BIOTECHNOLOGY RESEARCH AND AGRICULTURAL STABILITY

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A few years ago at the Smithsonian Institution's National Museum of American History, an exhibition entitled "The Changing American Farm: 1831-1981" celebrated the one-hundred-fiftieth anniversary of Cyrus McCormick's invention of the reaper, and more broadly, America's vaunted agricultural productivity. Various displays recounted the historical progression of mostly mechanical technology that has made the U.S. farmer the envy of the world: McCormick's reaper, John Deere's steel plow of 1837, Benjamin Holt's horse-drawn combine of the 1880's, Henry Ford's tractor of 1917, the self-propelled combine of 1938, the spindle cotton picker of 1943, and International Harvester's Axial-Flow combine of 1977.

This technology has helped make the United States a world leader in food production. In 1800, for example, it took 373 manhours to produce 100 bushels of wheat. Today it takes less than nine manhours to produce the same quantity. In 1900, one U.S. farmer supplied seven other people with food, fiber, and other agricultural products. Today the average U.S. farmer supplies more than 75 people.

Of course, this impressive productivity is not the result of mechanical invention alone, but also of scientific advances in plant breeding, livestock genetics, fertilizer and pesticide use, irrigation technology, and improved farm management practices generally.

Because of the interplay of genetics, fertilizers, and pesticides, for example, corn yields have increased about a bushel per acre every year since 1930--from an average yield then of 40 bushels per acre to more than 100 bushels per acre today. Similar productivity gains have been made in livestock. Although the U.S. dairy herd has been cut in half since 1950, it produces the same total amount of milk on one-third less feed. In all areas of plant and animal agriculture, "science power" has been the driving force behind steadily increasing yields. Our modern agricultural system and methods are now exported and propounded worldwide.

A VULNERABLE SYSTEM

Modern agriculture, however, is high-pedigree agriculture; it is a pampered system that is tended and maintained by technology and driven to perform at peak levels. In that sense our agricultural system might be compared to a thoroughbred race horse. It is a system built increasingly on hybrid crops and livestock, heavy inputs of fertilizer, antibiotics, water, and pesticides, a system that is capital, energy, and technology intensive. It is, in short, a demanding, high-strung system.

As such, it has its dependencies, its side effects, and its vulnerabilities. Because many of the inputs that sustain modern agriculture are petroleum-based and mechanically administered, agriculture has become energy dependent--with the high costs and insecurities such dependency entails. Despite dramatic hikes in nitrogen prices since the 1970s, heavy use of nitrogen fertilizer continues, with attendant problems of runoff and groundwater contamination. Nitrates and nitrites from fertilizer runoff have infiltrated some drinking water supplies, posing a health threat, especially to young children. Pesticides, too, are increasingly suspected as carcinogens and mutagens, in addition to their well-known deleterious effects on beneficial insects and wildlife. Moreover, despite our heavy use of pesticides and herbicides, nearly 40 percent of U.S. crops are still lost to diseases and pests -13 percent to insects, 12 percent to plant pathogens, and 12 percent to competing weeds.[1]

Monocultures of hybrid corn and Holstein cows have been and continue to be highly vulnerable to disease and pestilence. The extent of these vulnerabilities has been partly masked by surplus stocks, crop substitutions, and, in some cases, sheer luck. Nonetheless, the list of actual epidemics and near calamities in the past 15 years is substantial: the southern corn leaf-blight of 1970-71, citrus canker infestation in Florida, avian influenza in the mid-Atlantic poultry states, and the Mediterranean fruit fly, among others. In addition, the periodic ravages of drought and frost can humble even the strongest plant variety. Frost damage alone causes some $1 billion in losses annually in the United States, and $14 billion worldwide.

Geneticist William L. Brown, former chairman of the board of Pioneer Hi-Bred International and now chairman of the National Academy of Sciences' Board on Agriculture, has noted that when our agricultural system is running right, its performance is simply dazzling--"but watch out when something goes wrong." In 1983 something did go wrong for corn farmers in the Midwest: drought. "Many farmers incurred large economic losses," Brown explained, "because their investment in inputs to support a 150-bushel (per acre) crop withered along with their corn plants." Brown and others have begun to raise concerns about the volatility of our high-tech, high-yield system. "As we offer the farmer increasingly sophisticated and costly technological packages, we inadvertently exacerbate two related sources of instability in agriculture. High-yield production systems are often more volatile in terms of harvested production, and more erratic in terms of profit for the farmer," Brown says.[2] In other words, the thoroughbred runs well only when everything clicks.

Like a thoroughbred race horse, modern agriculture is a demanding, high-strung system, nourished by technology and driven to perform at peak levels.

