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EMERGING MAIZE BIOTECHNOLOGIES AND THEIR POTENTIAL IMPACT

by

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SUMMARY

Between 1955 and 1985 world maize production almost doubled. With little new land available, future growth in world production must come from higher yields and, hence, from new technologies. This paper describes some of the emerging maize biotechnologies, outlines progress made in R & D and discusses their possible impact on maize production.

At present, the new biotechnologies are directed more towards quality enhancement (modification of starch, protein or oil content) and towards endowing plants with particular properties (herbicide tolerance, resistance to pests or adverse weather conditions) than towards increasing yields *per se*. They offer hope for reduced environmental stress through reduced levels of application of agricultural chemicals. Like earlier technologies, however, most new biotechnologies will be incorporated in seeds and will therefore complement and continue to depend on, traditional plant breeding.

A new maize research and technology development system is emerging in which, in addition to the international research institutions (CIMMYT, IITA) and the national centres, the private sector is playing a crucial role. While in principle this new configuration would permit accelerated transfer of technology to developing countries, the new biotechnologies raise sensitive policy issues, such as the environmental safety of applications and intellectual property rights.

RESUME

Entre 1955 et 1985, la production mondiale de maïs a presque doublé. Compte tenu de la rareté des nouvelles terres disponibles, seule une augmentation des rendements permettra dans l'avenir un accroissement de la production mondiale, ce qui implique la mise en oeuvre de nouvelles technologies. Le présent document décrit quelques-unes des applications les plus récentes de la biotechnologie au maïs, indique les progrès réalisés dans le domaine de la R-D et examine leur incidence possible sur ce type de production.

A l'heure actuelle, les nouvelles techniques biologiques visent davantage à améliorer la qualité (modification de la teneur en amidon, en protéines ou en huile) et à doter les plantes de propriétés spécifiques (tolérance aux herbicides, résistance aux parasites ou aux conditions météorologiques défavorables) qu'à augmenter les rendements proprement dits. Ces techniques offrent l'espoir de réduire les contraintes qui s'exercent sur l'environnement en abaissant les taux d'application des produits agrochimiques. Tout comme les technologies antérieures, cependant, les nouvelles techniques biologiques seront pour la plupart appliquées aux semences et compléteront donc, sans pour autant s'y substituer, les techniques classiques d'amélioration génétique des plantes.

Un nouveau système de recherche et de développement technologique sur le maïs est en train de se mettre en place dans lequel, outre les organismes de recherche internationaux (CIMMYT, IITA) et les centres nationaux, le secteur privé joue un rôle déterminant. En principe, cette nouvelle configuration devrait permettre d'accélérer les transferts de technologie vers les pays en développement, mais le recours à de nouvelles techniques biologiques posent des questions de fond sur le plan de l'action, notamment celles relatives à la securité des applications à mettre en oeuvre du point de vue de l'environnement et des droits de la propriété intellectuelle.

PREFACE

The Development Centre is currently finalising research on "Biotechnology and Developing Countries: The Case of Maize", under the direction of Carliene Brenner. This has been undertaken in the broader context of the Centre's research programme on "Changing Comparative Advantages in Food and Agriculture".

The principal objective of the project is to assess the prospects, for a number of developing countries, of incorporating new technologies in maize production and, by implication, enhancing their competitiveness in relation to that crop. The research focuses on the institutional aspects of technological change in developing countries.

Maize was selected as the subject of the study for a number of reasons. It is one of the world's major cereal crops, an important food and/or feed crop in many developing countries and is a product for which demand continues to expand, particularly for use as livestock feed. Maize is also a crop on which considerable research effort is currently concentrated. It is therefore an eminently suitable subject for examining the issues raised for developing countries by the changes occurring in the research environment.

W.B. Sundquist has contributed this Technical Paper on "Emerging maize biotechnologies and their potential impact" to the project. It identifies the principal "frontier" biotechnologies related to maize and discusses the nature of their expected impact on maize production.

When completed, the project will include analyses of technology trends and of trends in the supply, demand and trade of maize internationally. It will also draw general conclusions and policy implications from four country studies (Brazil, Indonesia, Mexico and Thailand). The study is due for completion early in 1990 and will be published later in that year.

Louis Emmerij

President of the OECD Development Centre

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INTRODUCTION

The world acreage of maize in 1986 totalled about 131.5 million hectares with a production of about 480.6 million metric tons (1986 FAO Production Yearbook). This represents an approximate threefold increase in production over that in 1955. Since hectarage under production increased only by about one-fourth during this period, most of the production increase came via a more than doubling in yields per hectare (Echeverria, 1988). Although some very modest future increases in hectarage under maize production are likely, any major increases in world-wide production must come through additional increases in per hectare yields. And, despite the major yield increases of recent decades, future yields are expected to continue their trends to still higher levels. This is true because 1) much of the technology already in extensive use in the developed countries has not yet been transferred to many of the developing countries and 2) new technology, particularly in the area of the emerging biotechnologies, will be coming on stream in the near future. It is to this latter topic that this paper is mainly directed. However, some perspective on technologies which have fuelled past yield gains is relevant 1) because of the differential rates at which these technologies have been adopted and exploited to-date in different production environments and 2) because future technologies will interact in their impacts with those technologies already in use.

Although it is not uncommon to assess all maize production technologies in terms of their contribution to increased yields (sometimes expressed as a higher harvestability index), several other objectives also are important in inducing technological change. The more important include cost reduction (input savings), improved product quality and, of more recent importance, environmental cleanliness. And, of course, *ceteris paribus*, yield gains typically do have the salutary effect of reducing per bushel costs.

