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Evaluation of Five Emerging Biotechnologies for Maize

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EVALUATION OF FIVE
EMERGING BIOTECHNOLOGIES FOR MAIZE

by

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Evaluation of Five
Emerging Biotechnologies for Maize

ABSTRACT: Scientists were surveyed as part of an assessment of five emerging biotechnologies which are potentially applicable to commercial U.S. maize production by the year 2000. The largest gains expected by scientists were from plant growth regulators, followed by photosynthetic enhancement, cell or tissue culture and biological nitrogen fixation.

A project is under way in the Department of Agricultural and Applied Economics at the University of Minnesota entitled: "A Technology Assessment of Commercial U.S. Maize Production." One aspect of the study is to examine both existing technology and emerging biotechnologies from scientific, economic and institutional perspectives.¹ Emerging biotechnologies are characterized by the need for further scientific development before they can be adopted by the commercial sector. Four such emerging biotechnologies were identified from within the Plant Biology section of the USDA competitive grants program (USDA, 1980) - biological nitrogen fixation, photosynthetic enhancement, genetic engineering and cell or tissue culture.² The fifth technology, plant growth regulators,² is in a somewhat different category. While the use of plant growth regulators is routine in the production of some crops (e.g., sugar cane), it can be regarded as an emerging technology with respect to maize. A scientific evaluation of these technologies is clearly a prerequisite to any assessment of their potential from a broader perspective. This report contains the results of a series of questionnaires in which scientists working in each area,³ were asked to make an evaluation

in terms of: expected contribution to maize yields (or nitrogen fixation) in the year 2000; date of first significant commercial application of technology to maize; most likely mechanism for application; whether research funds were limiting progress, and if so, in what specific area(s).

The sample size, number of responses for each technology, the date of first significant commercial application, and the most likely contribution (to maize yield or nitrogen) of each technology by the year 2000 are given in Table 1. The rank of the technologies according to their expected contribution is: plant growth regulators, photosynthetic enhancement, cell or tissue culture and biological nitrogen fixation. Expected dates of first significant commercial application are all between 1990-1996 and cell or tissue culture is expected to be the first.

Table 2 indicates the percent of respondents anticipating a positive contribution from each technology to maize production by 2000, the most likely mechanism by which these contributions will come about, and the percent of respondents favoring this technology. For each technology, the percent of respondents expecting a positive contribution was well over 50%, except in the case of photosynthetic enhancement, where only 44% of respondents expected a yield increase (Table 2). There was unanimous agreement that the most likely mechanism for yield increases by photosynthetic enhancement would be through traditional breeding program (selecting for high CO_2 exchange rate). Sixty-six percent of respondents expected implementation of biological nitrogen fixation by the mechanism of non-nodular symbiotic association. These are not exactly the same 66% who anticipate a positive

Table 1. Date of First Significant Contribution to Maize Yield and Expected Contribution in year 2000.

Biotechnology	Date of First Significant Contribution	Expected Contribution to Yield in the year 2000 (kg/ha)	No. Questionnaires Mailed	No. Questionnaires Received
Photosynthetic Enhancement	1995	497 kg/ha	22	18
Cell or Tissue Culture	1990	195 kg/ha	37	31
Plant Growth Regulators	1994	988 kg/ha	22	19
Genetic Engineering	*	-	32	27
Biological Nitrogen Fixation	1996	29 kg/ha**	20	15

* This information was not specifically requested in the questionnaire for genetic engineering, but see Table 2.

** Nitrogen from biological nitrogen fixation was converted to maize yield equivalents as follow: $35.5 \text{ kg/ha} \times 44/11 = 142$ where nitrogen and maize prices are 44 and 11¢ respectively.

Table 2. Percentage of Respondents Expecting Contribution
and the Most Likely Mechanism for That Contribution.

Biotechnology	Respondents Anticipating a Contribution by 2000 %	Most likely Mechanism for Contribution	Respondents Anticipating Implementation by Listed Mechanism %
Photosynthetic Enhancement	44	Selection for high CO ₂ exchange within traditional breeding programs	44
Cell or Tissue Culture	71	Screening for disease resistance	23
Plant Growth Regulators	89	Increasing harvest index	42
Genetic Engineering	80	Transferring of single trait characteristics	*
Biological Nitrogen Fixation	66	Non-nodular symbiotic relationship between free-living microbes and corn plant	66

* While most respondents mentioned this mechanism, some gave more than one answer, so no percentage figure is calculated.

contribution from biological nitrogen fixation by 2000. However, there was near unanimous agreement that the most likely mechanism for biological nitrogen fixation by corn in the year 2000 would be non-nodular symbiosis between free-living microbes and maize roots. For the other technologies, there was no clear consensus as to the most likely mechanism through which the technology could be applied to commercial maize production. Twenty-three percent thought that cell or tissue culture techniques in maize would increase yield through facilitating screening for disease and other forms of resistance, and using anther culture to develop inbred lines. (Most applications of cell or tissue culture to commercial corn production would require the regeneration of whole plants from individual cells or tissues). The most popular mechanism indicated for yield enhancement with plant growth regulators was by altering the harvest index (proportion of total dry matter in the grain). Some people specifically thought that this would occur by delaying leaf senescence.

