Chapter 10

Impacts on the Environment and Natural Resources

Contents

Tables

Chapter 10

Impacts on the Environment and Natural Resources

Overall, the emerging technologies are expected to reduce land and water requirements for agricultural use. They are also expected to reduce certain adverse environmental impacts associated with land and water use, such as soil erosion, threats to wildlife, and pollution from the use of farm chemicals. What impacts will result from biotechnologies, however, are more uncertain, for there are no good predictive ecological models or systems in existence that could help evaluate the potential impacts of a release of genetically altered organisms into the environment.

This chapter evaluates the implications for the environmental and natural resource use of emerging agricultural technologies. It is divided into four parts: 1) impacts of technology, which includes the methodology for identifying the emerging technologies and evaluating their environmental / resource impacts, the evaluations of the technologies, and some limitations associated with the evaluations; 2) the relationship between the size and structure of farms and the adoption of new technologies; 3) environmental concerns of emerging technologies; and 4) policies for mitigating adverse consequences and for enhancing the favorable aspects of the new technologies.

IMPACTS OF EMERGING TECHNOLOGIES

Methodological Approach

One problem that arises in identifying the technologies to be evaluated is the establishment of a time horizon. Although the emerging technologies studied are expected to be adopted before the end of the century, some of the technologies identified are not expected to be introduced for commercial adoption until very late in the century. Even then, adoption may be rather limited, and widespread adoption may not occur until the first decade of the next century. Thus the environmental and resource impacts of such technologies may not manifest themselves until early in the next century.

Since policy concerns focus on technologies that should be discouraged or encouraged because of expected environmental / resource consequences, holding rigidly to the end of the century for evaluating the emerging technologies is too limiting, Therefore, the convention used in determining which technologies were to be evaluated was that the technology be *available* for adoption by the end of the century, even though the environmental and resource impacts from use of that technology might not occur until later.

The Delphi approach was used to facilitate consensus in the evaluation of the impacts of emerging technologies (Coates, in Teich, 1981; Gordon and Ament, in Teich, 1981). While the technique does not provide for a high level of scientific rigor, the difficulties inherent in foreseeing the myriad possible consequences of a new technology in a complex socioeconomic system require subjective evaluation from a well-informed, multidisciplinary team. The Delphi technique lends itself to identification of consensus.

A team of 11 experts was assembled for a 2-day workshop to perform the evaluation.[1] These

[1]This chapter is based largely on the results of the workshop as analyzed by James Hite in the OTA paper "Environmental and Natural Resource Impacts of Emerging Technologies in American Agriculture" and reviewed by the workshop participants.

experts represented a broad range of backgrounds and regions within the United States. (The names, affiliations, and disciplinary specialty of each member of the team is included in appendix C.) The first task of the team was to group the technologies in a way that was meaningful for evaluation of their environmental/resource impacts. The first division was between animal and plant agriculture.

Four general types of technologies related to animal agriculture were identified: 1) genetic engineering, growth and development, reproduction, and nutrition; 2) animal disease, pest control, environment, and behavior; 3) animal waste and crop residues; and 4) aquiculture.

The nine general areas of technologies related to plant agriculture included: 1) genetic engineering in plants; 2) photosynthesis; 3) nitrogen fixation; 4) plant growth regulators; 5) organic farming; 6) multiple cropping; 7) water and soil-water-plant relationships; 8) soil erosion and land management; 9) disease, insect, and weed control.

Each general area of technology was then evaluated relative to eight types of impacts: 1) water quality, 2) water quantity, 3) soil erosion, 4) soil productivity, 5) air quality, 6) wildlife, 7) solid waste, and 8) human health.

The evaluation was performed on a lo-point scale. A technology with a strongly favorable impact on the environment and/or natural resources would receive a rating of 10.0. A technology with a strongly adverse impact would receive a rating of zero. If the impact were judged to be neutral, the rating would be 5.0. A computer-driven device, a Consensor, was used to tabulate the ratings assigned by each expert. In addition, the device allowed each expert to weight his or her rating according to the degree of confidence he or she had in the rating. That level of confidence could be set at zero, 25, 50, 75, or 100 percent.

The Consensor provided an immediate video screen readout of the rating distribution, the weighted average rating, and the average degree of confidence. If the first vote showed a very wide distribution of ratings, those experts with outlying ratings were asked to explain their reasons for their ratings. After additional discussion, another vote was taken. Since lack of a consensus after such discussion is, in itself, an indication of considerable uncertainty about the impacts of new technology, no attempt was made to force a consensus beyond a second vote.

The "with and without test" was adopted as a basic guide in making the judgments necessary to assign a rating. Simply, the test involves evaluating what the environmental/resource situation would be with and without the technology. The rating, therefore, is based on an assessment of the net effect of the emerging technology. A rating that suggests that a particular technology will result in environmental improvement cannot be taken to mean that the environment will be better after adoption of that technology. Rather, such a rating means that the group's judgment was that the environment will be better with the new technology than it would be if the old technology were continued into the future. The converse is also true.