OBJECTIVES

This paper has two major objectives: 1) to identify and briefly describe principal current and emerging trends for maize production technology with emphasis on the emerging biotechnologies, and 2) to informally assess the research progress on these technologies and the nature of their expected impacts on maize production.

TRADITIONAL TECHNOLOGIES FOR MAIZE

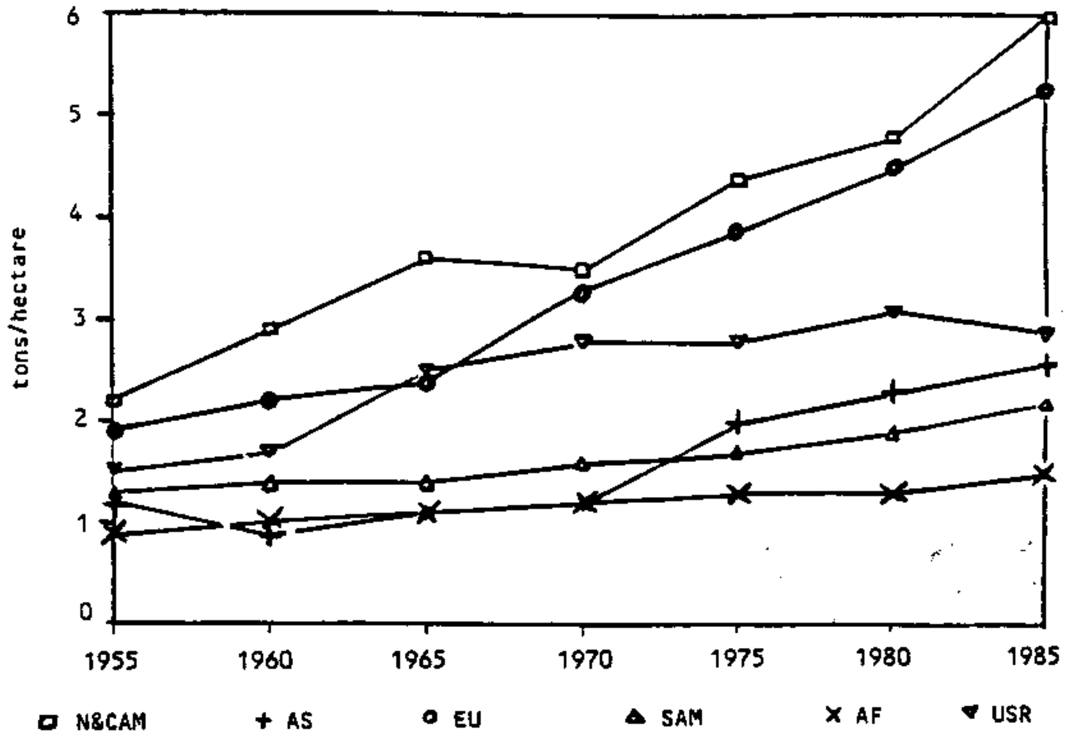
Sundquist, et al. (1982) used a "technology assessment" framework to evaluate impacts of the technologies applied to U.S. maize production over the five decade period from 1930 to 1980[1]. During this period, yields in the U.S. increased about fourfold from about 50 bushels to more than 250 bushels per hectare. Central to these yield increases were the development and application of fertilizer and conventional plant breeding technologies. Yield increases from soil moisture modification (irrigation and drainage) were important for some but not all production environments. Use of chemical pesticides had modest positive effects on maize yields via reduced stress from insects and weeds while the dramatic revolutions in mechanization technology and herbicide use had major impacts on maize production via an eighty-eight percent decline in labour hours per hectare from about 75 hours in 1930 to 8.7 in 1980. In addition, improved management and information systems, improved tillage methods, and other technologies, although contributing to increased maize yields, are not generally maize specific.

Analysis by Echeverria (1988) shows that the rates of maize yield increases for North and Central America and Europe from 1955 to 1985 far exceeded those for Africa, South American and Asia (Figure 1). This supports the hypothesis that substantial future yield increases in the developing countries are likely to occur from the further transfer, modification and adoption of production technologies already in use. In this paper, I use the term, "traditional" for those established technologies which preceded in their commercialization the so called "emerging" biotechnologies.

Of particularly worthwhile note with respect to the traditional technologies are the situations by which 1) a number of these technologies, (e.g., conventional plant breeding, chemical fertilizers, chemical pesticides, improved tillage methods and supplemental irrigation) exhibit a high degree of complementary-type interaction with each other in the generation of increased maize yields and 2) the emerging biotechnologies can also be expected to interact with several of these traditional technologies (e.g., conventional plant breeding, fertilizer, Figure 1. Maize Yield by World Region, 1955-85 and chemical pesticides). Conventional plant breeding technology, particularly, will be a crucial (complementary) link in moving the laboratory and field test achievements from the emerging biotechnologies into commercial (farm-level) utilization. However, in the case of chemical fertilizers and pesticides, particularly the latter, at least some of the emerging biotechnologies will have a <u>substitution</u> rather than a <u>complementary</u> effect with these traditional technologies. Thus, in any comprehensive analysis of the economic impacts (including both cost and yield effects) of the emerging biotechnologies, one should develop a matrix of expected interactions which permits both substitution and complementary effects in relation to existing technologies.

Since the traditional technology of conventional plant breeding is such a central component of future maize production technologies, I have also undertaken to profile this technology in the section which follows.

Figure 1. Maize Yield by World Region, 1955-85



Note: N&CAM = North and Central America
AS = Asia
EU = Europe
SAM = South America
AF = Africa
USR = USSR

SOURCE: Echerverria (1988) page 40.

