfer.
1. Elite lines		
2. Adapted populations		
3. Exotic materials		
B. Initial development cross (F1)	1 year	Somoclonal variation, anther culture, molecular diagnostics, RFLP mapping.
C. Prodution & Selection of Segregating, lines (F2-F3)	2 seasons	Pathogen elimination, micropropagation
D. Controlled imbreeding (F4-F7)	3-4 seasons	
E. Bulk increase of finished lines	2 seasons	Pathogen elimination, micropropagation
TESTING		
A. Observational trials and/or Preliminary Testing	2 seasons	
B. International trials	2 seasons	
C. Advanced testing in national coordinated trials	2 seasons	Molecular diagnostics
D. Farmer's field trials	2 seasons	
DISTRIBUTION		
A. Bulk increase	1-2 seasons	
B. Certification	1 season	Micropropagation
C. Quarantine	1 season	Disease indexing and eradication
		Disease indexing, molecular diagnostics, micropropagation

Source: Persley, Gabriells, Ed. (1987) "Agricultural Biotechnology Opportunities for International Development" (52).

TABLE No. 19 MAIN RESEARCH PROGRAMS ON MAIZE BIOTECHNOLOGY IN MEXICO

ORGANIZATION	ACTIVITIES
Depto. de Bioquímica-Fac. Quim. (UNAM).	1. Basic studies on embryo germination 2. Effect of 2,4-D and mecorprop on embryo culture. 3. Nitrogen metabolism.
Laboratorio de Biotecnología del Centro de Genética del Colegio de Postgraduados (C.P.).	1. Morphogenesis: Embryogenesis and organogenesis. 2. Somaclonal variation (genetic improvement). 3. In vitro regulation of growth and development of reproductive structures.
Depto. de Bioquímica de la Fac. de Quim. (UNAM) and Laboratorio de Biotecnología del Centro de Genética del C. P.	1. In vitro culture of mature and inmature embryos. 2. Cell suspension culture to induce somatic embryogenesis. 3. Studies on biochemical markers during embryogenesis process.
CIMMYT	1. Use of restriction lenght polimorfisms (RFLP's), and DNA probes to increase the efficiency of the breeding programs.

BIBLIOGRAPHICAL REFERENCES

1. Academia Mexicana de Ingeniería (1986). *Alternativas Tecnológicas.* Mesas Redondas, Consejo Nacional de Ciencia y Tecnología, Mexico, D.F.

2. Aceves N., Everardo (1988). *Uso y Manejo del Agua en la Agricultura Mexicana.* Comercio Exterior, Banco Nacional de Comercio Exterior, July 1988. Mexico, D.F.

3. Adelman, Irma and J. Edward Taylor (1988). *Changing Comparative Advantage in Food and Agriculture: Lessons from Mexico.* OECD.

4. Agrosíntesis (1989). *El Nuevo Maíz H-149E, el mas Productivo de México,* interview with M.C. Alejandro Espinoza C., expert with the INIFAP seed technology network. Vol. 20, No. 3.

5. Angeles Arrieta, Hermilo (1986). *Programa de Mejoramiento Genético de Maíz y sus Avances en el INIFAP.* CIDAGEM, PRONASE, Toluca, Mexico.

6. Ardito Barletta, Nicolas (1971). *Costs and Social Benefits of Agricultural Research in Mexico.* Ph.D thesis, University of Chicago.

7. Arroyo, Gonzalo and Mario Waissbluth (1988). *Desarrollo Biotecnológico en la Producción Agroalimentaria de México: Orientaciones de Politica.* Comisión Económica para América Latìna y el Caribe (CEPAL), Naciones Unidas, Mexico, D.F.

8. Badillo Navarrete, Ernesto (1981). *El Sistema de Semillas Certificadas en México.* M.S. thesis, Colegio de Postgraduados, Chapingo, Mexico.

9. Byerlee, Derek, Larry Harrington and Donald L. Winkelman (1982). Farming System Research: Issues in Research Strategy and Technology Design. *American Journal of Agricultural Economics, 64 (5).*

10. Carlson, Peter (1989). One Company's Attempt to Commercialize an Agricultural Biotechnology. In *Strengthening Collaboration in Biotechnology: International Agricultural Research and the Private Sector,* Bureau for Science and Technology, Agency for International Development, Washington, D.C.

11. Casas Díaz, Eduardo and Arturo Puente (1983). *La Perspectiva Alimentaria en México.* Colegio de Postgraduados. (mimeographed), Chapingo, Mexico.