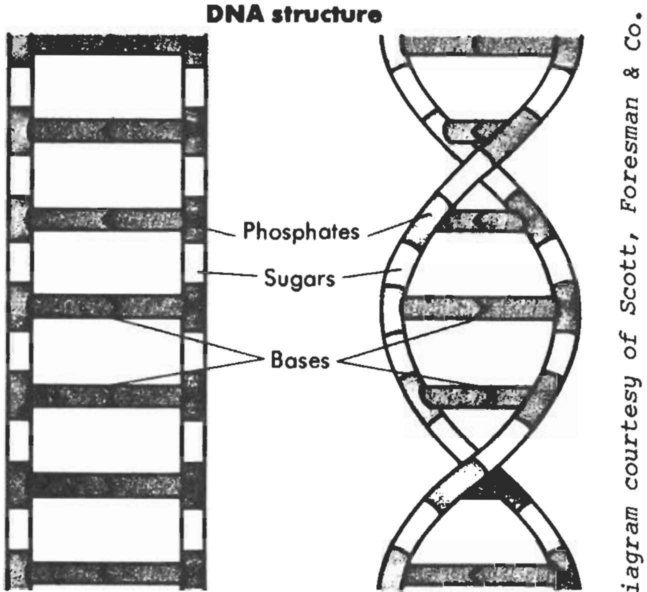
Into this agricultural system, with all its strengths, complexities, and vulnerabilities--both biological and political--comes biotechnology. We are now poised on the threshold of a new era of agricultural science and technology that may bolster, fortify, and eventually supersede the traditional techniques of plant and animal breeding, make obsolete the brute-force use of agricultural chemicals, and increase productivity beyond anything ever dreamed of.

Recombinant DNA and tissue culture techniques may offer new ways to enhance the nutritional content of food and forage crops and to develop crops resistant to insects and disease. Engineered biological pesticides may also be used to combat agricultural pests. Genetically improved herds of dairy cows and beef cattle, as well as hogs, poultry, and sheep, may produce more on less feed. Work is also under way on crops that are more tolerant of heat, cold, drought, flooding, and salty soils, and on crop plants that are resistant to herbicides and pesticides or that have improved response to fertilizer. Some biotechnologists promise a new genetic diversity throughout plant and animal agriculture, lower costs and higher profits for farmers, and better crops and livestock breeds for the third world.

Indeed, the promises being made in the name of biotechnology are substantial, even though the science underlying these applications is still uncertain. Generally, we know less about plants than we do about animals, in part because federal support for cancer research has focused attention on animal cell biology. Few genes in the plant realm have even been characterized. And when it comes to actual genetic engineering, scientists are only beginning to discover how to manipulate single-gene traits, let alone functions such as nitrogen fixation, believed to be governed by 30 or more genes.

But assuming that the scientific barriers will be overcome--and advances have been coming more rapidly than anyone ever thought they would even five years ago--the key question about agricultural biotechnology is, How will it be used? Will it simply add newer increments of pedigree improvement to the high-tech, high-yield system that is already in place--exacerbating its vulnerability, its side effects, and its volatility? Or will it reduce production costs for farmers, broaden the genetic and economic base of agriculture, and reduce negative environmental and public health side effects?

With this new technology we are at a crossroads, and the path we choose may affect not only the United States but much of world agriculture. Our decisions on research direction and investment must be made carefully for if commitments of scarce talent and capital are made in one direction, we may foreclose other options. Commerce and entrepreneurial genius have been a driving force in agricultural innovation and rising productivity in the past. The future direction of agricultural biotechnology, however, should not be left to the market alone. Thoughtful public policies are necessary to ensure that promising options are pursued--including those that are financially risky, longer term, and perhaps not as commercially



DNA can be described as "a winding ladder."

lucrative. We need to examine which historically neglected areas of agricultural research may profit from genetic engineering, where scarce research dollars should be put first, the research role of the U.S. Department of Agriculture (USDA) and land grant and private universities, and what new incentives might be created to encourage industry to pursue products it might otherwise neglect.

As a start in that process, it will be helpful to examine what biotechnology may or may not do in terms of increasing the efficiency of agricultural production (and here I mean more emphasis on productivity and less on gross output per acre), reducing farmers' costs, reducing agrichemical use, broadening genetic diversity, and increasing economic stability in agricultural production and world markets.

YIELD HAS BEEN THE GOAL

In the next 30 years world food production will have to double, it is estimated, to meet demand. This challenge cannot be met without substantial improvements in agricultural yields. Yield is what farmers buy and what political leaders with masses of people to feed hope most for their scientists to achieve, whether by classical breeding techniques, tissue culture methods, or genetic engineering. When Rajiv Gandhi visited the United States in June 1985, it was not the computer-based sciences and robotics that impressed him the most, but rather what biotechnology might do to help him feed his nation.[3] The semi-dwarf wheat and rice varieties introduced during the Green Revolution in the 1960s and 1970s helped provide India with the ability to feed itself; Gandhi sees even greater possibilities ahead with biotechnology.