Conventional Plant Breeding

Development of maize germplasm is accomplished by several mechanisms some of which are used mainly in developing country environments. The first is that of using so-called open pollinated varieties of germplasm from which farmers (or others) can collect their own seed. This is a common process in developing countries. A second procedure (sometimes referred to as non-conventional hybrids) takes two forms, a) the crossing of two open pollinated varieties (termed a varietal hybrid), and b) the crossing of an open pollinated variety with an inbred line (an improved line of germplasm which has undergone a process of selection and selfing) which is termed a top cross. Non-conventional hybrids are also used mainly within the plant breeding programmes of developing countries. The third process is that of conventional hybrids which include a) single crosses: the crossing of two unrelated inbreds, b) double crosses: crossing of two single crosses (which provides parentage from four unrelated inbreds), and c) three way crosses: crossing of a single cross with an inbred (which bases parentage on three unrelated inbreds). Most of the maize hectarage in developed countries is now grown with conventional hybrids. A variety of other breeding techniques are used, including so-called "backcrossing" to bring specific desired genetic traits into a line of otherwise satisfactory germplasm. This combination of breeding strategies permits a wide range of alternatives for developing improved plant materials. Excellent discussions of methods for germplasm enhancement are provided in Jugenheimer (1976), Aldrich, et al. (1986) and CIMMYT (1987). World maize areas under different seed types in 1985-86 are shown in Table 1.

Recent experimental data in the Unites States and in Mexico and Latin America have shown significant yield gains for hybrids over open-pollinated varieties. Among the hybrids, single crosses show the highest yields (by a small amount) followed by three-way crosses and then double crosses (CIMMYT, 1987). Yield differentials by seed types are, however, variable and need to be evaluated in terms of local plant materials and specific production environments.

Among the many objectives of conventional plant breeding have been those of increasing insect and disease resistance, increasing the yield responsiveness to chemical fertilizer, modification of plant forms, improved drought resistance, changes in maturity dates, etc., all of which contribute to the more general objective of yield enhancement. In addition, conventional plant breeding has often had the objective of modifying the protein content and other quality related characteristics of maize grain. More recently, attention has also been given to improving the harvestability and storage of maize grain.

Sundquist, et al. (1982) estimated that the annual yield gains in the United States from conventional plant breeding, in the presence of adequate plant nutrients, averaged about 2.5 bushels per hectare over the last several decades. Moreover, a similar rate of gain is expected to continue over the near term. Future increases from fertilizer technology, on the other hand, are expected to be minimal and per hectare application rates of N, P2O5 and K20 have all plateaued.

Despite broad past achievements from conventional plant breeding in yield gains, responsiveness to fertilizer, disease and insect resistance and maturity and grain quality modifications, major achievements continue to be made. For example, maize inbred lines have recently been released by Iowa State and Michigan State Universities which have resistance to the several generations of European corn borer. Moreover, it is to the technology of conventional plant breeding, along with chemicals (both fertilizers

TABLE 1 :

WORLD MAIZE AREA UNDER DIFFERENT SEED TYPES, 1985-86

	Total (million hectare)	Total Improved	Own Seed	Improved Variety	Hybrid Seed
		-- percent of total maize area --			
World	138.4	71	33	4	63
Developed Countries	57.3	98	2	0	98
Market economies	45.1	99	1	0	99
East Europe and USSR	12.1	95	5	0	95
Developing Countries	81.1	51	55	7	38
Less Argentina, Brazil and China	48.7	37	73	11	16
Africa	16.5	32	76	9	15
East and South	9.4	36	68	7	25
West	5.9	22	89	10	1
North	1.2	49	68	25	7
Asia	36.5	54	53	7	40
Asia less China	18.5	37	77	14	9
Middle East	1.2	44	66	11	23
South	7.7	34	83	6	11
Southeast and Pacific	9.0	37	76	21	3
East less China	0.6	68	40	8	52
China	18.0	72	28	0	72
Latin America	28.1	59	44	7	49
Less Argentina and Brazil	13.8	41	64	10	26
Mexico, C. America, and Caribbean	10.9	42	63	11	26
Andean	2.2	29	74	5	20
Southern Cone	15.0	76	26	4	70

Notes : In some cases, the percentage of total improved area is more than the sum of the areas under hybrids and improved varieties. Area improved accounts for varieties released during the past ten years, so it includes farmers' own seed that is derived from varieties released during that time.

Source : CIMMYT (1987) as presented in Echeverria (1988).

and pesticides), in some cases complemented by such new biotechnologies as plant tissue culture, that most of the near term yields gains will be achieved in the developing countries, particularly. In this connection, a very comprehensive list of open-pollinated maize varieties and hybrids recently released in 57 developing countries is presented in Timothy, et al. (1988).

An issue of continuing concern to maize breeders is that of developing excessive reliance on germplasm which may not have resistance to specific plant diseases. This concern became a reality in 1970 when the United States encountered an epidemic of race T of southern corn leaf blight and at least 80 percent of the maize crop was susceptible to the disease. Fortunately, in this case, genetic resistant germplasm was available and was quickly incorporated into commercial supplies of maize seed. This event supports the strong case for maintaining extensive germplasm banks to protect available genetic variability.

THE EMERGING BIOTECHNOLOGIES FOR MAIZE

Sundquist, et al. (1982) and Menz and Neumeyer (1982) assessed several of the emerging biotechnologies which scientists then expected to have significant future impacts on maize production. These were: 1) genetic modification at the cellular level via a) cell and tissue culture and b) genetic transformation, 2) photosynthetic enhancement, 3) plant growth regulators, and 4) biological nitrogen fixation. Research and development have since continued in all of these areas, and in others, but with varying degrees of achievement.