Genetic engineering technology is still in an early stage of development, therefore, no quantitative information was solicited in the genetic engineering questionnaire. Eighty percent of respondents thought that there would be contribution from genetic engineering to commercial maize production by the year 2000. The transfer of single gene traits was given as the most likely procedure for implementing some form of genetic engineering. Examples of single gene characteristics are: disease and herbicide resistance, nitrogen fixation and grain quality factors. The consequences of genetic engineering for commercial maize production are therefore likely to be less in the direction of yield enhancement and more in the direction of cost reduction. Many respondents emphasized that, while genetic engineering may speed up the processes of plant breeding it will not substitute for conventional

maize breeding programs.

We do not intend to draw any implications for public research policy based exclusively on the survey results, but it is possible to move slightly in that direction by converting the scientists' estimates of benefits into present value dollar terms. We do this on the assumption that there is a gradual increase in annual benefits between the starting date (Table 1) and the year 2000.⁴ Real maize and nitrogen prices of \$0.11 per kg and \$0.44 per kg are used. The conversion of future benefits into present value terms is made using a real interest rate of 7%. On this basis, benefits per hectare from each technology are expected to be: plant growth regulators \$131, photosynthesis \$56, cell or tissue culture \$42, and biological nitrogen fixation \$13. In 1980, 33 m hectares of maize were harvested for grain. Although year 2000 maize yield gains from cell or tissue culture are less than half of those expected from photosynthetic enhancement, the earlier expected starting date for commercial application of tissue culture results in somewhat similar present values of expected benefit. Although these benefits are expected, they may not in fact occur. The risks of non-occurrence differ between technologies, but may be highest in the case of photosynthetic enhancement, where a majority of respondents expected a zero yield increase (Table 1).

Although plant growth regulators show the highest expected benefits, no costs have been charged to the technology. However, from a producer's viewpoint, plant growth regulators are likely to be the most expensive technology because the others will probably be embodied in purchased seed which has a low per hectare cost. Furthermore, more significant interactions are likely to occur within the basic research areas of cell tissue culture, biological nitrogen fixation and photosynthetic enhancement. Research

developments in one technology may find applications in others. Developments in the various basic research areas would have spill-over effects in terms of benefits to other (non-maize) crops and to other (non-U.S.) countries (probably to a greater extent than plant growth regulators) with a consequent increase in payoff. Other (negative) forms of interaction may also occur (e.g., nitrogen fixation by maize may reduce grain yield).

One final note is that all of the above tables were based upon the assumption of a continuation of present funding levels. An overwhelming majority of questionnaire respondents felt that research funds were presently constraining progress. (The only exception was in the private sector of plant growth regulator research - apparently funds for the applied research aspects of this technology are not a problem). A lifting of public research funding constraints is likely to increase the pace of contributions in areas other than applied plant growth regulators research. Scientists were able to agree on the areas requiring further work, but only in the most general terms. There was no agreement about specific problems limiting progress.

FOOTNOTES

- 1 Detailed information on each of these technologies, along with an extensive discussion of the impacts which they are likely to have on maize production in the U.S., will be available in a forthcoming report by the authors.
- 2

Biological Nitrogen Fixation: The process by which atmospheric nitrogen is converted to fixed forms, by living organisms associated with maize, or directly by the maize plant itself.

Photosynthetic Enhancement: an increase in photosynthetic rate as measured by net carbon dioxide exchange per unit of leaf per unit of time.

Genetic Engineering: Modification of the genetic makeup of plants at the cellular level.

Cell Tissue Culture: the maintenance and multiplication of cells in a culture or medium.

Plant Growth Regulators: (synthetic or natural) organic compounds, other than nutrients, which promote, or otherwise modify, any physiological process in plants.
- 3 The scientists were identified through personal contacts with scientists working in each area at the University of Minnesota, Iowa State University and Pioneer Hi-Bred International, Des Moines, Iowa. The names on the list were confirmed by reference to the literature and/or to the competitive grants program of USDA. Our survey included most leading scientists. As the focus was on maize, there was some leaning towards those knowledgeable about maize.
- 4 The total yield increase (over 1980) was taken to be S-shaped over time, commencing at zero in the first year of significant application and rising to the level given in Table 1 in 2000.

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