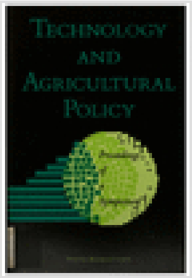

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

Since the mid-1960s the number of agricultural scientists in the world has tripled. A much smaller share of global agricultural research activity and a declining share of new agricultural technology are being generated by U.S. public and private sector agricultural research institutions. Within the United States, a much larger share of agricultural and agriculturally related research is being generated by private sector research institutions. The public sector is gradually losing control of the agricultural research agenda.

Moreover, in the United States, new agricultural technologies are met with growing skepticism. Farmers plagued with surpluses in the early 1980s wonder whether there is need for the boost in production promised by most new technologies, environmentalists question the likelihood for long-term health or ecological problems, and corporate decision makers are growing conservative in making projections of future markets. The effects of new agricultural technologies have been to both lower unit costs and increase production. During the 1970s, greater weight was given to expanding production. For the rest of this century greater effort must be directed to cost-reducing innovations.

The Board on Agriculture of the National Research Council convened the Conference on Technology and Agricultural Policy in December 1986 to explore new policies that would encourage this fundamental shift in U.S. agriculture—the shift from expanding production to incorporating cost-reducing innovations. Cosponsors of the conference were the John F. Kennedy School of Government at Harvard University and the National Center for Food and Agricultural Policy, Resources for the Future. The conference addressed emerging technologies of potential global significance to agriculture and public policy initiatives and their effects on technology development and adoption.

The purpose of the conference was to provoke a diverse group of experts to describe features of a more effective public policy, with the objective of fostering beneficial technological progress. (Beneficial technologies are defined as those having the potential to both reduce per unit costs of production and contribute to safe, sustainable agricultural management systems.) Conference participants were charged with discussing public policies, while focusing on three fundamental goals:

1. Sustaining the economic competitiveness of U.S. agriculture through development of new technologies and enhanced use of existing technologies that will reduce the real cost of agricultural production;
2. Ensuring that production practices and systems are safe and sustainable, and provide consumers here and abroad with low-cost products of the highest quality; and
3. Providing a technology and policy foundation for increasing the contribution of the U.S. agricultural sector to satisfy global food needs as well as to stimulate the growth of the U.S. gross national product.

Conference participants were asked to consider the interactions of technology and public policy as factors shaping—or influenced by—international trade, environmental and conservation policy, the structure of the farm sector, overseas development, and corporate strategies.

The conference was organized by Charles M. Benbrook, executive director, Board on Agriculture; Dale W. Jorgenson, director, Program on Technology and Economic Policy, Kennedy School of Government, Harvard University; Kenneth R. Farrell, director, National Center for Food and Agricultural Policy, Resources for the Future (currently vice-president, Agriculture and Natural Resources, University of California); Ralph Landau, fellow of the faculty at Harvard University, vice-president of the National Academy of Engineering, and consulting professor of economics at Stanford University; and Vernon W. Ruttan, member of the Board on Agriculture and regents professor, Department of Agricultural and Applied Economics, University of Minnesota.

The organizers proposed the following two hypotheses as the basis for discussion during the conference:

1. In the advanced industrial countries and in many less developed countries, agriculture has made the transition from a resource-based to a science-based industry. This means that the capacity to expand agricultural production under the stimulus of favorable economic incentives is extremely high. The long-run supply of agricultural commodities has become highly elastic with respect to price. This means that the cost of agricultural commodity policies that attempt to restrain production and enhance prices through land-use controls, as in the United States, has become extremely expensive. It also means that policies to enhance domestic prices through a combination

of trade barriers and export subsidies, as in the European Communities, have remained quite costly.

It is unlikely that the burden on national and consumer budgets can be sustained on either continent. Perhaps the time has come for a fundamental shift away from subsidizing prices to subsidizing incomes, with the idea that the smaller marginal farmers would thereby be kept in business as a socially desirable policy; but larger farms would have to rely on market forces for their returns just as any other business. The fundamental question is, Why should agriculture continue to be so heavily controlled by governments when so much of the rest of the economy is expected to function in the marketplace?

2. Reductions in the real cost of production must continue if the United States is to remain a major exporter of agricultural commodities. Failure to make the public and private sector research investments necessary to sustain productivity growth—measured by declines in the real cost of production—will inevitably weaken the competitive position of U.S. commodities in world markets. Maintenance of competitive capacity in world markets is vital to the producers of agricultural commodities, agribusiness, and rural communities throughout the United States.

Eighteen conference papers follow, and they fall into five categories:

- emerging biological, genetic, and chemical technologies significant for technical change in agriculture;
- the impact of public policies on technological innovation;
- technological innovation in agriculture;
- the global perspective on economic impacts of new agriculture technology; and
- agricultural and trade policy reform.

This report provides a cohesive view of not only U.S. agriculture, but also agriculture as a global endeavor. The Board on Agriculture's goal in issuing this volume is to provide scientific information and commentary on the interactions of domestic policy, international trade, and the promise of new technologies that will, in turn, stimulate new thinking and commitment to global agriculture.

CHARLES M. BENBROOK
KENNETH R. FARRELL
DALE W. JORGENSON
RALPH LANDAU
GEORGE E. ROSSMILLER
VERNON W. RUTTAN
Conference Organizers

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Agriculture at the Crossroads

Ralph Landau

Perhaps it would not be amiss for a nonagricultural expert to present a viewpoint that is shared by many outside observers not intimately involved in agriculture or the policies pertaining to it. Given that agriculture now contributes less than 3 percent of the gross national product, it is important to recognize that its demands for continuing protection and subsidization are increasingly looked at askance by the vast majority of taxpayers and policymakers who must either pay the bills or, as consumers, sustain higher than market prices in their food purchases. Moreover, it has become clear to most observers that agriculture all over the world has come to a number of forks in the road. The basic problem is how to resolve the issues represented by each fork.

The first set of forks pertains to *scientific and technical issues*. There is little doubt that world agriculture stands at the threshold of great new scientific and technical developments in biology, chemistry, genetics, agricultural engineering, information technology, and other fields. The former Secretary of Agriculture, Richard Lyng, recently stated that the rate of technical change in agriculture in the next 15 years will exceed the rate of the past 50 years. Many of the technical developments may well be less capital intensive and less land intensive than current methods and hold the promise of being environmentally friendly. Agricultural pesticides of biotechnological origin are already being introduced, as are species that are genetically engineered to be pest resistant or give higher yields. They should be of great significance for the smaller farmers and for those concerned about preservation of forestland and other fragile territories, as well as for the safety of our food supply.