Genetic Transformation

Phillips (1988), in a recent update on maize genetic engineering, documents the current availability of several methods to produce transgenic plants. These include direct transfer of DNA by microinjection, electroporation (electrical pulses causing entry of DNA through pores created in cell membranes), use of a chemical bonding agent that enhances DNA entry into cells, and use of the particle gun to bombard seed with DNA-coated microprojectiles. In addition, *agrobacterium* - mediated transfer is used for several plant species to move a portion of bacterial DNA to the plant chromosomes and then regenerate plants from the infected tissue. Thus, gene transfer technology is now available in several operational forms.

Maize also has been transformed in work reported by Rhodes, et al (1988). These researchers utilized the electroporation process to produce transgenic maize plants from protoplasts treated with DNA encoding a selectable marker for resistance to the antibiotic Kanamycin. Although the resulting plants were sterile, a reasonable expectation is that subsequent work will produce viable seed from transgenic maize plants. Although the transfer of Kanamycin resistance to maize plants is not, in and of itself, a development of commercial significance, the accomplishment of genetic transformation is. This is particularly the case with the expectation that the process will eventually be used to produce viable seed which can convey the genetic transformation to subsequent generations of maize plants.

A genetic transformation of more specific interest to the maize sector is that of producing maize plants that carry a plant vaccine, InCideTM, which produces a high degree of toxicity control for second and third generation European corn borers (Carlson, 1989). This product was developed by Crop Genetics International, Inc. using a generally previously unheralded type of biotechnology. In this case the biotechnology actually combines three technologies, 1) an endophyte (or delivery system) technology[2], 2) a seed inoculation technology (via use of pressure) and 3) a genetic engineering technology. The endophytic technology involves use of Cxc, a bacterial genome, which colonizes in maize and most intensely in mature tissue. The Bt gene is inserted into the endophyte and acts against the corn borer. Because the endophyte colonizes most intensely in mature tissue, the plant vaccine InCideTM is most effective against second and third generation insects. The claim is made that this technology is more effective than chemical sprays for second and third generation borers, the costs are estimated at one-half, and the technology is clearly more environmentally sound. In terms of the time path to commercialization, InCideTM was field tested for safety in 1988 and is scheduled for seed inoculation field testing in 1989 and for efficacy testing in 1990.

The manufacturer of this product estimates that current economic losses in the U.S. from second and third generation European corn borers is of the magnitude of one-half billion dollars annually. Moreover, the technology may have multi-product potential for insecticide, fungicide and growth enhancer applications. If so, it may make substantial inroads into the current seven billion dollar world market for crop spray materials. Products using this combination of technologies must be applied to all seed used, however, and will not reproduce from one generation of seed to the next.

In summary of the emerging biotechnologies for genetic transformation, there now appears to be widespread potential for these types of biotechnologies, although the initial applications do not generate yield enhancement capability as such. Incorporation of the technology into germplasm (seed) makes its eventual use by farmers a very simple procedure compared to a variety of technologies which are not incorporated into the seed.

Cell and Tissue Culture

In the area of cell and tissue culture, several developments with maize are of broad based interest. In vitro selection for herbicide-resistant cell lines has become a highly successful venture (Phillips, 1988). Anderson and Georgeson (1988) selected several corn lines resistant to an imidazolinone and a sulfonylurea herbicide. These two types of herbicides were found to affect the same enzyme, and genetic segregation tests of regenerated plants showed resistance to be controlled by a single dominant gene. Imidazolinone resistance in corn plants was patented in 1988 and is already being incorporated into about 100 maize lines by Pioneer Hi-bred International, Inc., the largest U.S. maize seed company. Expectations are that hybrids with this herbicide resistance may be available commercially by 1992.

Tissue culture research also led to the development of a selection protocol to alter the amino acid content of maize kernels (Green and Phillips, 1974). Subsequently, high threonine maize mutants were derived as were lines with 20 percent more methionine than standard inbred lines. In the United States, poultry rations are supplemented with synthetic methionine at a cost of about $200 million per year (Phillips, 1988), and poultry is an increasingly important protein source in the diets of many developing country populations. Moreover, beans, which are a staple food in many developing countries, are deficient in methionine. Thus maize, with this amino acid enriched, could be an important diet balancing food crop. More recently, it has been determined that high-methionine maize lines are also high in other amino acids, particularly lysine (Benner and Phillips, cited in Phillips, 1988).

In summary of the achievements of cell and tissue culture for maize, they already include both plant resistance to stress factors, on the one hand, and enhanced product quality for grain, on the other hand, and the expectation is for other successful applications.

Molecular Genetic Markers

Another biotechnology development for maize not identified in the earlier technology assessment, but a spin-off from plant molecular biology research, is that of molecular genetic markers which permit analysis to determine similarities in forms of genes in different plant materials. These markers can then be correlated with specific plant traits to identify with strong reliability the presence of specific traits in crosses of varietal lines. Such markers are termed restriction fragment length polymorphisms (RFLPs), and are an invaluable tool in selecting for desirable plant traits without having to select directly on the basis of such traits. According to Phillips (1988), genes of interest in exotic germplasm may be more readily transferred into adapted lines with the assistance of linked RFLPs. Various recombinants between positive and negative linked traits may also be detected using this technology.