Evaluation Results

Technology in Animal Agriculture

Genetic Engineering, Growth and Development, Reproduction, and Nutrition.—Emerging technologies in the broad area of animal growth and development center on recombinant deoxyribonucleic acid (rDNA), monoclinal antibodies, estrous-cycle regulation, and embryo transfer. All of these technologies are expected to lead to production of increased output with fewer animals and reduced input of feed. That means that a given future demand can be met with fewer animals, less land devoted to production of feed grains and to pasture, and, in general, less demand on natural resources than would otherwise be the case.

On the other hand is the effect these new technologies might have on the structure of animal agriculture. If the new technologies encourage fewer but larger herds and greater geographic concentrations of animal agriculture, localized environmental problems might intensify. For example, disposal of manure and increased use of antibiotics, hormones, and other chemicals could result.

The rating results indicate that only two of the nine environmental impacts—water quality and human health—were judged relevant to this group of technologies (table 10-1). Given fewer animals, some marginal improvement in water quality would result. The possibilities for using genetic engineering techniques to reduce unsaturated fats in red meats would have a marginally beneficial effect on human health.

Animal Disease, Pest Control, Environment, and Behavior.—The emerging technologies in the area of animal disease, pests, environment, and behavior combined biotechnology and computer systems. In addition, it is expected that increased use will be made of existing technologies for diagnostic testing, slow-release insecticides and vaccines, and photoregulation.

Technologies in this area are viewed as similar in their effects on production to those associated with the previous area of animal growth and development, reproduction, nutrition, and genetic engineering, as shown in the rating. The use of these technologies will result in increased output of animal products with fewer inputs of natural resources. The environmental/resource consequences were also judged to be essentially the same as those in the previous area. With fewer animals needed to meet a given future demand, less natural resources would be required for feed production. Thus reduced pressure would be exerted on the environment and natural resources. However, as indicated above, concentration of animals could cause environmental problems.

Animal Waste and Crop Residue.—The basic features of emerging technologies in the handling of animal waste and crop residues center on chemical and biological conversion, recycling, and fuel production. All of these technologies are already being used to varying degrees. The new features involve increased adoption and application of the technologies to specific crops. One example is the use of corn cobs as fuel in thermal gasifiers for drying.

In general, economic factors will prevent widespread use of biomass for fuel or the conversion of animal waste to methane for the foreseeable future. Incorporating crop residues into the soil is expensive and sometimes creates disease and insect problems. Only if the field burning of crop residues is banned bylaw, thus raising the cost of conventional methods of managing these residues, would many new technologies in this area be widely adopted.

Assuming that the new technologies are adopted, increased use of animal waste for energy would reduce some water pollution and would marginally improve water quality. If crop residues were removed from the fields in large quantities, some additional soil erosion and loss of soil quality would result from the reduction of humus, but it is thought that the new technologies would not have a large effect on residues left in the field. Any movement toward less burning of crop residues, however, would produce a marginal improvement in air quality in selected localities.

Aquiculture. —Aquacultural activities have considerable potential for adverse impacts on water quality and quantity. In some parts of the country, aquacultural enterprises remove large quantities of groundwater from aquifers. In addition, some potential exists for wastewater from such enterprises to pose a water quality

Table 10-1 .—Impacts of Animal Technologies on the Environment and Natural Resources

Technology group	Water quality	Water quantity	Soil erosion	Soil productivity	Air quality	Wildlife	Solid waste	Human health
Genetic engineering, growth, reproduction, and nutrition	5.9	NR	NR	NR	NR	NR	NR	5.5
Animal disease, pest control, environment, and behavior	5.9	NR	NR	NR	NR	NR	NR	5.5
Animal waste and crop residues	5.4	NR	5.0	NR	5.3	NR	NR	NR

Rating system: 10 = strongly favorable impact; 5 = neutral; O = strongly adverse impact; and NR = not relevant.

SOURCE Off Ice of Technology Assessment

problem. Yet there are important economic questions about the potential growth in markets for aquacultural products. Until these questions are answered, it is not possible to make meaningful comments about potential environmental/resource impacts.

Technology in Plant Agriculture

Genetic Engineering.–While the technology of genetic engineering in plants offers dramatic possibilities for agriculture, the scientists working in the area believe that actual adoption of new technologies on the farm is some years away. Basic work in developing gene maps for plants is somewhat behind that for animals.

The technology involves rDNA, cell culture, cell fusion, and monoclinal antibodies. Much of the effort will focus on moisture and drought stress in plants, suggesting a reduced need for irrigation water. There should also be reductions in the use of chemicals as resistances become engineered into plants, with favorable results for water quality. To produce a given level of output, increased yields will allow retirement of some marginal, erosion-prone land, increasing the amount of habitat available for wildlife. Possibilities for using genetic engineering techniques to improve soil microbes was thought especially promising for soil productivity. On balance, therefore, these genetic engineering techniques in plant agriculture would enhance the environment rather strongly (see table 10-2).

Enhanced Photosynthesis. -Technologies that enhance photosynthesis address the plant's central productive process, increasing yields per unit of land. With these technologies, marginal lands could be retired, water needs could be held down, and erosion would be reduced.