Today there is talk of 300-bushel per acre corn and sorghum, 200-bushel per acre wheat and barley, and 100-bushel per acre soybeans--double and triple current yields. Crop yield, however, is a composite of many plant processes ranging from how strong a crop's stalk is to the molecular intricacies of photosynthesis. High yield is not simply the consequence of one gene but of the interaction of many.

When breeders and biotechnologists talk of improving yield, they invariably talk of hybridization--the process of crossing two different plant varieties or animal breeds to obtain a genetically improved one. Corn and sorghum yields, for example, have increased more than 300 percent since they were hybridized in the 1930s and 1940s. However, other major crops like wheat and soybeans have been difficult to hybridize by traditional techniques, and producing commercial quantities of hybrid seed from these crops is costly and time-consuming. Now, however, biotechnology is being used to overcome some of these difficulties.

One company, Plant Genetics, Inc. of Davis, California, is using a tissue culture technique known as somatic embryogenesis to produce clones of a hand-pollinated celery hybrid. In this process tiny plant embryos are generated from the hybrid celery tissue and then "batched up" by the thousands in a fermentation process. These embryos, carrying the desired traits of the parent line, are then encapsulated in a polymer seed coat to be sold as "synthetic" hybrid seeds.

Agrigenetics Corporation of Boulder, Colorado, has patented a biotechnology process that allows for the rapid development and commerial production of hybrid seed without the traditional limitations on the genetic makeup of the parent lines. This process, according to the company, permits one or both of the parent lines to be genetically complex (heterozygous) rather than inbred for uniformity (homozygous), potentially reducing the time needed to develop hybrid seed.

Biotechnology may also help improve crop yield by improving the efficiency of certain biological processes in plant growth, such as photosynthesis. Most agricultural crops convert less than 1 percent of the energy they absorb from the sun, and even a tiny increase in this conversion process could mean a substantial increase in crop yield. The federal government and a few major corporations--including Dow Chemical, Monsanto, and Eli Lilly--have been researching the genetics of photosynthesis. Specifically, they are examining the genetics of chloroplasts, the site of photosynthesis within the cell. Eventually, it may be possible to genetically engineer these organelles to improve the efficiency of photosynthesis, although there is still a long way to go on this front.

Other companies are concentrating their efforts for increasing yield in one or more specific crops. DuPont, for example, has integrated its chemical growth regulator research with its plant breeding and plant biotechnology research in an attempt to achieve a 10 to 15 percent yield increase in soybeans, according to G.D. Hill of the company's agricultural chemicals division.[4]

"YIELD" REDEFINED

Alternatively, biotechnology also offers the possibility of improving productivity without increasing yield per se--in other words, increasing the efficiency of production. For example, some plants produce natural molecules that repel insects. As Sam Dryden, president of Agrigenetics, says, engineering such traits into agricultural crops. "could be several orders of magnitude more cost effective than traditional chemical approaches to formulating, manufacturing, and applying biocides." This approach, however, might also reduce yield somewhat. "The added value in this case may be one of cost reduction [eliminating the need for insecticide application], not of increased harvest index [yield]," explains Dryden. "In any case, we should be helped if we refined our use of the word 'yield' to mean return on investment rather than as measure of gross biomass per acre."[5]

Reversing the high-yield orientation of U.S. agriculture, even with a powerful tool like biotechnology, will be difficult inded.

That may be easier said than done, however. In the United States, as well as in many other countries, plant breeding programs, farm management practices, price support formulas, farm credit, and agribusiness product development are all predicated on high-yield agriculture. Reversing that high-yield orientation, even with a powerful tool like biotechnology, will be difficult indeed. Rather, biotechnology is more likely to be used to make the thoroughbred run faster, or produce more, than it is to make it stronger and more durable.

HIGH COSTS OF U.S. AGRICULTURE

Biotechnology, as noted above, may offer new opportunities to reduce farmers' costs--and those costs are substantial. In the aggregate U.S. farmers spend nearly two-thirds of their cash receipts each year to purchase farm supplies. In 1983, for example, farmers spent $18 billion for purchased feed, $7.4 billion for fertilizer, $4 billion for pesticides, $4 billion for seed, $9.8 billion for farm machinery and $15.8 billion for fuel, lubricants, and machinery up-keep.