One of the uses for which RFLP markets have attracted broad-based interest is for the identification of chromosomal regions that have major effects on agronomic traits. This is done by analyzing for associations between a specific RFLP and variation associated with a specific trait. These genetic regions are called Quantitative Trait Loci (QTLs) and knowledge of those QTLs with major effects on a specific trait is expected to aid the plant breeding process. The International Center for Maize and Wheat Improvement (CIMMYT) is developing international networks of private companies and public institutions to gain information on QTLs for various agronomic traits (Phillips, 1988). The CIMMYT-European RFLP network involves four private companies and six public institutions from four countries. The CIMMYT North/Latin American RFLP network will initially involve several public institutions, and laboratories in Mexico and Brazil.

Photosynthetic Enhancement

Photosynthetic enhancement is generally defined as an increase in net carbon dioxide (CO_2) exchange rate by plants with the usual measurement index being that of the net CO_2 exchange rate per unit of leaf area. An index of more likely economic relevance is that of the CO_2 exchange rate per unit of land. Gifford and Colin (1982) suggest that "plant scientists over the years have tried to improve individual components of crop photosynthetic systems with little or no success in terms of increased yield. This is because in a complex system of multi-nested subsystems, alteration of one part often results in compensation, or even overcompensation, elsewhere." In more general terms, the lack of success from genetic improvement to improved leaf photosynthesis "may be because for crops, which are relatively well adapted to their environments, as most are in established agrosystems, no single physiological attribute is outstandingly limited."

Research to optimise plant forms and plant populations have increased total photosynthate production per unit area. However, the greatest impact on maize yields has surely been to partition (via selection and conventional plant breeding) a higher portion of total biomass into the yield (seed) component. Several possible routes to increasing photosynthetic enhancement are still under evaluation (Bunce, 1982). And, significant research efforts are underway to discover those factors which may be limiting existing photosynthetic rates. But, as for several other areas of biotechnologies for maize, previous research emphasis targeted directly on photosynthetic enhancement, as such, has lost ground in recent years relative to that for genetic engineering to achieve similar yield enhancement goals.

Plant Growth Regulators

As in the case of photosynthetic enhancement technology, plant growth regulators (PGRs) have not yet realized the potential maize yield gains expected of them earlier by many scientists (Sundquist, et al., 1982). Though major yield gains from this technology were not expected before the mid-1990s, interest in the technology has waned in recent years. In fact, several of the major chemical companies which had large PGR research programs in the early 1980s have now reduced or abandoned these research efforts.

Powerful PGRs are available for plant retardation and their major application potential still being researched for maize is that for reducing lodging by reducing internode elongation and thereby shortening plant height. Research by Gaska and Oplinger (1988) evaluated the potential practical applications to maize of the PGR ethephon. They found that this PGR significantly altered both plant growth and yield components. However, results are variable between years and treatment rates. Since the incidence of plant lodging is strongly weather dependent, and since weather conditions vary greatly from year-to-year, there does not yet appear to be strong evidence that the near term systematic use of PGRs has adequate economic incentives for use on maize. As in the case of photosynthetic enhancement technology, previous R & D interest in PGRs has waned as research interests have shifted strongly to genetic engineering as a potential source of modifying plant structure and performance.

Biological Nitrogen Fixation

Since maize yields are highly responsive to increases in nitrogen available for plant use, and since industrially produced fertilizer nitrogen is an expensive and energy intensive input, biological nitrogen fixation (BNF) is an attractive technology which continues to receive major research attention. No maize N_2 fixing bacterial association is, however, in commercial use. And, it appears unlikely that such technology could be commercialized in the near term of 5 to 10 years.

BNF could potentially occur via the alternative routes of a symbiotic or associative relationship or by genetic transformation, directly conveying the genetics for nitrogen fixation into the maize plant itself (Döbereiner in Graham and Harris, 1982). The latter approach (termed autosufficiency) which would involve expression of genetically engineered bacterial nitrogen fixation (nif genes) in maize, would, if successful, be a biotechnology of the greatest importance, but it appears likely that a large number of genes would be involved in such a transformation. Although it is almost universally believed that either of the above-mentioned alternative possible routes to BNF would result in energy drains to the plant which would reduce maize yields, modest yield reduction, *per se*, would not suffice to exclude the economic use of BNF technology. Tauer (1988) provides convincing evidence that major gains in both producer and consumer welfare could be realized with the adoption of BNF technology were it available.

In the expected absence of near-term commercialization of BNF for maize, either through the routes of symbiotic or associative technologies or those of genetic engineering, maize production will benefit from BNF technology mainly from the recovery of nitrogen from leguminous crops grown in rotation with maize. Although this is a complex topic which cannot be addressed here in detail, it is the case that maize does utilize N produced via fixation by legume crops in rotation. Moreover, increased BNF achievements are being realised in leguminous crops including alfalfa (Heichel, et al., 1989), and BNF is an increasing source of N in tropical agriculture (Fuglie and

Welsch, 1988). As of this date, at least five of the international agricultural research centers have established BNF research programs.