Nevertheless, present technology has clearly resulted in a shift from the traditional family farm to a more nearly industrialized agriculture. Simultaneously, the conduct of research and development is shifting from the traditional government-supported system to one in which the private sector will increasingly provide the major scientific and technological changes.

Some of the current technological trends have resulted in the adoption by individual and smaller farmers of "boutique" farms of higher value-added and specialized crops. The commodity-producing smaller farms, however, are potentially if not currently in serious trouble. Another trend is the increasingly rapid diffusion of new technology from one country to another, even to undeveloped countries. Finally, regulatory and legal barriers have appeared, which existing governments seem to have little capability to resolve. In the United States, these barriers threaten to halt progress in using new technologies while foreign competitors rush to adopt them. Furthermore, there appears to be a growing reluctance on the part of young people to choose scientific careers in the food and agriculture industries. The relevant higher education system has been obsolescing and needs revitalization. Political pressures have been increasingly seeking to limit agricultural research that may appear to be economically harmful to smaller farmers or to farm workers.

In the *political* arena the 1986 elections in the United States demonstrated that the farm situation was grim enough to overturn Republican control of the Senate, which has affected politics since that time, even though the farm population is less than 3 percent of the work force and constitutes an even smaller percentage of the total population.

In Europe, the heads of the Common Market countries, being faced with early elections in France, the United Kingdom, and West Germany—where the farm vote can be very important—continue to avoid confronting the issues in agriculture.

Likewise in Japan, the liberal Democratic Party draws one of its principal supports from the 5 percent of its population that lives on farms. Ironically, these farmers are now indignant with the party for having eased agricultural imports under pressure from the United States.

As a result of such political pressures, the United States has attempted to limit some of the subsidies to agriculture provided in other countries, but only to encounter strong political objections from allies and competitors. Which fork in the road will be taken—collective action to reduce the burdens on the taxpayers or destructive nationalistic competition?

From an *economic* point of view, in the United States farm supports under the 1985 farm bill (Food Security Act of 1985) will cost over $14 billion in the fiscal year ending September 30, 1989 (a reduction from a peak of about $26 billion). At the same time, storage bins had overflowed with unwanted grains and other crops, until the recent droughts and Russian crop problems have, for at least a while, begun to reduce inventories. A substantial portion of farm profits are in fact directly attributable to these government subsidies. Despite the subsidies, the U.S. farm debt is still severe, having fallen last year to about $140 billion from a peak of $193 billion in 1983.

In Europe, subsidies and storage in 1986 accounted for two-thirds of the Common Market's agricultural budget of $22 billion, and the Common Market's expenses exceeded its income, largely for this reason. In late 1986, the Common Market had a record 15.1 million tons of surplus grain, its butter inventory was at 1.3 million tons, powdered milk was at 846,836 tons, and beef stockpiles were at 671,998 tons. Wine was in great surplus.

Japan engages in similar practices and the Japanese consumer pays up to 10 times world prices for basic commodities like rice.

Trends in the world economy are also pushing governments toward choosing a fork—continued subsidization or acceptance of a free market.

The *trade* picture is no rosier. As recently as the 1981–1982 fiscal year (a recession year), the United States had a positive trade balance in agriculture of $23.6 billion, which constituted a significant contribution to an overall favorable current account balance, and was more than that of any other sector of the economy. In the 1986–1987 fiscal year, the trade balance was only a little over $12.6 billion, and several months showed a deficit—a clear warning of imminent crises ahead, even though the trade surpluses improved subsequently during the worldwide economic boom to a level of $14.3 billion in 1988. As the U.S. agricultural trade balance has diminished, many countries previously our largest customers have become self-sufficient or exporters themselves, and new competitors have appeared in the export markets.

Concern for these trade issues has led the United States to insist on the highest priority for new negotiations (the Uruguay round of GATT) that will deal with these hitherto intractable relationships.

Many of these unfavorable trade developments in the United States cannot be separated from the broader economic policies of the country. Macroeconomic U.S. policy for years maintained an overvalued dollar by running large deficits and a correspondingly higher monetary policy, with high real interest rates. Although the dollar is down against the yen and the deutsche mark, it still has not changed enough relative to the currencies of many other countries. The budget deficit is only slowly showing signs of significant reduction. As a result of these "twin" deficits, the United States is importing substantial capital, because domestic savings are simply inadequate. Unless it can solve both deficits more or less simultaneously, the United States faces a catch-22 situation, in which the dollar weakens, the deficits continue, and inflation returns. Are the only alternatives a deep recession or rapid monetization of the debt? Or will we be lucky and achieve a "soft landing"? No one knows for sure.

The irony of all these trends is that the surpluses in Europe and the

United States produced by U.S. agricultural policies have served to provide the Soviet Union, the West's principal military adversary, with very low-cost food stuffs subsidized by Western taxpayers, thus to maintain large military expenditures which in turn force the West to maintain larger defense forces than they would like. Now this disastrous Soviet policy has been openly confessed by Mikhail Gorbachev, and a process has begun to solve Russian structural problems. This suggests that in the years ahead, Russian markets for U.S. agricultural products may shrink.

Even this cursory review of the present situation suggests that there are severe policy questions to be addressed. It is most unlikely that the world agricultural situation, which can only be characterized as a "mess," can continue for much longer without either collapse or radical change. To an outsider it would appear that if solutions are to be found, they will not likely come from within the agricultural community, which has pushed policymakers into these blind alleys. But what are the solutions, given the political realities? Is technology a boon or a bane? Should we adopt a Luddite position and refuse to follow the possibilities of greater productivity and lower cost crops that the new science and technology promise to offer us? The recent resistance by small farmers to the introduction of bovine growth factor is but a beginning in this process. Will our competitors imitate our example?

Why should the small farmer be the special object of all kinds of subsidies and supports when the millions of other small businessmen and the huge number of workers are not so favored? Is the United States prepared to pay for such costs for the indefinite future, or should there be some kind of phase-out or buy-out of the inefficient farmers?

How can the United States maintain a competitive agriculture in the face of worldwide gains in self-sufficiency and technology? What could be its positive sum strategy? Are not rapid adoption of new technologies and flexible farms of adequate size essential to maintain our competitiveness? Is not excess world capacity, sustained by subsidies, creating a negative sum game, with ultimate shrinkage of world trade?

Speaking even more bluntly, is not agriculture now in the same position as many private sector industries, which need to depend primarily on themselves for growth and competitiveness?

