Meeting World Food Demand

The Role of Biotechnology

Issue

Discussions on how science can be used to increase the world's food supply often focus on biotechnology as the key to rapid expansion (Mann, 1999a; National Academy of Sciences). Critics argue that biotechnology could export environmental problems to developing countries or put small farmers in developing countries at the mercy of large corporations. What is the potential for biotechnology to increase the world's food supply? How will biotechnology affect farmers and consumers in developing countries?

Context

World food demand grew at historically unprecedented rates over four decades from about 1950 to about 1990. Although this growth in consumption is slowing, population and income growth will continue to drive food demand higher. By far, the largest part of increased food demand will come from developing countries. Increases in income will also result in a shift in food composition—for example, toward greater consumption of livestock products.

By 2020, in one simple comparison, world demand for cereals is projected to be some 40 percent higher than it is today (Rosegrant, Agcaoili-Sombilla, and Perez; Pinstrup-Andersen, Pandya-Lorch, and Rosegrant). This increased demand will have to be met from a nearly constant land base, and at the same time, it is highly desirable that agricultural production not lead to environmental degradation (see box, "World Food Demand: Medium-Term Prospects"). In all countries, developing or developed, trade could become an even more important option in satisfying local food demand than it is today.

Challenges in Applying Biotechnology to Global Food Problems

Technical Options for Increasing Yields and the Role of Biotechnology

Increased yields through improved plant cultivars can be attained in two ways: increased yield at the fundamental physiological level, and improved response to stress, which reduces the gap between realized yields and the yield frontier. In essence, the higher physiological yield shifts the yield frontier, and maximum yield, upward. Improved stress response increases mean yields by raising the lower part of the yield distribution.

Most near-term biotechnology options to address problems of food production in developing countries involve better stress resistance or stress tolerance. Many presentations from the biotechnology industry provide fairly generic overviews of the three projected phases of biotechnology deployment—agronomic traits, value-enhanced products, and nutraceuticals—with some emphasis on agronomic traits and nutrient-enriched crops (see Kishore and Shewmaker, for example). Agronomic traits, such as resistance to pests and diseases, drought tolerance, tolerance to aluminum toxicity, and tolerance to salinity, could be addressed through genetic engineering and other biotechnology techniques, such as using molecular markers and tissue culture to facilitate the transfer of desirable alleles from wild relatives to cultivated plants. This research could have obvious benefits in developing countries.

Some scientists, however, such as Thomas Sinclair of USDA's Agricultural Research Service (ARS), point out that yield potential, or maximum possible crop yield, "is limited by the physics of intercepting photons and capturing carbon dioxide, the biochemistry of photosynthesis and the physiology of nutrient uptake

World Food Demand

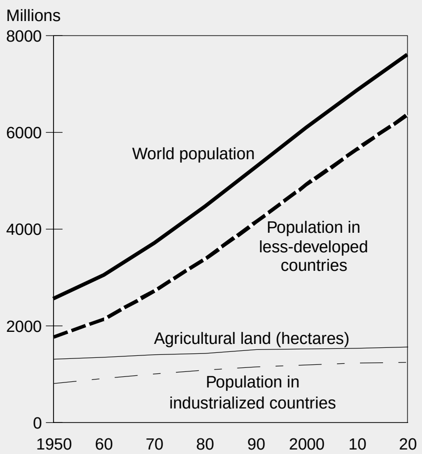
Medium-Term Prospects

Although the world population continues to grow, world agricultural land has expanded at a much slower rate (fig. A). Furthermore, food demand is projected to grow at a faster rate than population growth, as income growth contributes to growth in demand as well. Rising incomes can also lead to a change in dietary composition, with, for example, greater demand for livestock products. Over the next 20 years, population is projected to grow at about 1.1 percent annually, and demand for cereals is estimated to grow between 1.4 percent and 1.6 percent annually (fig. B).

Both per capita food and feed demand are forecast to increase in most developed countries in the near term, while feed demand is expected to shrink in the transitional economies of Eastern Europe and the former Soviet Union (fig. C). Total per capita food demand will remain fairly steady in developing countries, but per capita feed demand will increase. Although the absolute amount of this increase is relatively small, in percentage terms, it is much larger than the growth in food or feed per capita demand in developed countries. All in all, around 80 percent of the near-term increase in cereals demand is expected to come from developing countries: Over 50 percent due to population growth, 20 percent due to increased per capita feed demand, and a small amount due to the interaction of these two factors.