KEY CHARACTERISTICS OF THE EMERGING BIOTECHNOLOGIES

With respect to maize at least, five characteristics of the emerging biotechnologies seem worthy of note:

First, most of the commercial applications in the near term are those which will result in reduced environmental stress (e.g., herbicide tolerance, insect resistance, resistance to adverse weather conditions, etc.) or improved product quality (e.g., enhancement of protein content and/or quality). This is to say, they *will not have significant positive impacts on yield potential,* as such, but they will probably, on balance, reduce reliance on chemical pesticides. Yield-enhancing biotechnologies will generally need to await the capability to transfer rather complex configurations of genes. And, at least some maize producers will probably opt to delay their adoption of these new biotechnologies until they see significant yield gain opportunities;

Second, most, if not all, of these biotechnology achievements will be incorporated into improved germplasm (seed). This has some obvious implications relative to both the rate of adoption and the potential for technology transfer. The main investment by farmers for the technology will be the purchase of improved seed varieties. And, for example, maize producers will not be required to adopt greatly different cultural and management practices to gain the major benefits of the biotechnologies. Nor will a cadre of highly trained technicians be required to transfer the technology, although research to develop adaptable seed will generally be required for differing production environments;

Third, a significant contribution of biotechnology achievements to date have been in the form of developing the techniques and protocol for biotechnology research yet to come. For example, not only are there now multiple mechanisms for genetic transformation but the availability of molecular genetic markers opens the way for more rapid future progress in genetic engineering aimed at yield enhancement;

Fourth, the emerging biotechnologies have the potential for generating environmental benefits, particularly via the eventual reduction in the use intensity of agricultural chemicals. Successful transfer of the Bt gene into economic crops, including maize, is an example of such potential;

Fifth, and importantly, maize improvements achieved via the emerging biotechnologies will then need to be incorporated into plant material which must go through the processes of selection, crossing and seed multiplication which are accomplished through conventional plant breeding regimes. Thus, new biotechnologies <u>are not substitutes</u> for strong and productive plant breeding programmes.

KEY ISSUES OF THE EMERGING BIOTECHNOLOGIES

Two policy issues have generated a high degree of visibility relative to the emerging biotechnologies. One is the broad issue of the environmental safety of some applications and the second is that of intellectual property rights. Space permits only a very brief discussion of both issues.

Among the key questions surrounding the safety issue is that of accidental and/or deliberate release of potentially harmful genetically modified organisms. Earlier expressed fears relative to the creation and release of potentially "rogue" organisms have now greatly diminished. According to Regal (1985), "It is safe to say that contrary to other implications, no scientist...will now claim that all or even most recombinant DNA organisms will be categorically dangerous. This is a dead scientific issue in 1985." But, in another context, "there is an oversimplification of ecological issues in the claims that it will be quite safe to release essentially any genetically engineered form into the environment." Suffice it to say here that both the processes and products of the emerging biotechnologies (particularly those involving genetic engineering) will be subjected to intense surveillance, review and regulation, at least in the developed countries.

With respect to the issue of intellectual property rights, the emerging biotechnologies give rise to such concerns as the potential conflicts between private sector objectives and public research agendas. Other concerns relate to the freedom of exchange of technical information between public research institutions and private firms, and the nature of private property rights in maize varieties. In the United States, the passage of the plant protection act of 1970[3] and the 1980 Supreme Court decision (in re Diamond v. Chakrabarty) to allow patenting of life forms under Section 101 of the Patent Act have nominally increased the protection available to the seed industry and the genetic supply industry. However, members of both industries have expressed considerable discontent with the current laws, fearing they may not provide a level of protection commensurate with investment in R & D. Thus there may be increasing pressures on government to tighten or change some aspects of the patent/protection laws (Butler and Schmid, 1984).

Legislation for plant breeders rights (PBR) is now in effect mainly in the developed countries. Related issues of the conservation versus the erosion of genetic resources and equity issues involved in the development and diffusion (transfer) of new biological technology also involve the developing countries. In the case of maize, the native landraces and wild relatives are centered in Latin America and the Caribbean and the question of property rights to these genetic materials is a significant issue. Thus, the effectiveness of future maize germplasm development and transfer programmes can be materially impaired to the extent by which conflicting interests in plant property rights are not constructively resolved.

CHANGES IN MARKETS FOR MAIZE GRAIN

Until recently a very high proportion of U.S. produced maize found its way into domestic feed grain and export uses, and livestock feed, where enhancement of the quality and quantity of protein is highly desirous, continues to be much the largest use[4]. Between 1975 and 1986, however, food and industrial use increased by 134 per cent from about 502 to 1,175 million bushels with high fructose corn sweetners (HFCS), and alcohol representing the high rate increase items (Corn Annual, 1988). Among the wet milled products in 1986, 339 million bushels of maize were used for HFCS, 185 million for glucose and dextrose, 155 million for starch and 200 million for alcohol. In addition, for each bushel of maize used in wet milling, about 1.5 pounds of corn oil and 14 to 18 pounds of animal feed products are recovered. Use for dry milled products totalled 296 million bushels, of which 135 million bushels were for alcohol. Corn oil (crude and refined) shipments from the U.S. refining industry in 1987 totalled over 1 billion pounds.

Several developments account for the dramatic increase in the food and industrial use of maize. These include new and improved technology in refining, changing demand in food and industrial uses, and high price supports for the domestic sugar industry which also provides a price umbrella and profit incentive for HFCS. For wet milling, a gain of 1 per cent in the starch content of maize grain is estimated to be worth about 6 to 7 cents per bushel for grain used in ethanol production. Wide ranges in starch and oil composition have already been identified in existing maize germplasm, but maize seed companies are only now starting to put emphasis on breeding for protein, starch and oil content. And even such large U.S. industrial firms as Dupont have now established a "Division of Grain Quality" or its equivalent.

Currently in the United States, only about 3 per cent of the maize grain acreage is planted to special-use hybrids, including white maize for corn meal and grits, waxy maize for use as thickeners in the food industry and hard yellow maize for snack chips. The other 97 per cent is sold, mainly through country elevators, under the broad market classification of No. 2 yellow maize, without measurement of protein, starch or other quality characteristics Pioneer Hi-Bred International, the largest U.S. maize seed company, is expected to put a number of new specialty maize hybrids on the market within 3 to 5 years (Looker, 1989).