The challenge to those concerned with the future of agriculture, then, is to face the real issues squarely and to come out with a consensus that will impress even beleaguered political leaders. It is not inappropriate for an agricultural constituency to make its motto, "Let's call a spade a spade!"

A Positive Agenda for Agricultural Policy in Light of Emerging Technologies

Thomas N. Urban

Agriculture has had significant global success over the past 50 years as measured by the quantity, quality, variety, and cost of food. It would be hard to suggest that mankind is not better off now than in 1936.

During that 50-year period we have seen a reasonably efficient transfer of labor from farm to nonfarm activities, dramatic increases in the capital employed in agriculture, and significant productivity gains. There has been a successful reallocation of resources.

There are exceptions to this success story, of course, and some of them are dramatic. We have been unable to create effective food programs in parts of Africa, certain socialist economies, and specific regions within developed and developing countries. Such areas have not benefited from increased food quality and quantity, but most observers would agree that the lack of success has been the result of political decisions and usually not an absence of capital, labor, or technology.

Although our food system is significantly more effective now than 50 years ago, all is clearly not well; rural dislocation, overproduction, lack of purchasing power, uneven distribution, the misallocation of resources, and inequities between developed and developing nations indicate that policies and programs are not working as effectively as we would wish. Such problems are often exacerbated by inadequate policies, particularly policies that fail to take into account rapid changes in agricultural technology.

The effectiveness of any food policy is judged by at least five standards: (1) equity, the per capita income of farmers versus urban dwellers; (2) environment, the quality and sustainability of fertile land, water, and air; (3) social structure, the advantages or disadvantages of a sustainable dispersed rural population; (4) productivity, the efficiency of production; and (5) the quality, quantity, variety, and cost of the final product, food. A case can be made for the primacy of each of these standards and an overall evaluation of food policy cannot ignore the political, social, and economic forces created by each of them.

If the world's food system would stand still, we might be able to control it to achieve a desired outcome as measured against one or all of the above standards. It does not stand still, however. Technology drives dramatic changes in the food system and defies our attempts to freeze the system in a social, political, or economic form that pleases us at any point in time.

To be effective, food policies must take technological change into account while being continually reevaluated against the five standards set out above. That has been the rule since man became the inventor and will continue to be the rule as far as we can see into the future. To the degree that we ignore that rule, that we ignore the impact of technology on the food system, we will make poor policy. Effective policies embrace and anticipate technological change; poor policies reject or ignore technological change.

Four assumptions serve as the foundation for the discussion in this paper. First, the advancement of new technology creates economic, social, and political distortions. Second, the rapid adoption of new technology increases the standard of living around the world, and that, in turn, enables society to absorb the social turmoil and rectify the distortions that are created in the process. Third, extensively researched new technologies should be adopted as rapidly as possible. Fourth, policies that impede the adoption of new technologies should be revised.

If one assumes that clearing the way for new technologies will accelerate a naturally occurring development process and lead to an earlier-than-predicted increase in global living standards and a resulting reduction in social tensions—the desired outcome of effective policymaking—then a positive agenda for agricultural policy must, first of all, identify impediments to the adoption of new technologies and attempt to remove those impediments.

IMPEDIMENTS TO THE ADOPTION OF NEW TECHNOLOGY

At least 10 significant policy areas today impede the adoption of new technology. Other important issues could no doubt be included and the treatment of those listed could be more detailed, but the discussion that follows provides an overview of what is a very full agenda.

Technology Itself

The first impediment may well be technology itself. Technology appears to have an unrecognized and yet very important side effect. The assumption that technology can ultimately alter production and distribution patterns encourages nations faced with distortions in those patterns to hesitate to revise policies. That assumption reinforces traditional food policies, which are usually built on a concept of a static rural society. Political leaders may look to new technology to free them from making politically difficult decisions or to enable them to promise respite from current difficulties. (The Strategic Defense Initiative, or Star Wars, may be an example in a different policy sphere.)

As an example of how this impediment works, nations with significant agricultural production have hesitated to include agriculture in their analysis of opportunities to gain comparative advantage as they formulate trade and production policies. Promises inherent in new technology may encourage that hesitancy. Labor, rainfall, fertile soil, and temperature may become of less long-term importance in the minds of policymakers than gene splicing, nitrogen fixation, and growth hormones. If one waits long enough, one may be able to produce 200 bushels of corn in Saudi Arabia at a cost comparable to that in Iowa. At least, that is what the new technologies often seem to promise.

As another example, given the desire of cultures to protect politically strong rural constituencies, and the apparently natural drive for security through food self-sufficiency, the prevalence of unwarranted assumptions about the direction of technology makes it increasingly difficult to develop policies that promote trade and enable the world to produce the highest quality and quantity of food at the least cost at any point in time.

The dilemma, then, is that the promise of change embodied in technology may tempt nations to resist policy change. That does not bode well for an easy evolution in agricultural policymaking.

Farm Policy

The second impediment is farm policy in the developed world. The 1985 farm bill was heralded by many students of farm policy as a watershed in farm policy. It certainly was not that, however. Farm support policies based on controlling production and commodity prices in the developed world, whether they be in the European Economic Community, Japan, or North America, are anachronisms. Time is overtaking them and we must turn our attention to new realities. We must recognize that farming in the developed world is becoming a business subject to risks, which will be balanced by potential benefits. Price supports and attendant production controls that do not differentiate among producers with different cost structures and that ignore technological change will and should disappear. They will be replaced by social policy, trade policy, foreign policy, and monetary policy.

Farm programs as carried out today in the developed world do not deliver what they promise—and they cost too much. They have been overtaken by the reality of a world economy, the dependence of farming on purchased inputs, the significantly reduced value of farm-gate prices as a percentage of total food costs, a dramatic reduction in farm population, the exceedingly important part that off-farm income now plays in our rural economies, and the rapid development of risk sharing or vertical integration in the production of agricultural products. These new realities reflect a totally different view of our agricultural world than that which drives today's agricultural policies—the supposition that there is a static rural population, static costs, static yields, and equal profit margins by crop for all producers.

Unless we achieve a significant shift in agricultural policymaking in the developed world, we will find our ability to adopt new technologies severely retarded. The current system removes dollars from research, both public and private, and misallocates resources. The political nature and size of farm programs do not allow private and public policymakers to establish intelligent, long-term investment programs. Costly support programs in Japan, the European Economic Community, and the United States reduce the funds available for public research efforts, assuming those economies have finite resources. Private research dollars hesitate to follow public policies that subsidize agriculture, because those subsidies can be removed. Current policies, then, slow the adoption of new technologies that could enhance our ability to increase standards of living and smooth the way for social changes wrought by past, present, and future technologies.