In general, the technologies would be environmentally helpful. One possible exception concerns soil productivity. For example, with enhanced photosynthesis, crops on land left in production will draw out soil nutrients faster than would otherwise be the case. Therefore, the effect of the technology on those lands would be to reduce the natural productivity of the soils. However, with this technology there would be less land in production. On those lands not in production, soil productivity would be restored, or at least maintained. On balance, the effect of enhanced photosynthesis technologies on soil productivity would be about neutral.

Nitrogen Fixation.–Legumes have the ability to fix nitrogen from the atmosphere and transform it into plant food. However, cereal plants generally lack this ability. Breeding cereal plants with nitrogen-fixing abilities has long been the Holy Grail of agricultural geneticists, but many difficult problems have been encountered in its pursuit. Advances in genetic engineering, however, have opened up new avenues for plant breeders, and renewed hope exists of developing cereal plants with nitrogen-fixing capabilities. Even though the possibilities for significant breakthroughs prior to the end of the century are considered remote, some incremental advances are expected.

If such nitrogen-fixing technologies develop, the environmental/resource implications would be significant and positive. These technologies

Table 10=2.-Impacts of Plant Technologies on the Environment and Natural Resources

Technology group	Water quality	Water quantity	Soil erosion	Soil productivity	Air quality	Wildlife	Solid waste	Human health
Genetic engineering	6.4	6.9	6.5	7.4	5.9	6.3	5.4	6.1
Photosynthesis	6.2	6.2	6.3	5.0	NR	5.6	NR	NR
Nitrogen fixation	7.1		NR	5.6	5.4	6.3		
Plant growth regulators	6.2	6.2	6.3	5.0	NR	5.6	NR	NR
Organic farming	5.7	5.1	5.6	5.5	NR	5.5	5.5	5.9
Multiple cropping	6.4	4.8	6.8	5.0	NR	4.8	NR	NR
Water and soil-water-plant relationships	6.2	7.5	7.1	5.8	NR	5.0	NR	NR
Soil erosion and land management	6.3	6.6	9.1	7.7	6.6	6.7	NR	5.1
Disease, insect, and weed control	6.9	5.3	7.0	5.7	5.7	7.1	6.1	7.4

Rating system: 10 = strongly favorable impact; 5 = neutral; O = strongly adverse impact; and NR = not relevant,

SOURCE: Office of Technology Assessment.

would allow substantial reductions in the use of nitrogen fertilizers, resulting in a decrease in nitrogen runoff into surface waters and percolation into groundwater, with beneficial effects on water quality. With less nitrogen being manufactured, fewer people would be exposed to health risks in fertilizer plants and on the farm. Improved air quality would result from reduced fertilizer manufacturing, and wildlife, especially aquatic life, would also benefit from reduction of nitrogen runoff into surface waters.

Growth Regulation.—Plant growth regulators are typically organic chemical compounds sprayed on the surface of plants. They increase yield by affecting the way the plant uses its nutrients, Chemical concentration in the sprays is usually quite low. The compounds are rather quickly metabolized by the soil and usually present few environmental problems because the compounds themselves tend to break down quickly. The environmental/resource impacts of new technologies in plant growth regulation are likely to be quite similar to those determined for enhanced photosynthesis.

Organic Farming.—In some sense, organic farming represents an old and traditional set of technologies. However, in recent years, the concept of organic farming has undergone some changes. At the heart of organic farming are technologies concerned with nutrient self-reliance and recycling and minimum use of, but not necessarily total elimination of, chemicals. New organic farming in particular could be expected to make use of advances flowing from genetic engineering, enhanced photosynthesis, simultaneous cropping, and several other technologies discussed in this chapter,

Assessing the environmental/resource implications of organic farming presented more problems than any other single set of technologies. While there was general agreement that organic farming approaches would require more land to meet expected demand, there was skepticism about the extent to which organic farming technologies would be adopted. If widely adopted, organic farming would disperse animal agriculture geographically, since there would be a greater need to keep animals on many farms to produce manures. As a consequence, farm energy consumption would be reduced. If energy prices rise substantially, organic farming techniques might be adopted rather widely; but barring such an increase, the panel thought it unlikely that organic farming would account for more than a small percentage of the Nation's farm output.

Organic farming could have adverse impacts on environmental resources if it were widely adopted. Increased pressures would be brought on marginal and erodible lands, and widespread use of animal manures could have some negative consequences for water and air quality. While wildlife might be less threatened by the use of fewer chemical compounds, wildlife habitats could be threatened by the need for more land for crops.

Perhaps the strongest positive impact was thought to be in the area of human health. Organic farming would reduce human exposure to agricultural chemicals and could result in food products that have higher nutritional value and less chemical contamination,

Multiple Cropping.—The concept of multiple cropping involves two separate types of practices. The first, called simultaneous cropping, involves growing two or more crops in the same field at about the same time, The second type involves growing a second crop closely behind the harvest of another in the same field in the same year, The two types merge in some cases where one crop is begun before the other is harvested.

