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New technologies, cultural practices, and resources so far have enabled agriculture to keep pace with the expanding world population and increasing demand for food. The rate of increased agricultural productivity, however, has slowed in recent years.

Now advances in genetic engineering of plants and animals apparently will allow major, sudden increases in agricultural productivity. To some persons, genetic engineering and other new biotechnologies are the solution to the world's hunger and health problems. Public and private-industry scientists and research leaders, for example, ranked genetic engineering of plants and animals first when asked to evaluate areas of research with the greatest potential impact on agricultural productivity and with at least a 50 percent probability of being introduced for commercial adoption by the year 2000 (see Yao-chi Lu, "Forecasting Emerging Technologies in Agricultural Production" in *Emerging Technologies in Agricultural Production,* U.S. Department of Agriculture, October 1983). To others, genetic engineering conjures up a myriad of problems — ethical, environmental, economic, and political. The reality probably lies somewhere between these extremes.

In this report, we consider economic and policy ramifications that may accompany developments in genetic engineering, referring to a few specific projects for illustration. "Genetic engineering," as used here, is the manipulation of the information flow of a biological system that is performed by the genetic structure of an organism. This manipulation is accomplished by regulating or altering the genes.

By "revising" or recoding the genetic structure of an organism, researchers might make plants resistant to various diseases, herbicides, or unfavorable soil conditions; enhance the process of photosynthesis; or improve the chemical (nutrient or caloric) composition of the plant for human and/or animal consumption. With an understanding of the genetic workings of plant and animal defense mechanisms, scientists will be able to manipulate those beneficial to agriculture (for example, encourage stress resistance) or harmful to agriculture (for example, break down insect resistance to pesticides). The new technology has vast potential for plants and animals: growth regulation; embryo transplants; gene insertion; disease control; resistance to environmental and biological stress from, for example, saline or drought conditions; nitrogen fixation; and pesticide and herbicide tolerance. These accomplishments may take much less time by genetic engineering than by selective breeding or cross-breeding, if the more traditional methods could achieve such results at all.

Despite the strong interest and research emphasis on genetic engineering, the field is still relatively new. The theories and methods of gene splicing have been developed, but knowledge of which genes transmit a given trait is far from complete. Also, the factors that trigger the genes' activity are not yet known. Each plant or animal cell contains thousands of genes that affect particular physiological processes, but scientists can now work with only one gene at a time.

Advances in genetic engineering involve more than scientific breakthroughs. Potential economic effects - some possibly undesirable - also need to be considered.

Although altering the genetic structure becomes much more difficult as the number of genes involved increases, major achievements are on the horizon in cases involving relatively simple processes. Howard Bachrach, in the same publication as Lu, notes:

> Transformation that can be effected through single-gene splicings have the greatest prospects for early success. Fortunately, these include the resistance of plants to a wide variety of organisms including fungi, bacteria, viruses, mycoplasmas, nematodes and insects, which consume 25 to 30 percent of American crops.

Some new technologies will be in use by the end of the 1980s according to some observers. A California research company has put an herbicide-resistant gene into certain plants, which allows the plants to withstand weed spray. The company expects to commercialize this finding within two years. Another company has developed a bovine somatotropin (BST), which will significantly increase milk production in dairy cows. Commercial availability of BST is expected in the next two or three years. UC scientists have developed a bacterium that lowers the temperature at which frost develops on the leaves of plants. This type of research has enormous potential for increasing agricultural production (table 1).

While most people support such technological growth, there are many dimensions involved and many unforeseen outcomes for the future of agriculture. Individual producers, processors, wholesale and retail marketers, and consumers will feel the effects.

Farmers may have to make rapid changes in their operations to adopt the new technologies and remain competitive. They will expect reduced costs, increased yields, or both. The nature of the product itself may also change as genetic engineering alters protein content or enhances photosynthesis. Such developments will require a continued emphasis on management practices and planning.

Suppliers will face changing demand for products they market to farmers. The development of pesticide-resistant plants could increase demand for pesticides. There will be new products to market: hormone implants for animals, plant sprays, and new seed stock. New methods of marketing and providing service to customers will be required. The question of property rights on marketable biotechnologies is already an issue.

Food processors and marketers will be affected, because changing agricultural products may require changes in handling, safety standards, and processing techniques. For example, the development of a genetic structure to preserve freshness or shelf life of food products would affect inventory planning. Safety and quality regulations will need to be reexamined continually to keep pace with scientific developments.

Consumers should expect lower relative prices and improved quality from the new biotechnologies. (This does not necessarily mean, however, that per capita food consumption will increase.) New products and new forms of old products will call for education about their nutritional attributes.

Given such changes, planning is needed. Larger farms with innovative, welleducated managers and the ability to obtain financing and handle risk will have a distinct advantage. The position that one region or nation has over another in crop production because of weather, soil, and other environmental conditions could change if environmental tolerance is inserted into plants. Decisions on where to produce and process a crop could then be based to a greater extent on transportation and marketing considerations and the relative abilities to use the complex technologies.

The possible release of the production location constraint is significant to California agriculture with its important export markets. The creation of plants that tolerate drought, can use salt water, are nitrogen-fixing, or produce increased protein would greatly aid developing countries in meeting their own food needs, if the particular technological improvement is transferable.