This perspective does not mean that we should ignore the farmers' problems. There is a great need for social policy in the rural economies of the developed nations. Such policy is a legitimate requirement of a democratic society undergoing change. Nevertheless, the social problems in the rural United States, for example, cannot be solved by attempts to manage commodity prices. Those problems can only be tempered by specifically directed, well-funded programs that differentiate between those farmers looking for a labor income equivalent to that of urban dwellers and those farmers dedicated to the development of businesses that may or may not generate a profit over and above labor income. The link between production and the exercise of the U.S. commitment to positive social transition in rural areas must be broken if the United States is to move the farm policy debate onto fertile ground.

Surpluses

The third impediment to the adoption of new technologies is the current surplus. In the United States, nonagriculturalists, congressmen, and even some economists ask, Why should we invest in new technologies when we have a surfeit of food? The answer to that is evident, perhaps, if you are trained as an economist. But it does not seem as evident, or so simple, to the person on the street. It is going to take a great deal of discussion to sell the idea that we should increase our investment in, and the speed with which we adopt, new technologies when we appear to have too much food. The reasons for investments in such technologies are the U.S. competitive advantage; reduced comparative food costs, which increase the world's standard of living by enabling people to purchase a variety of high-quality foods; and an improved allocation of resources, which further raises the standard of living.

Unfortunately, the climate for debate in the United States is such that we may spend as much time arguing about how to slow the exchange of new technology as how to accelerate it. That is unfortunate, but a political reality and one that must be successfully addressed by land-grant institutions, the U.S. Department of Agriculture, and the private sector. A rallying point is clearly needed, but one has not, as yet, been identified.

Information Transfer

Information transfer has been, and will continue to be, extraordinarily important to agriculture. In the United States, we recognized that many years ago when we set up the extension and federal information services. The opportunities to exchange information among farmers and other members of the food chain around the world are extraordinary. Information exchange, alone, is helping to change how and where food is produced.

Information is integral to the rapid development and adoption of technology. The use of computers and real-time communication devices will dramatically affect the agriculture of the future. Our agricultural institutions need to rethink their effectiveness in an agricultural and informational environment that is vastly different from that of the era in which such institutions were formed.

Overseas Development

Much is being said in the United States today about overseas development efforts, that is, the role of public and private institutions, supported in part by the U.S. government, in helping fund technology transfer. Despite clear evidence that technology transfer speeds growth in the world's per capita income, which in turn improves diets and leads to expanded grain trade, we are beginning to hear the front end of what is likely to be a long and bitter debate about "helping our competitors." Although it is easy enough to say we must be careful not to slow the transfer of technology for fear of slowing the growth in per capita income, very soon we are going to have to deal with the political reality of significant U.S. opposition to such transfers. Such attitudes and opinions reflect the traditional "short-term, long-term thinking" issue that has plagued human beings throughout history. They reflect the significant contradiction between political rhetoric and the realities of technological change.

The problem will be overcome, but slowly, and only with a great deal of thinking, public research, and speaking out by informed and committed citizens. It will also require a significant educational effort in the media.

Conservation

The sixth impediment involves the issue of soil, water, and air conservation. The issue must be addressed more effectively if technologies are to be rapidly adopted.

Although the historical confrontation between the more extreme antitechnology "romantics" and those pursuing high-input agronomy has lessened as each side has come to respect the other's point of view, we still have some way to go. The needs of the nonirrigated Third World as well as the countries with rapidly eroding soils in parts of the developed world must be met. A great deal of research and institutional development remains to be done in both the public and private sectors before we can move away from, for example, a dependence on increasing quantities of herbicides, pesticides, and chemical fertilizers toward a better understanding of soil structure, crop rotation, and the interactions of plants and microbes. That will require a more intelligent blending of high technology and traditional practices than we have seen heretofore. That blending could release new technologies of which we are only dimly aware today.

Profit Versus Yield

The seventh impediment involves agriculture's traditional approach to increasing productivity. Removing this impediment to change requires discussion of profit versus yield as part of a positive agenda. This is not a new thought; such a shift is certainly taking place today, but it needs to be accelerated. Because we assume that as yields increase unit costs may decrease, resulting in higher profits, we have put much of our emphasis on maximizing harvestable yield. We should now ask, Are there as many opportunities to increase profit by reducing costs (perhaps slowing the rate of yield increases or even accepting somewhat lower yields) as there are in increasing yields? We have not asked that question as intelligently as we might. The answer may require, for instance, a much better understanding of how plants can be made to operate more efficiently. Perhaps the new biologies will help us gain that understanding. Asking questions correctly may open the door to a number of new technologies waiting to be perfected.

Our land-grant and other institutions have a critical role to play in that process.

Political Controls

It would be impossible to omit political control over the quality and safety of the food system in a discussion of a positive agenda. Clearly, the citizens of the United States and other countries are going through an often mind-numbing debate about risk and reward in all aspects of their lives. Whether it is atomic energy, liability laws, pesticides, car safety, or even the arms race, we are in the midst of a debate about the balance of risk and reward in society. On the one hand, there are those who are willing to take enormous risks with large numbers of people in order to accomplish a perceived long-term social good. At the opposite end of the spectrum are those who believe that any technology that puts a single human being at any risk at any time should be severely controlled.

Each new technology creates new and often unknown hazards, yet such technology advances our living standard or it will ultimately be rejected. Technology, by its nature, resolves short-term problems and creates long-term problems, which are in turn resolved. That never-ending cycle has been positive for mankind and will likely continue to be positive. A significant body of opinion questions and even disagrees with that position, however. For this group the value of much of our current technology is questionable.

It is also important to note that one cannot resist technological advances in one area of the economy, say agriculture, and allow technological change to occur in other areas. The system becomes unbalanced and the late adapter loses. Industrial substitutes for naturally produced products are an example. Such substitution would be the likely outcome of the proposed mandatory acreage control legislation that may come before the Congress.

The debate on the relevancy of new technology clearly needs to be resolved if we are going to speed the adoption of new technologies.

Public-Private Partnerships

The developing world and the Reagan administration have not been the best of friends of late, but in one area they are working from the same agenda, the one entitled "public-private cooperation." There is a growing debate in the world today about the relationship between the public and private sectors in agricultural development, as well as in other areas of the economy. The issues being debated range from denationalization in a number of developing countries to who should share the fruits of joint research endeavors between a university and a private company.