The prices paid by farmers for production inputs have risen precipitously during the last 15 years or so. USDA's index for general production inputs shows a doubling of prices paid by farmers between 1973 and 1983. For example, the average cost per farm of seed and plants soared by 164 percent between 1972 and 1977. Today a midwestern corn farmer spends on the average about $46 per acre on fertilizer, $17 per acre on pesticides, $17 per acre for seed, and about $18 per acre for fuel. Capital investments can be substantial, too. Irrigation investments in the Great Plains region were $103 per acre in 1950, rose to $201 per acre by 1970, and exceeded $500 per acre by 1979. Some farmers are now spending as much as $35,000 a year on herbicides and $50,000 a year to power irrigation systems. Rising costs are part of the reason why many farmers are now in economic trouble.

Will biotechnology change that? Because biotechnology is capable of turning out certain kinds of plant clones in the millions or producing livestock vaccines in huge quantities for pennies, it should, presumably, be able to deliver lower cost seed, feed, and pesticides. And insofar as the gene is the central ingredient of agriculture--determining to a large extent whether, or to what degree, supplementary ingredients such as fertilizer, pesticides, or water will be needed--"building in" traits that make crops hardier and able to resist pests should presumably do away with the need for some expensive supplements and capital equipment.

"Imagine a strain of wheat that grows well in the dry lands of western Kansas--without heavy irrigation," said Nicholas Reding, Monsanto's executive vice-president, at a January 1984 meeting of the Kansas Board of Agriculture. "Or a corn plant that fixes its own nitrogen. Or soybean plant that have even higher protein, or don't need to be processed before animal consumption. Or cattle that convert protein to meat with an efficiency we only dream about today ... These new technologies, like those of the past, will give American farmers the edge they need to remain the most productive in the world."

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BIOTECHNOLOGY: The Terms of the Trade

What is DNA?

DNA—deoxyribonucleic acid—is the genetic material found in all living organisms. The characteristics of every living organism can be traced to the code of its DNA. Recombinant DNA, (rDNA), is both the process of combining the DNA of different organisms and the product of this process.

What do genes do?

The genetic code is present in every cell of every organism. Depending on the cell's particular function, the code tells the cell what to do, how to act, and when to do it. For example, the human body has a gene, or several genes, that tell cells when to grow. Normally, this gene is "on" until a person reaches their early twenties or late teens. Then, another gene tells the body to stop producing the chain of reactions that stimulate growth, and the gene turns "off".

How do genes work?

Each gene produces an enzyme that contributes to a chain reaction; ultimately, normal functioning of the body is the result of a series of chain reactions. Another way to imagine how genes work would be to think of genes working together to create a domino effect. Generally, no one gene is responsible for a single action.

What is cloning?

Cloning occurs as a result of isolating the DNA within certain, specific genes. DNA is isolated by using "restriction enzymes," that separate segments of DNA from its longer strand. These segments are then transferred into bacteria. By this process, specific segments of DNA can be patched into the genetic code of other organisms.

Bacteria provides an especially hospitable habitat for cloning, because it is able to multiply rapidly. Since the piece of transferred DNA has been implanted into the bacterium's permanent genetic code, it is reproduced exactly through every generation of bacteria. When the bacteria are grown in large enough batches, the products from the new gene can be harvested and purified.

What is Biotechnology?

People often use the terms biotechnology, genetic engineering, and recombinant DNA (rDNA) interchangeably. Actually they describe different classifications of activities in biology. Biotechnology is the broadest category. It describes both old and new techniques of manipulating organisms for specific purposes. According to a 1984 Office of Technology Assessment Report, biotechnology includes any technique "that uses living organisms (or parts of organisms) to make or modify products, to improve plants and animals, or to develop micro-organisms for specific uses."

What is somatic gene therapy and how does it differ from germline gene therapy?

The idea behind somatic therapy is to replace genes whose absence or defectiveness causes genetic diseases (like cystic fibrosis or Huntington's disease). Scientists first remove the genetic code from a type of virus called a retrovirus, which is compatible with bone marrow cells, and substitute genetic material from a healthy gene. The altered virus is injected into the bone marrow, where it multiplies and forms healthy bone marrow cells. The bone marrow is then able to produce blood cells with healthy genes, which in turn produce the enzymes necessary for a normal metabolic process. Although still in the experimental stages, somatic therapy has been tested with success in laboratory animals.

Most authorities believe that genetic changes made in somatic therapy do not get passed on to generations via the sex—called "germ"—cells.

The other, more controversial gene therapy would involve changing the genetic make up of the genes carried in germ cells. While germ-cell alterations could reduce inherited genetic diseases, in the far-reaching future it could have the potential to alter genes that determine the hair and eye color, sex, and intelligence of an offspring. Both scientists and ethicists debate the consequences of germ-cell therapy, questioning the morality of tampering with already healthy genes. □

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