The private sector has been characterized by rapid growth of research companies (and the quick exit of some) in the search for the innovation that will provide the economic "gold mine." Patentable changes, through the Plant Variety Protection Act, offer monopoly power to the firm with the first "billion dollar gene." But monopolies may be broken overnight with the next discovery. Firms will have to make a substantial investment in research and development just to maintain their position in the industry.

Genetic engineering may substitute new inputs for existing ones (such as new seed stock) or add products for items now used (injections, sprays, implants for animals). New inputs will call for new supply firms, and if a desirable trait is not carried through from one generation to the next (as was the case with hybrid corn), an entirely new supply source will develop in response. New food products may be developed that can be produced in an entirely nontraditional, factory-like setting.

The following example illustrates some of the ramifications of genetic engineering and resulting policy questions.

Research at Cornell University indicates that the bovine somatotropin, when injected into a cow, has the potential to stimulate milk production by as much as 25 percent over the lactation period. While a somewhat higher energy ration must be fed, no ill effects on either the animal or milk quality have been observed during the relatively short time the experiments have been conducted.

Although the timing depends on how quickly producers adopt the new technology, the rapid addition of 25 percent more milk is not attractive in an industry whose excess capacity is already a severe problem. The price of milk could be expected to drop, because consumer demand for milk and milk products is relatively inelastic: total consumption doesn't increase as much in percentage terms as the price falls. The Cornell studies estimate that, if price supports for dairy products were removed and BST were introduced, the number of dairy farms could fall by 40 percent. With the same assumptions, Michael J. Phillips, of the federal Office of Technology Assessment, figures that cow numbers could drop by 30 percent.

A major question about increased production resulting from biotechnological developments such as BST is what would happen to the resources that would become redundant. If dairy farms were reduced by 40 percent, what alternative employment would producers have? With 30 percent fewer cows, what would happen to industries servicing dairies? What use would be made of the land no longer needed for growing dairy feed? Reducing demand for hay and grain would also decrease water needs for irrigation. Lower dairy production could permit reallocation of scarce water supplies for other uses, especially in urban areas. At the same time, higher energy feed requirements for the remaining dairy cows might require changes in crop rotation patterns to supply the feed.

The implications of BST thus extend beyond the dairy industry. A question facing members of government and industry is how supply can be controlled in the face of significant production increases stemming from a relatively low-cost genetically engineered alteration. Can such policy needs be foreseen to avert the economic consequences? What policy changes would facilitate the departure of unneeded resources? Advance planning is essential to ease the pain of severe adjustments in agriculture.

The biological effects of genetic engineering may sometimes be of greater concern than the economic consequences. Some groups fear that the altered organisms may cause damage or be able to gain a selective advantage over other organisms. Accidents may occur in the future, but overreaction to potential dangers also can result in excessive regulation that could stifle advancement.

TABLE 1. Projections of increased production by year 2000, various U.S. commodities

Commodity	Production 1982	Production 2000	Increase
			%
Milk per cow (1,000 lb)	12.3	24.7	101
Corn (bushels/acre)	115	139	12
Cotton (lb/acre)	481	554	15
Rice (bushels/acre)	105	124	18
Soybeans (bushels/acre)	30	37	12
Wheat (bushels/acre)	36	45	25

SOURCE: Michael J. Phillips, Office of Technology Assessment. "Enhancing Competitiveness: Research and Technology in Agriculture." Paper presented at Symposium on Competition in the World Market Place: The Challenge for American Agriculture, Kansas City, 1985.

Researchers have little experience with or knowledge of how genetically engineered plants and animals will interact with and affect the environment. Acceptable levels of risk need to be established by the scientists, on the one hand, and the public, on the other.

The questions accompanying BST and other developments illustrate the focus needed in policy planning for the new biotechnologies: the biological (environmental) and economic implications of successful research achievements. Assistant Secretary of Agriculture Orville Bentley, in remarks to the USDA Challenge Forum on Biotechnology (February 1987), reported that the USDA is developing guidelines for evaluating the former: "All phases of all federally funded biotechnology research will be subject to these unified federal guidelines, and we will encourage voluntary compliance by industry and other nonfederally funded organizations."

Coordinated planning for the economic policy implications of biotechnological developments remains to be implemented, although the Office of Technology Assessment and Cornell University have studied the expected productive gains and economic feasibility of some of the breakthroughs. The government, with its planning and policy agencies and its ties to land grant institutions, is in a good position to act as a catalyst to such coordinated research programs. Industry trade associations offer another mechanism for planning.

Federal constraints on research topics seem inappropriate and stifling. In the private sector, the feasibility of biotechnological research projects will be determined by the potential payoff and the likelihood of scientific success. Basic research will continue to be more the purview of the universities and public research bodies, but will require injection of outside funding support. While the availability of funding has a major impact on the direction that research programs take, it is doubtful that any one agency, private or public, has sufficient knowledge to prescribe what these programs should be. It is more efficient in the long run to allow research projects to develop freely, but with definite biological guidelines for release of new or altered products and with analysis of the potential economic effects in the context of existing and alternative agricultural policy.

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