A classic example of the problem in the United States is seeds. Historically varietal, as opposed to hybrid, seeds have been developed by public institutions. Private companies have recently become active, however, and as a result, public funding for such work is being reduced. At the same time, the U.S. farmer appears unwilling to pay the long-term costs of varietal research and development in the price of today's seed. The result may be a dramatic slowing of productivity growth in varietal seeds, which will make food costs higher than they need be and will make the United States less competitive in world trade, which in turn will result in reduced agricultural margins.

How we resolve the issue of public-private cooperative development will have much to do with the speed with which we adopt new technologies.

Financing Production and Distribution

Financing the production and distribution of agricultural products is a significant problem in the adoption of new technologies. In retrospect the funding sources for U.S. agricultural production over the past 15 years made poor decisions. They loaned money on the current balance sheet and ignored the long-term income and cash flow statement. It is true that the opportunities to make bad loans over the past 15 years have been many, given the rapid rise in agricultural land values, but even today, in times of low asset values and cash-flow difficulties, agricultural lenders are often not trained or prepared to understand and take agricultural lending risks. Further, borrowers usually do not have sufficient control over their input costs and selling prices to make intelligent borrowing decisions. The system cries out for funding mechanisms that blend borrower and lender risk management in new and creative ways. Such a system would reduce the costs and risks of production by rapidly increasing the adoption of new biological, genetic, mechanical, and chemical advances.

TOWARD A POSITIVE AGENDA

Encompassing all of the previously mentioned impediments to the adoption of new technologies is the effectiveness of our world trading system. Real growth in world trade is the key to long-term growth in per capita income. Talks among General Agreement on Tariffs and Trade (GATT) members are attempting to combine discussions of agricultural products and manufacturers. Agricultural production, it is said, should operate under the GATT rules and be tradeable against manufacturers and services. The underlying assumption is that agricultural production and trade are subject to discussion based on comparative advantage. That is, if we are to obtain the fruits of our technological investments in agriculture around the world, we must be able to accommodate changing cost structures.

Whether such a concordat is politically possible today is open to question. Success will require a significant change of attitude on the part of countries that are striving for food self-sufficiency to enhance their security, that see agricultural development as the engine for growth, or that have a relatively conservative and active rural population.

A first step needs to be taken in the decision-making process before GATT negotiations on agricultural products will be successful. There appears to be a role for an interim institution that would concern itself not only with agricultural trade but with national and international solutions in the 10 policy areas discussed previously.

There is a great similarity between the food policy problems facing North America, Japan, and the European Economic Community and their common problems relative to the developing world. A structure is lacking, however, for the discussion of long-term global food policies and emerging technologies. There are food forums, all of which touch on the issue peripherally, and meetings and symposiums are held from time to time. But, despite the importance of food in the world, there does not appear to be a structure or institution for convening international discussions of food policy and technology in an atmosphere somewhat free of the political constraints of day-to-day policymaking.

The Food and Agriculture Organization (FAO) is potentially such a forum, but it is encumbered by traditional political considerations and an element of bureaucracy. A discussion of overall long-term policy coordination under FAO auspices would probably founder. Commodity discussions and agreements have existed for many years but are rather narrow in focus and concentrate on production control. They do not appear to deal with the underlying problems of food policy.

One opportunity, then, as we set a positive agenda for agricultural policy development, would be to establish an institution in which the key players in the world could talk about their ability, desire, and need to produce and trade food. An understanding of new technologies; adoption rates; political, economic, and social impediments to transfer; and the politics of food production, food security, and trade might lead the key players to devise more effective food policies. Revised policies are needed if the world is to break out of its current economic slump and the resulting protectionist political pressures. The shift from import substitution and industrial development to export-driven, agriculturally supported growth in the developing world may be having a significant effect on world trade. There is a growing awareness in the developing world that rural income growth, driven by effective agricultural policies, will be the engine for long-term national growth. An institution devoted to learning and acting on the long-term implications for world trade of that recognition would be timely. The National Center for Food and Agricultural Policy at Resources for the Future has given thought to such an institution and has received expressions of interest from over 30 leaders in nine countries. That effort is to be applauded and encouraged.

At the beginning of this paper four assumptions were identified: (1) the advance of new technologies creates economic, social, and political distortions but, on balance, new technologies have dramatically improved the lot of mankind; (2) the rapid adoption of new technology increases our standard of living, which enables society to absorb the social turmoil created by those technologies; (3) new technology should, therefore, be adopted as rapidly as politically possible; and (4) policies that impede the adoption of new technology should be revised.

For some, those four assumptions may appear to have ignored a legitimate concern for the social consequences of technological change in agriculture. That was done by design so that the issue could be treated separately. A considerable literature has been generated since the 1920s about the social responsibilities of agricultural research. Many are familiar with that useful discussion, perhaps encapsulated, in *Hard Tomatoes, Hard Times* by Jim Hightower (1973).

Agricultural research has been production driven. In times of shortages that research has been applauded. In times of surplus such research has often been derided. When the social fabric of the rural United States is stressed, researchers are often castigated for not having foreseen the political, economic, social, and health consequences of new technology. As researchers work to improve the productivity of farming, they are accused (by those blessed with the wisdom of hindsight) of having ignored issues of health, income distribution, worker displacement, soil erosion, water quality, the needs of developing countries, and a host of other significant issues, perhaps reflected in the term "sustainable agriculture."

To attempt to control the scope and direction of agricultural research based on unpredictable social consequences, however, would severely retard long-term improvements in the quality of our lives. Although the term "predictive ecology" (used to identify a method of predicting the future effects of new technologies) has a nice ring to it, it also contains an element of hubris that promises more than can actually be achieved.

Significant social problems do, however, result from technological change. They have been well documented. The obvious consequences of new techniques and products should, of course, be understood. Research designs must attempt to measure environmental consequences as well as changes in productivity. The effects of technology should be consistently and constantly monitored and corrected. Both the study of consequences and the search for solutions deserve significant funding support. Such support should be applauded by agricultural researchers and should be a significant element in our educational institutions.

What should not occur, however, is an attempt to direct, redirect, or stifle the push for continued increases in productivity. That search for new and innovative technologies will enable us to continue to make increasingly efficient use of our resources and improve our standard of living. We should use an iterative approach in resolving the negative social and environmental effects of agricultural technology, not our current "apocalyptic" approach.

CONCLUSION

Impediments to the adoption of new technologies slow the improvement in global living standards, which exacerbates the social consequences of new technologies. A positive agenda would attempt to remove those impediments. As those impediments are removed, we will deal more effectively with the impact of new technology on future policies.