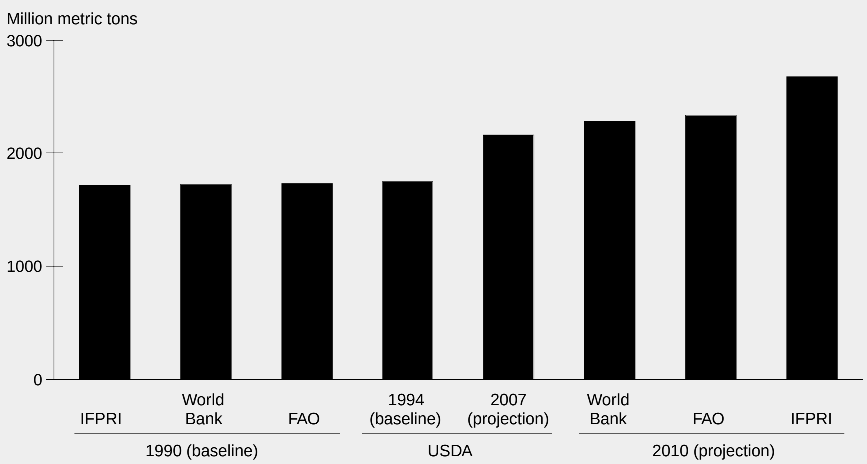
Agricultural land, on the other hand, has been growing only at less than 0.3 percent annually; there are relatively few areas in the world where relatively high-quality land lies unexploited. As a result, it is clear that increasing crop yields must be the primary means by which food supply is increased to meet demand at the same time that real food prices remain stable or continue their historical downward trend. Although these yield increases will be less than those of the last few decades, they pose a considerable challenge to agricultural researchers and the agricultural input industry. First, over the last decades, higher rates of fertilizer application and expanded irrigated area contributed a great deal to increased crop yields. Over the coming years, expansion of fertilizer consumption and irrigated area is expected to be much slower. Second, renewed appreciation for the environmental services consumed by agricultural production means that it is highly desirable that expanded agricultural production not come at the cost of damage to the natural resource base.

Figure A
World population growth, population projections, and agricultural land



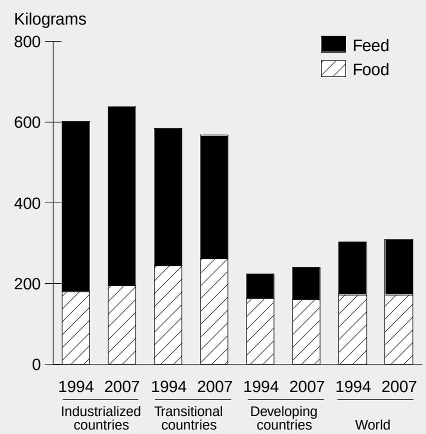
Sources: U.S. Bureau of the Census; IFPRI (Rosegrant, Agcaoili-Sombilla, and Perez); FAO (Alexandratos).

Figure B
Baseline and projected world cereals demand



Sources: IFPRI (Rosegrant, Agcaoili-Sombilla, and Perez); World Bank (Mitchell, Ingco, and Duncan); FAO (Alexandratos); USDA, ERS.

Figure C
World per capita cereal consumption, 1994 and 2007



Source: Calculated from ERS data, Market and Trade Economy Division, Economic Research Service, USDA, 1998.

and utilization" (Fedoroff and Cohen). In the longer term, biotechnology may contribute to increasing world food supplies by manipulation of multiple genes to alter such basic processes as photosynthesis (Mann, 1999b). At present, this appears to be a very long-term goal.

Alternatives to Crop Improvement for Increasing Yields

Other observers suggest that, as long as crop yields in some parts of the world remain well below potential yields, crop improvement, where biotechnology could make an immediate contribution, may not be the major means of increasing the world's food supply. Alternatives include precision crop management (Cassman), including integrated pest management (Thomas), and reducing losses in post-harvest storage and distribution (Fedoroff and Cohen). A key question is how to raise yields in parts of the world—for example, in some regions in sub-Saharan Africa, that have been relatively unaffected by pre-biotechnology yield-increasing techniques that are in wider use elsewhere.

