IMPLICATIONS OF EMERGING BIOTECHNOLOGIES

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The following definition of biotechnology goes beyond the rather limiting concept of genetic engineering. Biotechnology is defined simply as those biological means used to develop processes and products employing organisms or their components. Those biological means include:

1. Bioreactors and bioreactor support systems (bioreactions).
2. Immobilized cells, organelles, or cell components (enzymes).
3. Plant and animal tissue and organ culturing.
4. Recombinant DNA (genetic engineering, gene transfer).
5. Hybridoma techniques.

These new abilities--microculture, cell fusion, regeneration of plants from single cells, and embryo recovery and transfer--are creating vast new opportunities all across the agricultural sciences. The tools of biotechnology are being applied to viruses and bacteria, to insects and weeds, to plants and animals, in all stages of their life cycles from replication through aging.

Agricultural scientists increasingly speak a common language, centering on the cell--the basic unit of life. The critical importance of single cells lies in the fact that they are the units into which engineered genes are likely to be introduced--by transfer, by cell fusion, or by microinjection.

Major efforts are being placed on finding ways to culture single cells from a wide number of agronomic plants, and to regenerate them into whole organisms with the genetic message intact and properly expressed. In animals, embryonic single cells-the fertilized egg--may well be the recipients for gene transplants. Techniques such as embryo recovery, splitting, and transfer are playing critical roles in genetic engineering efforts.

Other new and promising techniques now make it possible to determine much more quickly the precise chemical makeup of genes and their protein products, condensing into days what might have once required years to accomplish.

Genes can also be located in their chromosomal packages relative to each other much more easily than in the past. More difficult, however, is the identification of the mechanisms regulating gene expression--what turns any given gene's activity on or off. It is not gene transfer capability that will constrain biotechnological solutions to problems. Rather, it is the lack of base data relating to gene identification for selection of genes to transfer, gene expression information, plant differentiation control knowledge, and a host of other functions.

Very little is known about controls that ensure genes for a specific activity are operating--when and where they are supposed to--for proper growth and maintenance of the organism. A great deal of basic knowledge must be assembled regarding these controls and other interactions within and among cells before the improvement of plants and animals through gene transfer can be intelligently accomplished.

A number of research areas in agriculture are being considered as candidates for the new biotechnologies--research areas that were not approachable before recent technological breakthroughs. For example, new techniques now allow much more detailed studies of the defense systems in plants and animals than was ever possible in the past. New knowledge of the immune system in animals promises improved approaches for disease and parasite control and faster, more accurate diagnosis.

More effective ways for increasing the plant's or animal's own genetic resistance to pests and other stresses are envisioned. Conversely, improved techniques for sabotaging the defense systems of insects, weeds, and other pests also seem possible.

A growing understanding of how the chemical messengers known as hormones operate as intermediaries in growth and development processes also promises more progress. This is an area that has been studied extensively, and one that has seen much progress in the past.

Another area of challenge is to develop entirely new food products using plant protein.

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This is a challenge to food scientists--to produce a product that does not attempt to mimmick animal protein. The result could give us an entirely new class of food unlike anything we now have.

Model systems and computer simulations are being developed specifically for agricultural research, and more are needed.

A few examples of major innovations that will likely be available within the next 20 years are:

* Crops that will be less susceptible to diseases caused by viruses, bacteria, fungi, and insects.
* More efficient crops that will better absorb and utilize fertilizer.
* Plants currently not able to fix their own nitrogen will be able to do so.
* An increase in plants' photosynthetic efficiency by manipulating their energy conversion systems.
* A greater resistance to stresses brought on by drought, salinity, chill, and frost.
* Genetic regulation of plant growth to achieve such goals as: higher ratios of edible to nonedible parts, longer seed filling times, corrected structural weaknesses, and higher yields of economically important plant constituents.
* Improved quality, such as improving the amino acid balance and nutritive value of small grains for animal and human consumption.
* Regulations of plant growth to allow harvest of fruits and vegetables at uniform ripeness. This will help maintain and deliver desired quality produce to consumers through complex systems of transport, processing, and marketing.

Applied and fundamental research in agriculture are so intimately intertwined in the biotechnologies that many specific practical spinoffs may emerge. At the same time, fundamental inquiries will continue to pursue the basic knowledge necessary to make wide-ranging applications.

Agricultural economists will have a vital role in helping guide these new dynamics within the agricultural production system. Production efficiency is the name of the game. The new biotechnologies will impact upon the efficiency of production, so that we can maintain our position in terms of the economics of the world market and the economics of the U.S. dollar--that's where the major impact will be.

In assessing the impact of the new biotechnologies over a longer timeframe--50 to 100 years, futurists have described a totally revised system of agriculture. In the interest of conserving our natural resources--soil, water, and fossil fuels--needed for long-term sustained agricultural production, more conservative production means for food than conventionally envisioned are predicted. Increased production of components of foods by biotechnological or combined systems as opposed to producing plant organs will be joined with reconstitution of the components into consumer-acceptable traditional foods. Sugar syrups, for example, would be converted from food components derived from chemical feed stocks made from nonedible parts of plants such as celluloses and lignins. These syrups might then be moved by pipeline or tank car to biotechnological food production facilities close to population centers in any part of the country.