Setting a positive agenda suggests strong support for an institution that would focus on overcoming policy impediments to the adoption of new technologies in the belief that it is time to deal with food issues on a global basis. Such an institution would be an important factor in untangling the effects of policymaking and technological change on world trade.

Technology will advance whether we like it or not. Such is the nature of *Homo sapiens*. But, if we believe that a more rapid adoption of new technologies advances our standard of living and that a rapidly advancing standard of living, combined with flexible social institutions, smooths the way for social change flowing from new technologies, we must work diligently on each of the impediments to technological advance.

This will not be an easy task, and yet, if we approach each impediment in a deliberate manner, understanding that our goal is to free the human mind to use creatively the resources about us, then the effort will be worthwhile.

REFERENCE

Hightower, J. 1973. Hard Tomatoes, Hard Times. Cambridge, Mass.: Schenkman.

Plant Production

Ralph W. F. Hardy

Technological change has become the standard for agriculture in developed countries and, to some extent, developing countries in the twentieth century. Mechanization with some help from agrichemicals has eliminated the need for most of the labor input for crop agriculture. Fertilizers, synthetic agrichemicals, improved varieties (including hybrids), irrigation, and cultural practices have increased production per acre (yield).

Developed-country crop agriculture—because of the excess production encouraged in part by inaccurate 1960–1980 projections of growing world need and faulty, variable national policies—is recovering from an unstable, inadequately competitive state. To improve competitiveness in crop production agriculture, there must be additional technological change to improve productivity in the 1990s and beyond. Specifically, the new technologies must meet one or more of the following key needs of crop production agriculture:

- Decreased cost of production,
- Increased value-in-use of the product,
- Products for nonfood, nontraditional markets, or
- Environmental neutrality.

The focus of this paper is new, emerging technologies that are of significance for crop production. The paper by Giaquinta (this volume) addresses those technologies that are of significance for crop protection. The new technologies for crop production, which are based mainly on biotechnology, have the potential to meet the four key needs listed above; those for crop protection will meet one and possibly two needs—decreasing the cost of

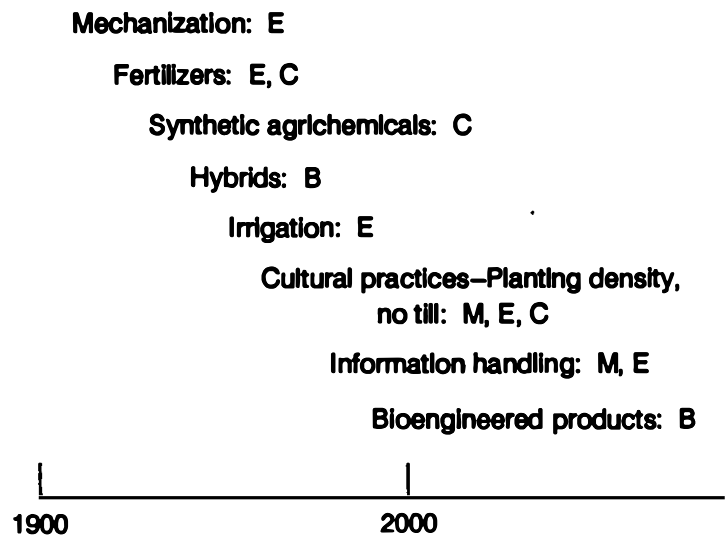

FIGURE 1 Technological inputs to crop production. Key innovations: E—engineering; C—chemotechnology; B—biotechnology; M—management.

production through decreased cost of crop protection and alternatives to synthetic pesticides that are more environmentally friendly. The impact of biotech agents on crop production is expected to be much greater than on crop protection, but the timing may be earlier for crop protection.

The following topics are considered in this paper: technological change in crop production, change throughout the crop production community, the needs of crop production agriculture, technical advances in agriculture, and new products and processes expected from biotechnology and their impact on crop production.

TECHNOLOGICAL CHANGE

Key innovations during the twentieth century have driven improvements in crop production. Those innovations have reflected advances in engineering and chemotechnology and, to a lesser extent, biotechnology and management practices. The resultant technological inputs are well known: mechanization, fertilizers, synthetic agrichemicals, hybrids, irrigation, and cultural practices (Figure 1). The introduction of technology has been continuous, and industry, academe, and government and other sectors have all contributed. The Boyce Thompson Institute, for example, a nonprofit independent plant research institute, discovered the first major synthetic selective herbicide—2,4-dichlorophenoxyacetic acid—as a product of basic research in the 1930s and 1940s on hormones that regulate plant growth and development. Synthetic selective herbicides now constitute about an $8 billion annual input to world crop production.

Adoption of the technological changes for crop production has provided necessary improvements in yield and labor reduction. Both have been vital to enabling the world to feed 5 billion people and to freeing labor for other activities. In the 1980s, they have contributed, along with other factors, to overproduction in crops such as wheat, corn, and soybeans—a normal growth stage for any industry experiencing significant technological improvements (Schneider, 1986a).

In a free market, however, only the most competitive survive producing those products for which there is overcapacity, and the United States is not competitive in many agricultural commodities (Schneider, 1986b). The import of South American grains to the United States in 1985 at prices below those for U.S.-produced grain, for example, documents the overall noncompetitive grain productivity of the United States.

Technologies are now needed to improve production efficiency to aid the competitiveness of the survivors. Such technologies for improved productivity are biotechnology for bioengineered products and processes and information handling for improved management (Office of Technology Assessment, 1986). Other technologies, also based on biotechnology and possibly information handling, are needed to provide alternative crop production opportunities for those who are unable to compete in producing major commodities, such as corn, wheat, and soybeans.

A continuous sequence of appropriate and changing technologies that address real needs in a timely manner is essential to maintain a strong, competitive position in crop agriculture (Ruttan, 1986). The next section examines the unprecedented incidence of changes throughout the crop production community and provides a base for identifying the needs of crop production agriculture.

CHANGE THROUGHOUT THE CROP PRODUCTION COMMUNITY

The crop production community is composed of many members, including agribusiness, farming, food processing, consumers, society, and public research, development, and extension organizations. All are in a state of unprecedented change, which is expected to continue for some time (Hardy, 1985a).