Intellectual Property Rights, the Private Sector, and Biotechnology Applications in Developing Countries

Commercial application of biotechnology has taken place primarily in the United States, to date, and primarily through the private sector. How can biotechnology be brought to bear on the agronomic and nutritional problems of developing countries? Dating at least to Griliches, it has been recognized that key determinants of the private sector's decision to invest in agricultural research are the perceived size of the market and the ability to reduce transaction costs when farms are larger. Both developing-country markets and farms, in many instances, are small.[9]

Lack of intellectual property protection could make private companies less willing to invest in developing countries. Indeed, in developing countries with more advanced scientific capabilities, piracy rather than market transfer might be an alternative means of biotechnology acquisition (Tarvydas et al.). The Technology Protection System (see box on p. 42), or lower cost hybridization methods, could increase incentives for private companies to invest in research for self-pollinating crops like wheat, where the ability of farmers to replant saved seed without yield loss has meant that private firms capture a relatively low proportion of the benefits from research.

Unless research and seed delivery institutions are redesigned, however, it is unclear that strengthened property rights in plant breeding products is likely to lead to substantially greater private-sector investment in research for crop production in developing countries, particularly for staple foods. Consider the pre-biotechnology record of adopting improved varieties in developing countries. In maize, as corn is known worldwide, hybridization allows "trade secret" protection, and thus greater incentives for private research. Yet only 45 percent of area in developing countries is planted to hybrids, and 40 percent is planted to unimproved materials. Excluding China, Brazil, Argentina, and South Africa, only 20 percent of the maize area is planted to hybrids and 60 percent is planted to unimproved materials.[10] In contrast, improvements in wheat and rice in developing countries have relied primarily on public-sector breeding and farmer-to-farmer seed diffusion. In these crops, at least 75-80 percent of the total area is planted to semidwarf or hybrid varieties (fig. 4).

Furthermore, historical experience with adoption of "green revolution" wheat and rice in developing countries and, for that matter, hybrid maize in the United States suggests certain rules of thumb for widespread adoption of new yield-increasing technology. In relatively low-yielding environments, rapid diffusion is usually stimulated by yield increases of at least 15-20 percent over farmers' varieties, coupled with seed prices that are no more than 5-10 times the price the farmer receives for grain. Whether or not private companies can package enough traits to create this kind of yield advantage at these seed-grain price ratios is unclear. It appears more likely that initial applications of biotechnology in developing countries will be confined to countries with more commercialized agriculture (for example, Argentina and Brazil), higher current yields, or certain specialty crops. Consumer acceptance of genetically modified crops, in trading partners or domestically, is likely to be a major determinant of the use of biotechnology in these countries in the short run, just as it is in large, industrialized agricultural producers like the United States.

[9]Some examples from developing countries demonstrate that the obstacle of small farm size is not insurmountable, if other conditions favor small-farm use of such purchased inputs as seed.

[10]In these countries, maize is primarily planted by large-scale farms, planted in temperate growing areas, or both. Temperate maize growing areas can benefit much more readily from research spill-ins from the United States.

Other Issues Facing Developing Countries

Developing countries may find gaining access to biotechnology difficult because of insufficient numbers of trained resources. In countries with severe resource constraints, the allocation of training across a large number of apparently high-priority areas, and the assurance that sufficient resources are working productively within these countries, are difficult issues to resolve.