Before it is profitable for a large number of farmers to grow special-use maize hybrids, effective new marketing channels will need to be developed to permit farmers to capture price premium incentives for their marketed products. Since it will probably be a number of years before most country elevators can accommodate the marketing of specialty varieties, direct contracting between processors and growers is expected to play an important role in developing the market for these special-use varieties.

Although characteristics of food, animal feed and industrial markets differ greatly among countries, it is clear that the end uses of maize grain are changing dramatically and this will be reflected into changing signals for research on the quality and composition of maize grain, These signals will serve to affect the research objectives of both public and private and both biotechnology and conventional plant breeding research.

PUBLIC/PRIVATE INVOLVEMENT IN R & D AND TECHNOLOGY TRANSFER FOR MAIZE

Evenson (1983) suggests that public research can be classified into three stages: that for pre-technology; prototype technology; and usable technology. He further suggests that private R & D should concentrate mainly on the development of usable technology, less, but some, on prototype technology and little, if any, on pre-technology. Clearly, the foremost interest of private companies in the area of biotechnologies (and other technologies) applied to maize is that of developing and distributing seed and other marketable inputs. Generally in order to capture the economic rent available from proprietary products, seed suppliers must market hybrids which have the characteristics of a trade secret, or other genetic materials or processes which can be protected by patents. Given that only 63 per cent of total world maize hectarage was planted to hybrids in 1985-86, and given the large total size of the world market for maize seed, it is small wonder that private seed companies are actively involved in the business of developing improved seed varieties and exploring markets on a world-wide basis. There is probably no single historical situation in which private sector agribusiness firms were poised to develop and service such a massive potential market for agricultural inputs! As shown in Table 1, major areas of the developing world currently use farmer-saved seed and represent a potential new market for hybrid seed.

Private sector involvement in maize-related R & D is a complex phenomenon because of the variety of institutional modes under which R & D efforts are undertaken and because of the lack of any systematic required reporting of R & D expenditures. Historically much of the private sector research in the United States on maize was done by seed companies with modest investments also being made by these companies in university and/or USDA research projects. With the advent of the emerging biotechnologies, however, a number of large chemical companies and specialty biotechnology firms joined the R & D effort with a variety of organisational and contractual arrangements. Moreover, much of the chemical and biotechnology research has both multiple process and multiple product objectives.

The consensus of estimates of agricultural research expenditures indicates a substantial increase in the ratio of private to total research (from about 50 per cent in 1961 to about 60 per cent in 1986), but available estimates are subject to substantial error (Pray and Neumeyer, 1989). Pray estimates private sector agricultural research expenditures in 1984 at $115 million for plant breeding, $638 million for pesticides and $100 million for biotechnology, the latter including both plant and animal applications. Other unpublished estimates are that in 1970, research expenditures on maize improvement in the United States were about equally split between public and private, but by the mid-1980s, 60 per cent of the roughly $100 million spent directly on maize improvement was by private seed companies. This rapid rise in private research expenditures is almost certainly somewhat related to the passage of the Plant Variety Protection Act of 1970.

Estimates of the amount of total biotechnology R & D by the private sector in the U.S. also vary greatly. But, there is consensus that expenditures for biotechnology research have gone through three stages (Pray and Neumeyer, 1989). During the first stage (early 1970s to about 1978) almost all of the private research was by small companies financed by venture capital. In the second phase, many of the large pharmaceutical and chemical firms started to finance biotechnology research in the small firms through research contracts and by buying equity in these small firms. The third phase, starting about 1982, featured large firms starting to make large investments in their own biotechnology laboratories. In addition, there are multiple R & D linkages between private sector firms and research universities, both public and private. In the case of biotechnology R & D for maize, private institutional linkages now exist also between large chemical companies, seed companies and smaller biotechnology firms specialising in agricultural applications.

More recently, a number of biotechnology firms have encountered substantial financial problems and a number have gone bankrupt (Wall Street Journal, 1989). In addition to problems of inadequate long-term financing, governmental regulation and a backlog in the processing of patent applications have contributed to the demise of a number of biotechnology firms. The future configuration of private firms doing biotechnology R & D is likely to be that of a few large, well financed chemical and pharmaceuticals and a few specialised biotechnology firms which have successfully developed and marketed proprietary products.

In the United States, most of the public sector research on maize is conducted by the U.S. Department of Agriculture (USDA) and the State Agricultural Experiment Stations (SAES). Other developed and developing countries have a wide configuration of public sector research institutions which concentrate mainly on research for improvement of the domestic maize sector. At the international level, research initiated by the Rockefeller Foundation in Mexico in 1943 broadened to involve the Ford Foundation and other foundations, FAO, USAID, and a number of other developed and developing country institutions. But of crucial importance to maize research in the developing countries has been the establishment of the system of International Agricultural Research Centers (IARCs) of which two, CIMMYT, headquartered in Mexico (with the largest on-going maize research programme) and, more recently, the International Institute for Tropical Agriculture (IITA), headquartered in Nigeria, play major roles in the improvement of maize germplasm and related technologies (Timothy et al., 1988). Thus a broad research network of private and public research institutes are already in place conducting a broad program of maize related research.

There are a number of ways in which new and/or improved technology can be acquired by a country. Pray and Echeverria (1987) identify four which have been important for maize. They are: (1) imported technology in the form of varieties or hybrid seed; (2) local research and seed production by multinational companies; (3) research and seed production by local companies; (4) research and seed production by local government, sometimes with the assistance of international organizations such as CIMMYT, IITA and others.