TABLE 1 Companies Engaged in Agricultural Biotechnology

Development-Stage Companies	Established Companies
Agracetus	American Cyanamid
Allelix	Ciba-Geigy
BioTechnica	Du Pont
Calgene	Grace
Crop Genetics International	Hoechst
DNA Plant Technology	ICI
Ecogen	Eli Lilly
Mycogen	Lubrizol
Native Plants	Monsanto
Phytogene	Pfizer-DeKalb
Sungene	Pioneer Hi-Bred International
	Sandoz
	Upjohn

Agribusiness Input

Most industries that produce agricultural inputs are maturing and consolidating. Examples are the farm equipment industry, in which such major companies as International Harvester and Allis Chalmers have been acquired, and the agrichemical industry, in which acquisitions of this business from Shell, Union Carbide, and several others have reduced the total number of agrichemical companies in the world by about 25 percent. Undoubtedly much additional consolidation will occur before the end of this century. This consolidation phase suggests the approaching commodity status of these inputs. Fertilizers, of course, have been commodities for several decades. An acquisition stage is also occurring in the seed industry—chemical and energy companies, especially European-based ones (e.g., CIBA-GEIGY, ICI, Sandoz, and Shell), are acquiring major U.S. seed companies.

Several entrepreneurial development-stage companies as well as established chemical, energy, and seed companies are developing biotechnology capabilities to provide inputs for crop production (Table 1). Although the size of private investment in agricultural biotechnology (Table 2) is about 20 percent of that in health care (Murray, 1986), it is substantial and growing, and agricultural products are expected to be the next major biotechnical products after health care (Hardy, 1985b). Since biotechnology has the potential to combine the equivalent in many cases of the agrichemical,

TABLE 2 Private Sector Biotechnology Investments

Area	Amount (in billions)
Therapeutics	$2.5
Diagnostics	0.5
Crop agriculture	0.6
Specialty chemicals	0.2
Animal health	0.1

SOURCE: Murray (1986).

fertilizer, and seed input into a single input—seed, it is probable that a biotechnology-driven consolidation of the nonequipment agricultural input industries into a single type will occur about the turn of the century.

Farming

The mid-1980s deterioration in the economic health of crop production farming in developed countries has led some to say that world agriculture is in a "mess." Clearly, production of commodity grains in the world's traditional breadbaskets exceeds the need, ability, and willingness of the rest of the world to purchase. In addition, a major trend in developing countries from insufficiency to self-sufficiency to export of grain has been in progress for several years. Outstanding successes have been achieved in India and China (Akbar, 1986; Burns, 1985) and should be anticipated in other countries including possibly even the USSR with its changing policies. The importance of developed countries as world breadbaskets will decline; increased productivity will be essential for competitiveness in such a market.

Food Processing

Food processors have usually created value in their products through either engineering- or chemotechnology-based processing of, for the most part, commodity farm products. Biotechnology provides the opportunity to bioengineer value into the crop and decrease the need to add value through food processing. The outcome of specialized value-in-use crops would be back-integration of the food processor to the food producer and possibly, vertical integration into plant breeding to contact the desired "specialty" and probably the proprietary commodity.

The Consumer

The consumer is the ultimate customer of agriculture and major change is occurring in the consumer's food needs (National Research Council, 1986a, 1988). The need is for food that is perceived to be healthful. An example of that concern is the decline in consumption of red meat and the increase in consumption of poultry and seafood. This increased emphasis on the healthfulness of food will grow, and the farmer and the food processor will have to provide products that meet this and other consumer needs. Biotechnology, again, is key since it has the potential to change the composition of food, thereby increasing its perceived and probably actual healthfulness.

Society

Society in developed countries has several concerns. For one, it is becoming less willing to subsidize farming. Farming is being viewed as no different from other business sectors. The U.S. grain farmers who are not competitive in the world market, for example, are no different from workers in other industries that have become noncompetitive (e.g., the steel and automobile industries). Future subsidization of agriculture on a regular basis will be minimized. However, it is of note that agriculture is one of the few industries that has maintained a positive balance of payments throughout the 1980s.

In addition, society is becoming increasingly concerned about the environment, especially with global environment. Groundwater pollution by agrichemicals is of concern (National Research Council, 1986b). Future technologies that provide environmentally neutral products and processes will be favored. The longer term impact of agricultural practices must be considered and effects such as sustainable agriculture are being discussed, although this specific term does not yet have a consistent definition among the various discussants. Biotechnology, which has centuries of favorable experience behind it, appears to be a technology that will be favorable to the environment and to the longer term, but the record for chemotechnology is much less favorable. Society is also concerned about minimizing world hunger and will continue to support efforts to this end.

Technology

Technology for agriculture is also changing. Chemotechnology and engineering are maturing while biotechnology and information handling are growing. Several reports project the growing importance of biotechnology and information and information handling (Gibbs and Carlson, 1985; Hardy, 1985b; National Research Council, 1987; Office of Technology Assessment, 1986). A Du Pont study that polled informed farm, agribusiness, and public sector leaders concluded that biotechnology would be the dominant source of innovation in crop production by the early twenty-first century.

Public Institutions

The U.S. public agricultural research, development, and extension system has served agriculture in an outstanding fashion. Many question its appropriateness for the future, however. It will probably have to change as the previously noted members of the agricultural system change (Hardy, 1985a, 1986). The new skills of biotechnology at the molecular and cellular level will have to be integrated into the more traditional organism and systems approach to agricultural research. The disciplinary structure of agricultural research and development (R&D) will need to be reorganized around problems and opportunities, for example, plant protection, plant production, plant value-in-use, plants for nonfood use, and environmental quality. Socioeconomic considerations will have to be integrated into these problem or opportunity areas to assist in achieving technical focus and generating realistic policy. We are restructuring the Boyce Thompson Institute for Plant Research at Cornell in recognition of the changes necessary for effective research and development in the age of biotechnology.

NEEDS OF CROP PRODUCTION AGRICULTURE

As noted previously, crop production agriculture has four major needs. They are improved production efficiency, higher value-in-use products, products for nonfood markets, and environmental neutrality of products and processes.

For commodity products such as wheat, corn, and grain, production efficiency is of utmost importance. The era of yield as the dominant goal of commodity research and development has now been superseded by the era of production efficiency. The farmer must have increased product per input if he is to be competitive. One major approach is to lower the cost of inputs. Replacing costly chemotechnology inputs, such as fertilizer and agrichemicals, with genetic inputs, such as microbes and seed or only seed, could lead to major cost reductions. Agricultural research and development must emphasize these targets rather than yield.

An even more attractive need or opportunity is developing higher value-in-use crops. This area has, in general, been underinvestigated in recent decades while commodity crops have received the major emphasis. Such an objective may be pursued by modifying existing crops. The modification of rapeseed to canola will be described in the section on value-in-use as an example of a modified crop; kenaf for paper is an example of a new crop. (Other new or modified crops include crambe, guar, guayole, Jerusalem artichoke, jojoba, lesquerella, milkweed, speedwell, and sweet sorghum.) Biotechnology is uniquely relevant to the need for new or modified crops, and research in this critical area needs to be reemphasized.