This future accomplishment is the agricultural equivalent of reaching the moon. Research agencies —federal, state, and private sector— have the responsibility to develop all the future food production options possible. As the basic knowledge to use the new biotechnologies are developed, each discovery introduces a crossroad between that immediate application and a future orientation. Agricultural economists must provide evaluation of options developed by biotechnology research. Ultimately, the economics of agricultural production—and the availability of water, land, and energy—will shape the future application of these biotechnologies.

Biotechnology research currently underway by Agricultural Research Service (ARS) scientists—often in cooperation with university, state experiment station, or private sector researchers—illustrates the range of economic evaluations needed in the not so distant future.

A tiny capsule containing one one-hundred-and-fourteenth (1/114) of an ounce of viral insecticide in a water soluble capsule is enough to spray and protect an entire acre of cotton plants against the cotton bollworm and budworm. This first viral insecticide kills the Heliothis Zia caterpillar—commonly known as the cotton bollworm. The slightest touch will cause the dead caterpillar to instantly rupture and release *billions* of additional virus particles that can spread to protect other plants. In addition to controlling bollworms and budworms on cotton acreage, the microbial insecticide has been approved for use in controlling the Heliothis species on corn, sorghum, and tomatoes—against the earworm, podworm, and fruitworm. Heliothis insects are a worldwide problem. They damage about 30 different commodities—all but a few of them important to the U.S. economy.

The cereal leaf beetle–once a scorge of wheat and other small grain crops in the Eastern and Central United States—is now finally under control. After a 20-year fight, scientists are winning the war, using biological controls. Spraying was down from a million and a half acres in 1966 to about 20 thousand acres in 1981. USDA researchers, working with university colleagues, have developed excellent biological means to control the cereal leaf beetle population. One of the most effective insect controls has been a parasitic wasp that injects its eggs into the cereal leaf beetle's eggs. In this way, the wasp becomes the carrier for the beetle control. At the same time, work is progressing on breeding plants resistant to the cereal leaf beetle. Scientists have field tested more than 30 thousand lines of wheat, and oats for natural resistance to the beetle. There is no doubt that genetic engineering will speed this kind of work, greatly reducing the time involved in arriving at new and more desirable plant varieties.

One advanced achievement of the breeding work has been the release of a moderately resistant soft red winter wheat variety. The new variety, named Downy, yields well under beetle-infested conditions. The new plant's longer leaf hair interfere with the larva's movement, its feeding habits and digestive system. In this way, chances for plant damage by the larva–even chances for larva survival—are reduced.

Breeding plants to make better use of available water–possibly to need less water–also shows progress. Closing of the stomata, tiny, pore-like openings in the leaves, is the chief way plants control water loss under stress. To measure resistance to water loss under drought conditions, researchers use a porometer to evaluate stomatal closure. These and other experiments are helping identify "waterwise" sorghum genotypes to help plant breeders who are working to develop varieties with greater dry-weather resistance.

Guayule is a desert shrub with a history as fascinating as it is promising. Discoveries of the effect bioregulators have when sprayed on guayule plants have led scientists to take a serious look at the plant. Guayule was the source of about half of all U.S. rubber in the early part of the century–and it came to the rescue again in World War II when Asiatic sources of supply for natural rubber were cut off. Now, researchers have found that carotenoid compounds, which determine the color of lemons, have "building blocks" similar to those that produce rubber in the guayule plant. The same chemicals that stimulate the building blocks to put more red in the lemon also stimulate the guayule plant's building blocks to put more rubber in the guayule plant.

Plasmids in the mitochondria have been discovered which could be used to breed plants with desirable traits, such as disease resistance, increased yield, and improved seed quality. Genetic engineering potential will be realized when genes necessary for plant improvement can be isolated and inserted into the plasmids, together with a system to detect altered plants.

One genetic transfer in what may have been an extremely useful and versatile model system for genetically engineering plants was the "sunbean." A gene that directs the production of a major seed portion has been moved from its native location in the French bean to the foreign environment of a sunflower cell. DNA is separated from the bacterial extract and fragmented. Then, fragments are separated by gel electrophoresis. In this purification process, "wells" in the gel are filled with DNA solution and electrical charges flow through the gel to separate the fragments according to size.

Highlighting the success of the research team producing the "sunbean" from the sunflower and the French bean was their observation that the transplanted gene is stable in its new environment and can produce small amounts of phaseolin–specific messenger RNA–the messenger that carries the genetic information from the gene to the protein synthesizing machinery of the cell. The bacteria was Agrobacterium tumefaciens, a species that transfers a piece of genetic material into plants that it infects.

The new biotechnologies in animal agriculture offer promising new research in animal science such as the micro-injection of genes for growth hormone into recently fertilized pig and sheep eggs. When the injected eggs are transferred back into the female, some will continue to develop into embryos. The birth of pigs and lambs that have incorporated the growth hormone genes for a faster growth rate is anticipated. These techniques will be useful for introduction of other economically important genes in the future.

The ability to select the sex of offspring would enable animal producers to optimize production of meat and milk. ARS research on the sexing–of sperm resulted in a breakthrough–a way to differentiate between X and Y sperm by DNA content. The research now underway is attempting to sort the two populations of X and Y sperm to determine a marker–or identifier–in developing a practical technique to separate X and Y sperm. If sorting is successful, micro-injection of the X and Y sperm into eggs will be done to verify sex.

A new scientific/technological revolution for agriculture is in the making that may well lead to developments which will dwarf past accomplishments in agricultural science. It seems irrefutable that the potential is great for major scientific breakthroughs. All participants in the change must work together to bring it about in an orderly and constructive manner that will be of benefit to all.