The latter type of multiple cropping has been increasing rather rapidly in the Southeast and in California. Because the land is covered with a crop for longer periods during the year, runoff and erosion are reduced, The result is improved water quality and soil conservation. In certain instances, increased irrigation water is required. Multiple cropping can be either beneficial or harmful to soil productivity, depending on the crops grown. In the wheat-soybean systems of the Southeast, for instance, multiple cropping might improve soil productivity marginally, but other systems would intensify the removal of soil nutrients.

On balance, multiple cropping would probably have some adverse consequences for wildlife. Machinery would be in the fields more often, disturbing nesting areas and wildlife generally. Also, there would be less stubble and other crop residues available for cover and feed. On the other hand, however, multiple cropping has the potential to reduce the land needs of agriculture and, as a result, to protect habitat and soil resources.

Water and Soil-Water-Plant Relationships.—Technologies that affect water and soil-water-plant relationships include certain genetic engineering approaches. Improvements in plants' capabilities to close leaf pore openings (stomata) for longer periods to retain moisture are possibilities. The ratings, however, were assigned primarily on perceptions of still-to-be-applied irrigation technologies, particularly improvements in onfarm irrigation technologies.

Movement toward improved irrigation efficiency is considered environmentally benign. Less water applied means less return flow and, thus, less threat to water quality. It also means substantial savings in water and reduced soil erosion. The effects on soil productivity are mixed, however. While improved technologies will allow plants to make better use of existing soil nutrients, they will also allow those nutrients to be used up faster. So, improved irrigation technologies would have a marginally beneficial effect on soil productivity. Similarly, effects on wildlife are likely to be mixed. The concentration of salts in runoff water might be higher, and with less water, there might be fewer reservoirs and other habitats. On the other hand, with less water being drawn away from irrigation, more clean water might be available elsewhere. Thus the impact on wildlife would probably be neutral.

Soil Erosion/Land Management.—One major technological change in agriculture in the 1970s was the growth of what is called conservation tillage. Conservation tillage implies limited tillage. It has several forms: in some cases, corn and other grains are actually planted into grass or stubble along with an herbicide applied in a very narrow strip where the seed is injected. A newer innovation is called prescribed tillage, a practice that uses computer technology to monitor soil conditions. This technique integrates such information with weather forecasts, for example, to determine when and how to undertake tillage.

Conservation tillage has enormous possibilities for reducing soil erosion. The major environmental problem is the increased use of herbicides. Another problem is the reduced crop yield that results from conservation tillage. To meet given production demands additional acreage must be cultivated. Although the health impact on humans is likely to be negative because of an increased threat to groundwater from agricultural chemicals, reduced tillage could reduce mechanical energy consumption and incidence of farm accidents associated with tillage activities.

Disease, Insect, and Weed Control.–The emerging technologies in plant disease, insect, and weed control begin with integrated pest management (1PM), an approach to pest control that does not eliminate use of pesticides but does attempt to minimize those pesticides by making maximum use of predators, by attempting to protect beneficial insects, and by applying pesticides in limited quantities only after no other control mechanism is deemed feasible. 1PM has the potential to reduce pesticide use by as much as 50 percent.

Integrated weed management is similar in concept. In this practice changes in cultivation practices are integrated into reduced use of herbicides.

These new technologies, combined with a new generation of agricultural chemicals expected to appear on the market by late in the decade, will tend to cause considerable environmental improvements over existing technologies, if properly applied. However, some concerns were expressed about application in the field. Application machinery often is not precise, and knowing that, farmers sometimes deliberately use a greater application rate than that called for in farm-chemical instructions. Unlike many of the other technologies examined, these disease, insect, and weed control technologies will reduce the amount of land needed for crops. Most of the environmental improvements are expected to be associated with reduced use of agricultural chemicals, which will clearly be environmentally beneficial to water quality, soil quality, human and animal health, air pollution, and energy requirements.

EFFECTS OF FARM STRUCTURE ON THE ENVIRONMENT

To evaluate the impact of farm structure on the environment and natural resources, three scenarios related to three different structures of production agriculture were postulated:

1. a continuation of current policy, which could be expected to result, by the end of the century, in a notably dual distribution of farms by size—many small farms with sales of less than $20,000 annually and many large farms with annual sales of $500,000 or more each year;
2. policies that accelerate the trend toward a dual distribution and a significant reduction in the number of moderate farms; and
3. policies that would slow down the move toward the bipolar distribution, maintaining the number of moderate farms at the expense of larger farms.

The question posed was: what effect, if any, would these structural scenarios have on the environment and on natural resource use? The scale used in assigning ratings was the same as that used in evaluating the various sets of technologies, that is, a rating of 5.0 meant that the scenario was expected to make no perceptible difference. Ratings higher than 5.0 suggested environmental improvement, all things being equal, whereas ratings below 5.0 suggested some environmental degradation.

Considerable evidence suggested that large farms were more likely than small farms to adopt new technologies. Small farms are constrained by time limitations in the use of technologies that require intensive management. They may also be constrained by access to financing. In this context, both considerations are especially important, since many of the new technologies are management-intensive and will require substantial front-end outlays.