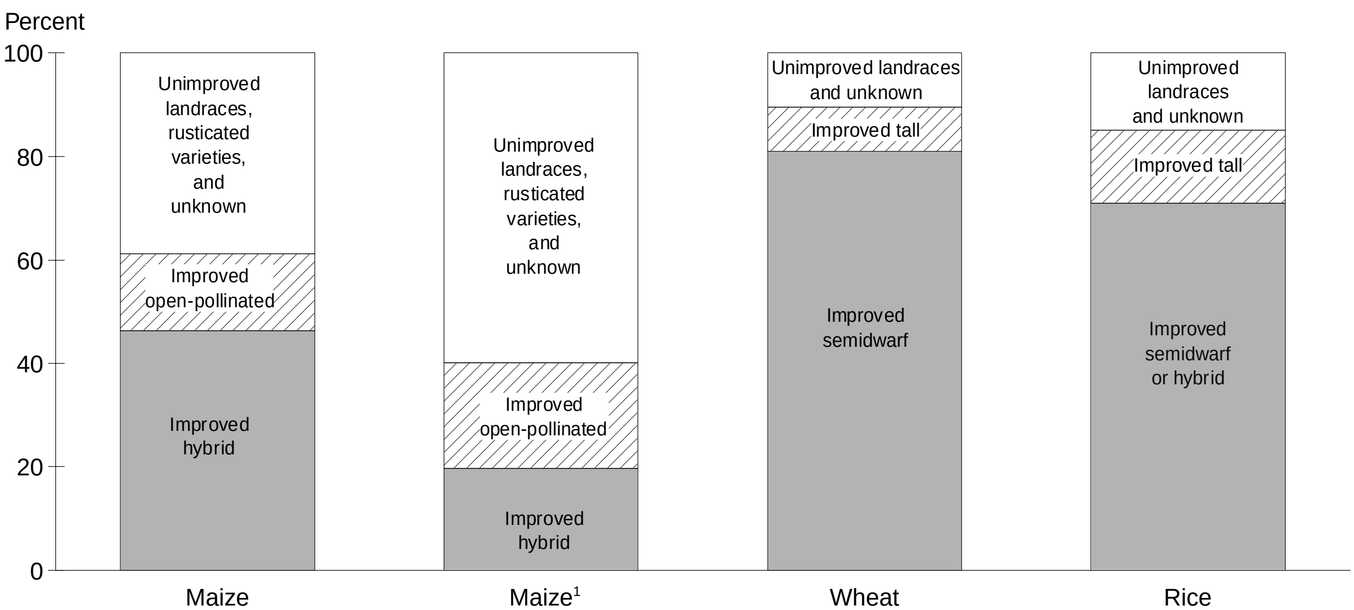
As in industrialized countries, biotechnology might not be universally accepted. Environmental and food safety concerns might play a role in developing countries, although these concerns are likely to have different dimensions than in industrialized nations (see "Consumer Acceptance" on page 28). For example, regulatory systems in developing countries are generally far less mature than in developed countries. Relatively rich developing countries that are major agricultural exporters, like Argentina and Brazil, might face the same questions of access to European markets as does the United States. Another concern, particularly relevant in poorer countries, is that small farms could become increasingly dependent on large corporations and lose many of their genetic resources.

Advances in agricultural biotechnology, particularly in developed countries, may have additional impacts on trade with developing nations. First, biotechnology-derived substitutes for commodities traditionally exported from developing countries may lower incomes in these developing countries. Second, as in the case of any technology that shifts supply out in one region but not another, producers in nonadopting regions or countries may be hurt as prices fall. To the extent that biotechnology and other agricultural technologies improve productivity in developing countries, this tendency could be counteracted.

Policy Issues

In short, biotechnology is likely to be a major option for meeting increased world food demand over the next several decades, but it is not the only one (Weeks and others; Persley and Lantin). What is the appropriate role of biotechnology in the research portfolios of international and national public-sector research programs directed at developing countries? How can scientific capacity in these countries be increased? On the one hand, given the resources and experience of large private-sector life sciences firms, it is unlikely that many biotechnology options will be developed fully without the

Figure 4
Share of cereals area in developing countries planted to improved varieties



[1]Excluding China, Brazil, Argentina, and South Africa.
Source: CIMMYT; Morris and Heisey; Heisey, Lantican, and Dubin; Pingali and Smale.

participation of these companies. On the other hand, present incentives for private investment are unlikely to direct large-scale resources toward solving many problems in developing countries. How can institutions be redesigned to allow access to knowledge and technologies in the private sector to benefit the international public? What intellectual property arrangements and regulatory mechanisms will be most successful in harnessing private-sector research for the purpose of real increases in the world's food supply? How can possible adverse trade-mediated biotechnology impacts on developing countries be mitigated?

References

Alexandratos, N. (ed.). *World Agriculture: Towards 2010, An FAO Study*. Food and Agriculture Organization of the United Nations. J. Wiley and Sons Ltd., Chichester, U.K., and New York, NY (in French by Polytechnica, Paris; in Spanish by MundiPresa, Madrid and Mexico), 1995.

Cassman, K.G. "Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture." Paper presented at the National Academy of Sciences Colloquium, Plants and Population: Is There Time? Beckman Center of the National Academy of Sciences, Irvine, CA, December 5-6, 1998. Retrieved from <http://www.lsc.psu.edu.>

Fedoroff, N.V., and J.E. Cohen. "Plants and population: is there time?" An overview of papers presented at the National Academy of Sciences Colloquium, Plants and Population: Is There Time? Beckman Center of the National Academy of Sciences, Irvine, CA, December, 5-6, 1998. Retrieved from <http://www.lsc.psu.edu>

Griliches, Z. "Hybrid corn: an exploration in the economics of technological change," *Econometrica*, Vol. 25, 1957, pp. 501-522.