12. Centro de Estudios en Planeación Agropecuaria (CESPA) (1982a). *El Desarrollo Agropecuario de México: Pasado y Perspectivas.* Tomo V, La Problemàtica Alimentaria, Secretaría de Agricultura y Recursos Hidráulicos, Mexico, D.F.

13. Centro de Estudios en Planeación Agropecuaria (CESPA) (1982). *El Desarrollo Agropecuario de México: Pasado y Perspectivas.* Tomo XIII, Perspectivas de la Demanda y de la Oferta de Productos Agropecuarios, Secretaría de Agricultura y Recursos Hidráulicos, Mexico, D.F.

14. CIMMYT (1989). *CIMMYT in the year 2000: a Strategic Plan.* Mexico, D.F.

15. CIMMYT (1987). *1986. CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.* Mexico, D.F.

16. CIMMYT (1986). *Development, Maintenance, and Seed Multiplication of Open Pollinated Maize Varieties.* Mexico, D.F.

17. Colegio de Postgraduados (1989). *Investigación en el Colegio de Postgraduados y sus Perspectivas.* Memoria, Montecillo, Mexico.

18. Echeverría, Ruben (1988). *Public and Private Sector Investments in Agricultural Research: The Case of Maize.* Ph.D thesis, University of Minnesota.

19. Evenson, Robert and Johnathon Putman (1989). Intellectual Property Rights and Biotechnology. In *Agricultural Biotechnology Opportunities for International Development.* CAB International, U.K. (in press) (as cited by Persley, 1989).

20. FAO (1984). *Estructura y Caracteristicas de la Economía Mundial de Maíz Blanco.* UN Committee on Problems of Primary Products, Rome.

21. FAO (1981). *Agricultura: Horizonte 2000.* United Nations, Rome.

22. Gilliland, Martha (1988). "A Study of Nitrogen Fixing Biotechnologies for Corn in Mexico". *Environment,* April 1988.

23. González Estrada, Adrian (1989). *El Apoyo Financiero del Estado a la Investigación Agropecuaria y Forestal en México.* Coordinación del Programa de Diagnóstico Socioeconómico, INIFAP, Chapingo, Mexico.

24. Grupo Interinstitucional (1989). *La Producción Nacional de Productos Básicos y el Comercio Mundial.* Síntesis Ejecutiva, SARH, Mexico.

25. Hernández Laos, E. and J. Córdoba, Ch. (1979). *Estructura de la Distribución del Ingreso en México.* Comercio Exterior, May 1979, Mexico, D.F.

26. Hernández Xolocotzi, Efraìn (1987). "Consumo Humano de Maiz y el Aprovechamiento de Tipos con Alto Valor Nutritivo" In *Xolocotzi: Obras de Efraín Hernández Xolocotzi,* Revista de Geografìa Agrìcola, Universidad Autónoma, Chapingo, Mexico.

27. Instituto Nacional de Estadística, Geografía e Informàtica (1988). *Abasto y Comercialización de Productos Bàsicos: Maíz.* Mexico D.F.

28. Instituto Nacional de Investigaciones agrícolas (1982). *Diagnóstico de la Investigación Realizada por el INIA.* INIA, Secretaría de Agricultura y Recursos Hidráulicos, Mexico, D.F.

29. INIFAP (1985). *Antecedentes Históricos del Instituto Nacional de Investigaciones Pecuarias.* Secretaría de Agricultura y Recursos Hidráulicos, Mexico, D.F.

30. INIFAP (1989a). *Aportación del INIFAP a la Soberanía Alimentaria.* Mexico, D.F.

31. INIFAP (1989b). *Marco Orientador General Institucional. Instituto Nacional de Investigaciones Forestales y Agropecuarias.* Mexico, D.F. (mimeographed).

32. Instituto Politécnico Nacional. Centro de Investigaciones y de Estudios Avanzados (CINIVESTAV) (1987). *III Reunión Nacional de Bioquímica y Cultivo de Tejidos Vegetales.* Irapuato, Gto. Mexico.

33. Instituto Politécnico Nacional. Escuela Nacional de Ciencias Biológicas (1988). *30 Años de Investigación en Biotecnología en México.* VII Congreso Nacional de Ingeniería Bioquímica, Mexico, D.F.

34. Jewell, David (1989). *Gene Technology and Plant Breeding at CIMMYT.* CIMMYT, Mexico, D.F.

35. Jiménez Sánchez, Leobardo (1988). Mexico Learns from Plan Puebla, in *Fighting Rural Hunger in a World Full of Grains.* Ed. by L. Jiménez *et al,* Colegio de Postgraduados, Montecillos, Mexico.