On the other hand, it was noted that some large farms may currently be more heavily leveraged financially than the moderate farms. Moreover, since almost all of the small farms are operated by persons or families with some outside income, the small farms may be less constrained financially to use technologies that save labor and do not require enormous front-end outlays that necessitate borrowing. Organic farming is an example of a technology that may have more appeal to small than to large farmers.

It is also important to note that many large farms making use of hired labor may concentrate on minimizing labor costs. The new technologies, in the main, are not primarily labor-saving. The principal savings to be had from these new technologies are in a reduction inland and environmental degradation. Since the environmental effects are usually offsite and external to the farm firm's accounts, there may be only modest incentives for some of the larger farms to adopt the new technologies unless the farms are under strong regulatory pressures from environmental agencies.

On balance, however, the technologies would favor large-farm operators. Because the technologies, in general, tend to be environmentally enhancing, it follows that movement toward a greater concentration of production in the hands of large operators would have beneficial environmental effects. However, several panelists insisted on the caveat that the major factors influencing adoption of the new technologies are access to front-end capital and managerial capability. Thus the technologies are not confined exclusively to large farms; many moderate farms are also in a position to adopt the technologies. In the areas of animal agriculture, particularly, many of the new technologies are being adopted first by seed-stock producers, who tend to be moderate operators.

These reservations are important as background for the interpretation of the ratings. Scenario 1 represents a continuation of recent trends and, given the "with and without" rule used in evaluating the technologies, must be assigned a rating of 5.0 (environmentally neutral) in all impact areas. Movement toward greater concentration of production on large farms would, in the panel's judgment, have a general tendency to enhance the environment because the larger farms (as a class) will be more likely to adopt the new technologies. The panel emphasizes, however, in strong terms, that movement toward greater concentration of large farms is not a necessary condition for realization of environmental improvement flowing from the new technologies. Public policies that improve the access of small and moderate farms to the new technologies would accomplish the same end.

Scenario 3 represents public policy designed to improve the survival rates of moderate farms. Such policy, taken alone, was judged to have unfavorable environmental consequences in five of the nine impact areas addressed. If such farms survive, but do not prosper, they will have few resources available to use in adopting the new technologies. Policies that improve the opportunities of moderate farms to prosper and survive, however, would allow such farms to avail themselves of new technologies that are environmentally enhancing. Indeed, under such conditions, moderate farms might well adopt these new technologies more rapidly than the larger farms for those reasons cited above.

ENVIRONMENTAL CONCERNS Of EMERGING TECHNOLOGIES

Looking at all the technologies assessed, the environmental/resource impacts were believed by the majority of the panel to be, at least marginally, environmentally enhancing. The panel noted particularly the potential for new tillage technologies to reduce soil erosion and improve soil productivity, for new irrigation technologies to conserve water, for nitrogen-fixing technologies to improve water quality by reducing nitrogen runoff, and for genetic engineering to improve agricultural productivity. The technologies should reduce land needs and thereby reduce threats to wildlife habitats. They should also reduce the use of chemicals and the resulting possible threats to human health.

In only a few cases were the new technologies thought likely to have unfavorable environmental or resource impacts. Those concern the impacts of multiple cropping on water quality and on wildlife. In both these cases, however, the unfavorable impacts were thought to be relatively mild. Concern also arose over possible problems associated with human error or machine malfunction in the application of chemicals used in conservation tillage.

Perhaps the chief cause for concern was the lack of knowledge about the potential effects on the environment of the release of genetically altered organisms. Most of the biotechnologies applicable to agriculture that are expected to be commercially adopted in the next few years involve release of new organisms into the environment. The question of "deliberate release" of engineered micro-organisms has already arisen in agriculture, however, in connection with the testing of genetically altered bacteria in potato fields to prevent freeze damage. Other cases are almost certain to arise. The potential for these genetically altered micro-organisms to interact with the environment in unpredictably harmful ways cannot be ignored. Considerable debate is occurring within the scientific community and within the Federal bureaucracy over proper controls on the testing and use of genetically altered organisms prior to deliberate release. The economic benefits from uses of biotechnology that require deliberate release of modified organisms probably are substantial, but the panel recognized the need to work out suitable regulatory safeguards controlling such releases (Doyle, 1985; Healy, 1985; Kendrick, 1985; Schatzow, 1985).

The safety issue of biotechnology was debated when the first gene was about to be inserted into a micro-organism. Concerned about potential hazards of new rDNA techniques, a group of the world's leading scientists, headed by Paul Berg, met *10* years ago for the second time at the Asilomar Conference Center in Pacific Grove, California. They agreed to strictly regulate those experiments using rDNA techniques until more data could be collected for assessing the potential hazards and until safety could be assured. One day after the second Asilomar conference, a National Institutes of Health (NIH) Recombinant DNA Advisory Committee, commonly known as RAC, held its first meeting and began drafting a set of safety guidelines for the rDNA experiments, guidelines that have governed rDNA research in the United States ever since (Tangley, *1985).*

As scientists learned more about rDNA techniques, the guidelines were periodically revised. Each revision further relaxed the rules as scientists came to realize that the fears of hazards from rDNA research, although not groundless, were greatly overestimated a decade ago. During the last decade, hundreds of laboratories around the world have been cutting and splicing DNA in a multitude of combinations.