Heisey, P.W., M.A. Lantican, and H.J. Dubin. "Assessing the Benefits of International Wheat Breeding Research: An Overview of the Global Wheat Impacts Study," Part 2 of Pingali, P.L. (ed.), *CIMMYT 1998/99 World Wheat Facts and Trends; Global Wheat Research in a Changing World: Challenges and Achievements*. Mexico, D.F.: International Maize and Wheat Improvement Center, 1999.

International Maize and Wheat Improvement Center (CIMMYT). *1993/94 CIMMYT World Maize Facts and Trends. Maize Seed Industries Revisited: Emerging Roles of the Public and Private Sectors*. Mexico, D.F., 1994.

Kishore, G.M., and C. Shewmaker. "Biotechnology: enhancing human nutrition in developing and developed worlds." Paper presented at the National Academy of Sciences Colloquium, Plants and Population: Is There Time? Beckman Center of the National Academy of Sciences, Irvine, CA, December 5-6, 1998. Retrieved from <http://www.lsc.psu.edu>

Mann, C.C. "Crop scientists seek a new revolution," *Science*, Vol. 283, 1999a, pp. 310-314.

Mann, C.C. "Genetic engineers aim to soup up crop photosynthesis," *Science*, Vol. 283, 1999b, pp. 314-316.

Mitchell, D.O., M.D. Ingco, and R.C. Duncan. *The World Food Outlook*. Cambridge: Cambridge University Press, 1997.

Morris, Michael L., and Paul W. Heisey. "Achieving Desirable Levels of Crop Diversity in Farmers' Fields: Factors Affecting the Production and Use of Commercial Seed," *Farmers, Gene Banks and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice*. Ed. M. Smale. Norwell, MA: Kluwer Academic Press, 1998.

National Academy of Sciences. Plants and Population: Is There Time? Colloquium at the Beckman Center of the National Academy of Sciences, Irvine, CA, December 5-6, 1998. Retrieved from <http://www.lsc.psu.edu>

Persley, G.J., and M.M. Lantin (eds.) *Agricultural Biotechnology and the Poor: Proceedings of an International Conference, Washington, D.C., 21-22 October, 1999*. Washington, DC: Consultative Group on International Agricultural Research and National Academy of Sciences, 2000.

Pingali, P.L., and M. Smale. *Crop Genetic Diversity: Has the Intensification and Commercialization of Agriculture Made a Difference?* CIMMYT Economics Working Paper, Mexico, D.F.: International Maize and Wheat Improvement Center, forthcoming.

Pinstrup-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. *World Food Prospects: Critical Issues for the Early Twenty-First Century*. 2020 Vision Food Policy Report. Washington, DC: International Food Policy Research Institute, 1999.

Rosegrant, M.W., M. Agcaoili-Sombilla, and N.D. Perez. *Global Food Projections to 2020: Implications for Investment. Food, Agriculture, and the Environment* Discussion Paper 5. Washington, DC: International Food Policy Research Institute (IFPRI), 1995.

Tarvydas, R., J. Gaisford, J. Hobbs, and W. Kerr. “Agricultural biotechnology in developing countries: will technology be transferred through the market or piracy?” Paper presented at the NE-165 Symposium, Transitions in Agbiotech: Economics of Strategy and Policy, June 24-25, 1999, Washington, DC.

Thomas, M. “Ecological approaches and the development of ‘truly’ integrated pest management.” Paper presented at the National Academy of Sciences Colloquium, Plants and Population: Is There Time? Beckman Center of the National Academy of Sciences, Irvine, CA, December 5-6, 1998. Retrieved from <http://www.lsc.psu.edu>

U.S. Bureau of the Census. <http://www.census.gov/>

U.S. Department of Agriculture, Economic Research Service. *International Agricultural Baseline Projections to 2007*. AER-767. 1998

Weeks, D.P., J.B. Segelken, and R.W.F. Hardy (eds.). *World Food Security and Sustainability: The Impacts of Biotechnology and Industrial Consolidation*. NABC Report 11. Ithaca, NY: National Agricultural Biotechnology Council, 1999.