36. Jones, K.A. (1987). *Gradient of Biotechnologies.* International Center for Research in the Semi-Arid Tropics (ICRISAT), Hyderabad, India. (mimeographed).

37. Lamartines Yates, Paul (1978). *El Campo Mexicano,* Ediciones El Caballito, Mexico.

38. López Portillo, José (1982). *Sexto Informe de Gobierno.* Presidencia de la República, Mexico, D.F.

39. Madrid Hurtado, Miguel de la (1987). *Quinto Informe de Gobierno.* Presidencia de la República, Mexico, D.F.

40. Màrquez Arias, Edagar (1975). *Evaluación de la Inversión en Investigación Agrícola: Caso del Maíz y Sorgo en México.* M.Sc. thesis, Colegio de Postgraduados, Chapingo, Mexico.

41. Márquez Sánchez, Fidel (1986). *Análisis de la Investigación en el Mejoramiento Genético del Maíz en México.* Chapingo, Mexico, September 1986. (mimeographed).

42. Martínez, J. Carlos, *et al.* (1986). *Toward Farm-Based Policy Research: Learning from Experience.* CIMMYT, Mexico, D.F.

43. Matus Gardea, Jaime and Ralph W. Bierlen (1987). *A Review of the Mexican Grain Situation.* Presented at KIFP/FS, Workshop on Grain Trade, Ithaca, N.Y., September 1987. (mimeographed).

44. Moncada de la Fuente, Jesús (1988). *Evolution, Challenges and Perspectives of Agricultural Research in Mexico.* January 1988, Mexico, D.F. (mimeographed).

45. Montañez, Carlos and Arturo Warman (1985). *Los Productores de Maíz en México: Restricciones y Alternativas.* Centro de Ecodesarrollo, Mexico.

46. Ortíz Cereceres, Joaquín (1988a). *La Formación de Recursos para la Investigación y la Producción de Semilla.* Centro de Genética, Colegio de Postgraduados. (mimeographed).

47. Ortíz Cereceres, Joaquín (1988b). *Algunas Consideraciones y Justificación para el Reforzamiento de los Programas de Mejoramiento del INIFAP.* Red de Maíz, INIFAP. (mimeographed).

48. Ortíz Cereceres, Joaquín (1988c) *Importancia de la Investigación en el Mejoramiento Genético en la Red de Maíz del INIFAP.* Red de Maiz, INIFAP. (mimeographed).

49. Ortíz Cereceres, Joaquín (1987). *Redituabilidad de la Investigación en el Mejoramiento Genético del Maíz.* Centro de Genética, Colegio de Postgraduados, Chapingo, Mexico. (mimeographed).

50. Pereira, Gonzalo et al (1987). *Análisis Económico del Cultivo del Maíz en México en el Ciclo Primavera-Verano.* Revista de Econotecnica Agrícola, Dirección de Economía Agrícola, SARH, Mexico.

51. Pérez Espejo, Rosario (1988). *El Sector Pecuario en México: Caracteristicas y Perspectivas.* Comercio Exterior, August 1988, Mexico.

52. Persley, Gabrielle (ed. 1989). *Agricultural Biotechnology Opportunities for International Development.* Synthesis report, World Bank, ACIAR, AIDAB, ISNAR.

53. Poder Ejecutivo Federal (1984). *Programa Nacional de Desarrollo Tecnológico y Científico (PRONDETYC) 1984-1988.* Poder Ejecutivo Federal, Mexico, D.F.

54. Puente González, Arturo (1983). *Evaluación de la Productividad de los Insumos y del Efecto de la Investigación Agrícola en los Sectores Productivos de la Agricultura Nacional.* B.Sc. thesis, UACH, Chapingo, Mexico.

55. Puente González, Arturo (1984). *Impacto del Uso de Semillas Mejoradas en la Producción.* Colegio de Postgraduados, Chapingo, Mexico.

56. Quintero Ramírez, Rodolfo (ed. 1985). *Prospectiva de la Biotecnología en México.* Fundación Javier Barrios Sierra, CONACYT, Mexico, D.F.

57. Reyes Osorio, Sergio (1981). *Producción y Consumo de Alimentos en México: Una Imagen al Año 2000.* (mimeographed).

58. Roberts, Donna H. and Myles J. Mielke (1986). *Mexico: An Export Market Profile.* Foreign Agricultural Economic Report 220, USDA, Washington, D.C.