As new products of rDNA research approach field testing, clinical trials, and commercial introduction, safety and ethical issues have rekindled. Unlike 10 years ago, when concerns came exclusively from scientists, concerns today come from scientists, industry, social activists, and the public, all for different reasons. Some scientists, social activists, and members of the public are concerned about possible adverse impacts on human health and the environment, while some scientists and industry fear that public concerns may lead to overregulation.

One example illustrates the controversy over rDNA research in agriculture. Two years ago, Steven Lindow and Nicholas Panopoulos of the University of California, Berkeley, successfully constructed non-ice-nucleation bacteria that inhibit frost formation on potato plants. As these researchers readied to field test the new organisms to see if they could protect crops from frost damage, a coalition of public interest groups filed a lawsuit to postpone the field trials (Tangley, *1983).* These groups believe that field tests of genetically modified organisms should not proceed until scientists develop a method for establishing the safety of such releases. In May *1984,9* days before the scheduled release of the micro-organisms, a U.S. District Court issued a temporary injunction halting the first proposed release and prohibiting NIH from approving any more releases until the case was fully resolved (Bioscience, *1984). 111* February *1985* a U.S. Court of Appeals upheld part of the lower court's decision, stating that NIH was required to prepare an environmental assessment of the one field test in question but that the institute could go ahead and consider other release proposals. Recently, the Environmental Protection Agency approved the first two field tests of genetically altered organisms. In the first experiment, Agracetus of Middletown, Wisconsin, would test the effects of their new products, genetically modified disease resistant tobacco plants, on the natural environment. In the second experiment, Advanced Genetic Sciences of Oakland, California, would test bacteria that have been genetically altered to prevent frost formation on strawberry plants. This company would spray the modified bacteria on 2,400 blossoming strawberry plants on a one-fifth acre plot in Salinas Valley.

The central issue of these controversies is whether genetically engineered micro-organisms will disrupt the ecosystem into which they are released and will have adverse impacts on human health and the environment. In the case of non-ice-nucleation bacteria, scientists know virtually nothing about the normal role these bacteria play in the biosphere. Closely related bacteria are apparently ubiquitous, and some scientists suggest that they play a role in the moisture nucleation in clouds, and consequently in rain or snowfall (Feldberg, *1985).* What happens, however, if these new strains really are effective in competing for the same ecological niche as the natural strains? What if they allow clouds to hold much more moisture before precipitation occurs?

The major point the proponents of biotechnology, mainly the biotechnology industry and some scientists, use to defend biotechnology is that genetic engineering techniques have been used in plant breeding and animal husbandry for centuries. During the last several decades, biotechnology has been used in chemical and food processing industries (Fraley, 1985). For example, antibiotics, amino acids, and other supplements produced by fermentation technology are routinely added to feeds to stimulate animal growth and prevent disease. Microbial seed inoculums are commonly used to increase crop yields. Immobilized cells and enzymes are being used extensively to catalyze biochemical conversions in the production of specialty chemicals and feedstock (Fraley, 1985). Genetic engineering methods for manipulating genes in micro-organisms such as bacteria and yeast have also existed for several years.

Speaking for the biotechnology industry, Hardy and Glass (1985) argue that genetically engineered organisms are similar either to genetically engineered organisms already in commercial use or to naturally occurring organisms indigenous to habitats where they would be introduced. The fact that similar organisms exist or have been previously introduced into the environment suggests that no adverse effects would occur from the introduction of novel micro-organisms. Hardy and Glass claim that after nearly 10 years of close scrutiny, risk assessment studies, and worldwide experience with molecular and cellular genetic manipulations, there is no evidence of any significant hazards associated with this technology. The risks remain only speculative. In fact, with the accumulation of knowledge, many of the fears voiced in the early days of molecular genetics have been shown to be unfounded. Therefore, there is no reason to believe that cellular and molecular genetic engineering should present any greater hazard than that posed by the whole-organism genetic manipulation that has been practiced for centuries. With millions of dollars invested in biotechnology research and development, industry is concerned with over-regulation that could stifle future growth of the biotechnology industry and cause the U.S. industry to lose its competitive edge.

Opponents argue that the issue of deliberate release of genetically engineered micro-organisms into the environment is quite different from the genetic engineering methods, such as production of antibiotics and amino acids by fermentation technology, used in the past. McGarity (1985) points out several reasons why risks of large-scale release of micro-organisms are of much greater concern than the risks of fermentation biotechnology; for example: 1) a large-scale release of genetically engineered micro-organisms into the environment significantly reduces the degree of human control over the novel micro-organisms; 2) biological containment, by which strains of micro-organisms are weakened so that they cannot survive outside the laboratory environment, can no longer be used as a safeguard against potential hazards; and 3) it is difficult to assess potential risks to human health and the environment.