During the period 1967 to 1985, U.S. maize seed exports more than quadrupled from 9,234 metric tons in 1967 to 37,964 metric tons in 1985 (Pray and Echeverria, 1987). In addition, other developed countries had a minor involvement in seed exports. Two major U.S. based multinational companies (Pioneer Hi-Bred International and Cargill) are currently testing hybrids in about 100 countries and have experiment stations in 15 to 20 countries. Other multinational firms also have significant operations in multiple countries. The extent of maize research and seed production by local companies varies so greatly by countries as to defy generalization. The involvement of CIMMYT and other international agencies in technology transfer has been and will continue to be a major factor in moving maize technology to countries of the developing world. On the negative side, vis-a-vis the rapid transfer of maize technology, there are restrictions in some countries on the importation of technology and research inputs and on which companies can do research and what research they can do. Moreover, excessive regulatory mechanisms in a number of countries stifle technology development and/or transfer, as does the inability of private firms to protect intellectual and product property rights. In most cases, private companies must see the potential for future profits (through property rights) before they will commit major financial resources to maize research and technology transfer.

SUMMARY AND CONCLUSIONS

Over the next five to ten years, most of the technological gains in the world-wide maize yields and product quality will continue to come from the traditional technologies of conventional plant breeding for germplasm enhancement, increased fertilizer use (particularly nitrogen) and improved cultural practices. By the early 1990s, the emerging biotechnologies will be contributing to herbicide resistance, to resistance to European corn borer and perhaps to other dimensions of production efficiency and grain quality enhancement. Even now, such new biotechnologies as plant tissue culture and molecular genetic markers are evolving as useful tools in the selection of improved germplasm and in focusing the efforts of new and traditional research efforts. Many of the tools required for broad based genetic transformations are now at or near the stage for effective utilisation, but any major gains in yield enhancement from the emerging biotechnologies are probably still some years away.

The emerging biotechnologies appear to have great potential for eventually reducing the environmental problems associated with heavy use of chemical pesticides, although maize production will continue to be heavily dependent on chemical fertilizers, particularly nitrogen. Moreover, it appears that it will be some time before BNF will be of assistance in maize production other than through its contribution to legumes in rotation with maize.

In the areas of photosynthetic enhancement and PGRs, earlier (1960s to early 1980s) R & D efforts have diminished in favour of hopes of accomplishing similar objectives via genetic transformation. It appears highly unlikely that private sector firms will invest significantly in these areas of biotechnology (except via genetic transformation) in the future unless significant research breakthroughs occur. ,These do not appear to be on the near-term horizon.

Finally, although there are and will be a number of environmental and safety issues regarding the approval, regulation, and adoption of some agricultural biotechnologies, these issues do not appear central to applications for maize.

A world-wide system for expanded R & D for maize, including private seed and chemical companies and national and international research institutions is rapidly evolving under multiple leadership spearheaded by CIMMYT and with a growing contribution from IITA and other international and national agencies. Moreover, this private/public R & D system will dramatically reduce the time for the transfer of new maize technologies to those developing countries which have heavy reliance on maize both as a staple food crop and as a major feed grain source. This is not to say that all will go smoothly in the future for the private/public R & D system. Even now, there are numerous examples of problems in the broad-based sharing of research results.

NOTES AND REFERENCES

1 A procedural framework used in this technology assessment is provided in Appendix A. Because of the necessary brevity of this paper, such a comprehensive technology assessment was not employed.

2 Carlson described the characteristics of a good endophyte as having, a) no pathalogical effect on hosts, b) no persistence in the environment or in host residue and c) no dispersal from innoculated hosts.

3 The U.S. Plant Variety Protection Act (PVPA) of 1970 extended previous protection rights for asexually reproduced species to new sexually reproduced, self-pollinated seed varieties.

4 In addition to the obvious advantages of improved protein quality and quantity in maize used for poultry and swine feed, it is estimated by Iowa State University scientists that with maize prices at $2.50 per ton and soybean oil meal at $250 per ton, a one per cent increase in the protein content of maize is worth about 12.5 cents per bushel in the feed-lot concentrate ration of growing (700 pounds or less) cattle.

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Appendix A

A FRAMEWORK FOR ASSESSMENT OF TECHNOLOGIES

Although it was impossible to carry out all of the stages listed below for the assessment of individual technologies for maize production, an effort was made to consider all stages and to implement them to the extent possible.

(1) Provide a definition and description of the technology;

(2) Specify the direction and magnitude of the technology;

(3) Assess the direct effect of the technology on:

- a. per acre yields, costs, profitability, and aggregate production capacity;
- b. productivity, as measured by the total output/input ratio and/or by partial productivity or intensity of factor use measures for specific inputs including land, energy and labor;
- c. input demand;
- d. a broad range of economic, environmental, legal, social, institutional, demographic, political, and safety considerations;

(4) Identify and evaluate the interaction(s), if any, with other technologies (possible interactions include those of both substitution and complementary effects);

(5) Assess other (indirect) effects of the technology in order to help:

- a. identify gainers/losers from the technology;
- b. identify long-term effects of the technology;
- c. identify risks and uncertainties associated with the technology (including vulnerability to shocks from natural forces such as weather, pests, diseases, etc., and from economic forces such as major changes in supply, demand, and prices);

(6) Assess feasibility of the technology in terms of criteria listed above; also, are the required inputs available for adoption of the technology on a broad basis?

(7) Specify alternative technology options for achieving objectives (this involves mainly an examination of the opportunity costs of the technology under consideration but many also involve identifying non-economic advantages/disadvantages of alternative technologies); and

(8) Assess management strategies for the technology - specify (and evaluate) the alternative courses of action for promoting, demoting, managing, modifying, or monitoring the effects of this technology.