59. Roca, William (1985). *Directorio Latinoamericano de Biotecnología Agrícola.* Centro de Investigaciones de Agricultura Tropical, Colombia.

60. Rodríguez Vallejo, José (1988). *La Producción y la Demanda de Granos Básicos en México: Sus Proyecciones al año 2000.* Comercio Exterior, July 1988, Mexico.

61. Ruvalcaba Limón, Jaime (1988). *Evaluación Económica de la Investigación del INIA en el Cultivo del Maíz en México.* B.Sc. thesis, UACH, Chapingo, Mexico.

62. Secretaría de Agricultura y Recursos Hidráulicos (1982). *Memoria de Labores de la SARH, 1977/1982.* SARH. Mexico, D.F.

63. Secretaría de Agricultura y Recursos Hidráulicos (1984). *Consumos Aparentes de Productos Agrícolas 1925-1982.* Econotecnica Agrícola, Vol. 1, No. 8, Mexico.

64. Secretaría de Agricultura y Recursos Hidráulicos. Centro Nacional de Investigaciones Agrarias (CNIA) (1987). *Cuadernos de Biotecnología Agroalimentaria.* Cuernavaca, Mor., Mexico.

65. Secretaría de Agricultura y Recursos Hidráulicos (1988). *Encuesta Nacional de Costos, Coeficientes Técnicos y Rendimientos de la Producción Agrícola.* Resultados 1985/1987, Dirección de Planeación.

66. Secretaría de Educación Pública. Consejo del Sistema Nacional de Educación Tecnológica (1984). *La Investigación en Biotecnología y Bioingeniería.* Catálogo 1984, Mexico, D.F.

67. Secretaría de Educación Pública. Consejo del Sistema Nacional de Educación Tecnológica (1984). *Potencial para el Desarrollo de la Ingeniería Genética.* Catálogo 1984, Mexico.

68. Serrano, José Luis (1987). *Estudio Económico Sobre la Investigación, Producción y Comercialización de Semillas Mejoradas en México.* Mexico, D.F. (mimeographed).

69. Sistema Integral de Estímulos a la Producción Agropecuaria (SIEPA) (1987). *Proyecto Estratgico de Fomento a la Producción de Maíz.* SARH, Mexico.

70. Timothy, David H., Paul H. Harvey and Christopher R. Dowswell (1988). *Development and Spread of Improved Maize Varieties and Hybrids in Developing Countries.* Bureau for Science and Technology, Agency for International Development, Washington, D.C.

71. Turrent Fernández, Antonio (1988) *Aportación del INIFAP a la Soberanía Alimentaria.* Mexico, D.F. (mimeographed).

72. Turrent Fernández, Antonio (1986). *Estimación del Potencial Productivo Actual de Maíz y Frijol en la República Mexicana.* Colegio de Postgraduados, Chapingo.

73. Turrent Fernández, Antonio (1985). *Research and Technology for Mexico's Small Farmers.* Mexico, D.F. (mimeographed).

74. Universidad Autónoma Chapingo y Sociedad Mexicana de Fitogéntica (1988). *Resúmenes del XII Congreso de Fitogéntica.* Chapingo, Mexico.

75. Universidad Autónoma de Nuevo León y la Sociedad Mexicana de Biotecnología y Bioingeniería, A.C. (1989). *III Congreso Nacional de Biotecnología y Bioingeniería.* Memorias, Monterrey, Nuevo León, Mexico.

76. Universidad Autónoma Metropolitana. Departamento de Biotecnología. *Folleto,* Mexico, D.F.

77. Universidad Nacional Autónoma de Mexico, Coordinación de la Investigación Científica (1984). Centro de Investigación sobre Ingeniería Genética y Biotecnología. *Folleto,* Mexico, D.F.

78. Wellhausen E.J., L. M. Roberts, E. Hernández Xolocotzi, P.C. Mangelsdorf (1987). "Razas de Maíz en México", (1951), in Xolocotzi: *Obras de Efraín Hernández Xolocotzi,* Revista de Geografía Agrícola, Universidad Autónoma, Chapingo, Mexico.

79. World Bank, ISNAR, AIDAB, ACIAR (1989). *Summaries of Commissioned Papers.* Biotechnology Study Project Papers.

80. World Bank, ISNAR, AIDAB, ACIAR (1989). *Summaries of Country Reports.* Biotechnology Study Project Papers.