Alexander (1985) also expresses concerns that there is not enough information to predict the ecological consequences. The best model for predicting ecological consequences is the exotic species model, but this model has been criticized as inappropriate for predicting the potential ecological consequences of the deliberate release of novel micro-organisms because the model is based on outdated ecological thinking (Regal, 1985). Because there is no adequate model, Alexander (1985) suggests that history be used as a guide for the future. The history of the application of these emerging technologies provides lessons for assessing new technologies. Alexander asserts that no technology was without risk, and a risk-free technology probably does not exist now. Regal (1985) also indicates that there is no great power that is only good, that has no dangers, and that cannot be misused. Although the risks from deliberate release appear to be small, the consequences of an unlikely event could be disastrous. It is the fear that new micro-organisms or their genetic traits might survive and multiply unchecked and thus have adverse impacts on the ecosystem that make scientists worry about the release of the novel micro-organisms (Robbins and Freeman, 1985).

Now rDNA technology is entering a crucial stage in its development from laboratory to the marketplace. Goldberg (1985) demands that there be a social responsibility to ensure that rDNA technology is safe and suggests that all sectors of society must participate in decision-making about new developments such as the release of genetically modified organisms, In light of public concerns, proponents of biotechnology realize that without public confidence and support, this promising technology could falter as it moves from the laboratory to the marketplace. Those scientists who believe the risk of genetically modified micro-organisms is next to nothing envision that public concerns about such organisms must be addressed. Industry also recognizes the need for some regulation of the environmental applications of genetic engineering and suggests that better risk assessment tools be developed (Hardy and Glass, 1985).

Some biotechnology companies that are or will be introducing genetically engineered products believe that public perception translates into public policy and that commercialization of biotechnology may be in peril if ignorance engenders fear of biotechnological research and applications (Price, 1985). They call for public education about biotechnology research and applications.

Since deliberate release of genetically engineered micro-organisms is such an important and controversial issue, OTA and the National Science Foundation cosponsored a workshop late in 1985 to address this issue.

POLICY IMPLICATIONS

Although the discussion above addresses some policy matters obliquely, the purpose of this section is to discuss the way public policy might enhance the positive environmental effects or mitigate the negative effects of the emerging technologies,

The first point on which a consensus emerged was the observation that the net movement of new technologies is environmentally enhancing. Given the public pressure for environmental improvement and the increased regulatory activity by Government in the environmental area, that movement is consistent with economic theory. It follows, then, that increased Government expenditures on research and education would tend to have positive environmental effects. The assessments presented here suggest that there is a strong public interest in accelerating technological change in agriculture, and if that is the objective, the action required is increased research and education.

The second approach, which complements the research and education effort, is to develop more stringent environmental regulations and provide stronger enforcement of regulations. Such regulations tend to have the economic effect of raising the cost of using the environment in agricultural production, Economic theory suggests that as costs of particular inputs are increased, economic agents will find ways to reduce the use of the relatively higher priced inputs. So, increasing the costs of environmental inputs through stronger regulations and better enforcement will accelerate the adoption of the new technologies and give impetus to research that has further environmental benefits.

Finally, policies that reward farmers who adopt environmentally enhancing technologies have some precedent. Cost-sharing programs in the area of soil conservation are the best known example. Targeted cost-sharing and creative use of the relationship between environmentally enhancing farm practices and the price support program, such as the so-called cross-compliance proposal for using conservation cost-sharing funds, represents, at least in a generic way, a policy option likely to enhance the environmental benefits of the new technologies.

Turning to policies to mitigate the undesirable environmental impacts of new technologies, the panel moved quickly to the classic prescription of exacting a user charge. If the research base were available to determine the appropriate *T* value for soil erosion, a soil erosion tax could be levied on each ton of loss above that level. Ideally, the tax would be equal to the environmental damage caused by the erosion, Unfortunately, the research base for setting the *T* value is not sufficient. There would also be very difficult enforcement problems with such a tax. But the idea of making users of environmental inputs pay for them was considered fundamental to policy that mitigates undesirable environmental consequences.

More practical applications of this concept focus on raising the costs of agricultural chemicals by placing excise taxes on those chemicals. The more expensive the chemicals, the less they will be used and the greater care the user will take to be sure that the application rate is not excessive. Similarly, policies to raise the price of irrigation water might have some beneficial impacts on water quantity (although there are studies suggesting that the price elasticity on such water approximates unity),

SUMMARY AND CONCLUSIONS

In general, with a few notable exceptions, most of the emerging technologies are expected to reduce substantially the land and water requirements for meeting future agricultural needs. As a result, these technologies are also expected to reduce environmental problems associated with the use of land and water. The technologies were thought to have beneficial effects relative to soil erosion, to reduce threats to wildlife habitat, and to reduce dangers associated with the use of agricultural chemicals. New tillage technologies, however, may reduce erosion and threats to wildlife while increasing the dangers from the use of agricultural chemicals.

The panel concluded that the new technologies were most likely to receive first adoption by farmers who were well financed and were capable of providing the sophisticated management required to make profitable uses of the technologies. In the main, such farmers will tend to be those with relatively large operations. Hence, the technologies will tend to give additional economic advantages to large farm firms relative to moderate and smaller farms, accentuating the trend toward a bipolar or dual farm structure in the United States.

In addition, since the new technologies tend to be, at the margin, environmentally enhancing, there is public interest in research and education that leads to their rapid development and widespread adoption. That conclusion becomes even stronger if public policy is aimed at maintenance of the moderate farm. Larger farms, with their own access to research results and scientific expertise, may be able to advance the new technologies with relatively little publicly sponsored research. But moderate and small farms will have to depend on publicly sponsored research and extension education to obtain access to the new technologies and to adapt them to their individual situations.

The new technologies will require more stringent environmental regulations and stronger enforcement of regulations. The complexities of some of the emerging technologies will pose significant challenges for promulgation of wise environmental regulations. The economic benefits from the technologies cannot be passed by, but users may have little private incentive to make use of the technologies in ways that avoid unnecessary, adverse, third-party effects. The panel considered that economic incentives or disincentives, including the use of excise taxes to discourage overuse of potentially threatening materials, represented a more intelligent approach to protection of environmental values than did direct regulations. Yet the panel also concluded that: 1) some additional effort to enforce existing regulations would hasten the adoption of the new technologies that are, at least potentially, less environmentally threatening; and 2) new regulations will be required to deal with some aspects of the emerging technologies.

Perhaps the most revolutionary of the new technologies are those associated with rDNA. While specific applications of such technologies that are currently apparent would appear to reduce resource needs and threats to the environment arising from agricultural activities, the panel recognized possible dangers associated with the deliberate release of genetically altered micro-organisms. The very revolutionary nature of the new biotechnologies and the lack of a scientifically accepted predictive ecology prevented the panel from providing specific evaluations of resource/environmental impacts associated with the deliberate release of new forms of life,

Ten years ago, scientists concerned about the impact of rDNA agreed to regulate the rDNA experiments. Now many scientists see little danger in the applications of the planned rDNA technology. But as new products of rDNA research approach field testing and commercial introduction, safety and ethical issues have rekindled. Both sides of the issue agree that more research should be conducted to assess the potential benefits and risks.

CHAPTER 10 **REFERENCES**

Alexander, Martin, "Ecological Consequences: Reducing the Uncertainties, " *Issues in Science and Technology,* spring 1985, pp. 57-68,

Bioscience, "Court Halts Genetic Engineering Field Test, " 34:4, July/August 1984, p. 413.

Doyle, Jack, "The Regulation of Commercial Biotechnology, " Testimony Before the Subcommittee on Investigations and Oversight of the Committee on Science and Technology, U.S. House of Representatives, Washington, DC, Apr. 17, 1985.

Feldberg, Ross, "Framing the Issue: The Social Implications of Biotechnology," *Science for the People 17:3,* May/June 1985, pp. 4-9 and 53.

Fraley, Robert T., "Impact of Genetic Engineering on Plant Agriculture, " paper prepared for the Office of Technology Assessment, Washington, DC, 1985.

Goldberg, Terri, "Social Responsibility and Applications of Biotechnology," paper presented at the annual meetings of the American Association for the Advancement of Science, 1985.

Hardy, Ralph W. F., and Glass, David J., "Our Investment: What Is At State?" *Issues in Science and Technology,* spring 1985, pp. 69-82.

Healy, Bernadine, M. D., "Statement," Testimony Before the Subcommittee on Investigations and Oversight of the Committee on Science and Technology, U.S. House of Representatives, Washington, DC, Apr. 17, 1985.

Hite, James C,, and Laurent, Eugene A., *Environmental Planning: An Economic Analysis (New* York: Praeger Publishers, 1972).

Kendrick, Edgar L., "Statement," Testimony Before the Subcommittee on Investigations and Oversight of the Committee on Science and Technology, U.S. House of Representatives, Washington, DC, Apr. 17, 1985.

McGarity, Thomas O., "Regulating Biotechnology," *Issues in Science and Technology,* spring 1985, pp. 40-56.

Price, Harvey S., "Biotechnology: The Need for Public Education," *Bioscience* 35:4, April 1985, p. 211.

Regal, Philip J., "Biotechnology and a Safe Future: Mobilizing Scientific Expertise," paper presented at the annual meetings of the American Association for the Advancement of Science, 1985.

Robbins, Anthony, and Freeman, Phillis, "Biotechnology and the Public Purpose, or a Public Agenda for Biotechnology in the Congress," paper presented at the annual meetings of the American Association for the Advancement of Science, 1985.

Schatzow, Steven, "Statement," Testimony Before the Subcommittee on Investigations and Oversight of the Committee on Science and Technology, U.S. House of Representatives, Washington, DC, Apr. 17, 1985.

Tangley, Laura, "New Biology Enters a New Era, " *BioScience* 35:5, May 1985, pp. 270-275.

Tangley, Laura, "Engineered Organisms in the Environment? Not Yet, " *Bioscience* 33: 11, December 1983, pp. 681-682.

Teich, A.H. (cd.), *Technology and Man Future,* 3d ed. (New York: St. Martin's Press, 1981).