The size of the food market is, to a first approximation, constant. An increase in the use of oil from canola for margarine, for example, is matched by a decrease in the need for oil from soybeans for the same food use. Crop production agriculture also needs products for new, nonfood markets as the roles of the United States, Canada, and Australia as the world's breadbaskets decrease. Such opportunities may take the form of polymers, chemical intermediates (Ng et al., 1983), paper, fuel, and other products. For many of these uses, improved crop growth and development as well as efficient processing of the crop to the product must be found. Again, biotechnology is uniquely relevant to this need. Eroding energy prices have reduced current research and development in this area, but erosion is temporary and the long-term trend must be substantially upward given the finiteness of fossil energy reserves.

Crop production agriculture must also take place in a way that is as environmentally neutral as possible. The favorable environmental track record of biotechnology in agriculture, based on the crop and animal breeding practiced for centuries, provides support for products of this technology (Hardy and Glass, 1985).

TECHNICAL ADVANCE

There is a strong momentum of biotechnical advance relevant to agriculture in the 1980s (Moffat, 1986) that exceeds the general recognition by those outside the agricultural biotechnology field. One concludes that major new technical inputs to meet current and future needs of agriculture will be achieved. A concern at this time is the effect of regulation on the rate at which laboratory successes are converted to products useful on the farm. While regulation in the mid-1980s was at least constraining and, more realistically, may even have been blocking the development of agricultural biotechnology, considerable progress had been made by the late 1980s with upwards of 50 field introductions in the United States, a number far in excess of that for any other country.

A few examples from 1986 will document the technical momentum. The first genome sequence—the tobacco chloroplast—was completed in 1986 with 155,844 base pairs. This landmark accomplishment was achieved by some 20 Japanese scientists (Shinozaki et al., 1986). The luciferase gene was introduced into microbes and plants, which enabled them to emit light (Koncz et al., 1987; *Scientific American*, 1987) and thereby provide a useful marker with which to follow genetic manipulations (Schneider, 1986c). Many popular publications reported this accomplishment by scientists in New York, Germany, and California. Single cells of rice were regenerated to plants by scientists in the United Kingdom and Japan (Marx, 1987). Techniques for introducing foreign genes into cereal plants were demonstrated in the United States and Europe to complement those already shown for noncereals (Schmeck, 1987). Genetic elements for organ-specific, light-induced expression of plant genes were identified in the United States. Understanding of the control of biological nitrogen fixation was advanced with a plant alkaloid shown to regulate nodulation genes. In food processing, a genetically engineered yeast made possible the brewing of "light beer" in a natural, single step (Yocum, 1986). This ability to extend shelf life of food plants was demonstrated in the tomato with a special molecular technique called "antisense RNA."

Other relevant advances also occurred. For the first time, a U.S. patent, number 4,581,847, was awarded for a sexually reproduced plant—in this case, a novel corn seed (Jones, 1986). This strengthens the claim to proprietariness that will be necessary to obtain appropriate return for a major improvement and thereby encourages increased private research and development. The first field trials of plants genetically engineered by molecular techniques were approved and completed in 1986 (*Chemical Week*, 1986) with upwards of 50 approved tests of plants and microbes by 1989. None of the first field test plants, however, could be taken beyond the vegetative stage, but this has now been overcome. In fact, a workshop report (Boyce Thompson Institute, 1988) stated that there is negligible risk to the environment of field introductions of genetically engineered major U.S. crops in the United States for either testing or commercial use. Regulation of biotechnology products to enable the necessary field R&D increasingly is based on scientific assessment of realistic risks and benefits and not on unrealistic perceptions (Hardy and Glass, 1985).

BIOTECHNOLOGY PRODUCTS AND PROCESSES FOR CROP PRODUCTION

Four types of products or processes for crop production are expected from biotechnology. These are diagnostics, microbes, seeds, and chemicals. Diagnostics have already been introduced; the use of microbes is expected by the early 1990s provided field regulations are realistic. Seeds will probably not be marketed until the mid-1990s, and chemicals probably thereafter. These products or processes will improve production efficiency or increase value-in-use for food and nonfood markets (Table 3). In the longer term, value-in-use benefits will probably greatly exceed those of production efficiency.

TABLE 3 Biotechnology Crop Production Products and Processes for Food and Nonfood Markets

Product/Process	Production Efficiency	Value-in-Use
Diagnostics		Proprietary material Quality Composition
Microbes	Crop preservation Nutrient input Growth and development	
Seeds	Nutrient input Growth and development	Food composition Food function Nonfood uses—such as chemicals, paper, materials, energy
Chemicals	Nutrient input Agriregulator chemicals	

SOURCE: Compiled by R. W. F. Hardy (1987).

Diagnostics for crop production will support value-in-use changes by providing the means for identifying proprietary materials and measuring quality and composition, thereby also providing a basis for pricing agricultural products based on these characteristics. The use of diagnostics for identifying proprietary microbes and seeds has been demonstrated.

Microbes will be used to improve production efficiency, and improved products from traditional biotechnology will be used to preserve silage and to provide fixed nitrogen to legumes (discussed in the following section). Microbes are also expected to benefit plant growth and development through provision of regulating agents. The molecular genetic engineering of microbes is more advanced than that of higher plants; as a result advances may come more rapidly in the microbial area.

By far the largest impact of biotechnology on crop production is expected from seed products. Production efficiency and value-in-use of agricultural products for food and nonfood markets will be significantly affected. Nutrient input (example follows) and growth and development will benefit through decreased costs of production per unit of product. Food composition and food production will be altered to convert commodity agricultural products to higher value-in-use specialties as well as to convert nonfood plants to food plants. In addition, the nonfood uses of crops should grow substantially. For the first time one can modify any crop in a direct way to meet a nonfood use, such as the production of specialty chemicals or chemical intermediates or materials. Even energy is a realistic market for plants with much improved production efficiency, including increased solar energy conversion to an appropriate composition. Herein lies one of the major opportunities in crop production research for a world that will decreasingly rely on the historic breadbaskets for food as each country moves toward self-sufficiency.

Biotechnology may be used to produce chemicals, such as fixed nitrogen for nutrient input, that will be useful in crop production. Such an approach, however, will probably be less economic than the direct use of a microbe or seed to meet this need. A more attractive possibility is the use of chemical agriregulators. Understanding from biotechnology may enable design of chemical compounds to regulate gene expression so as to control, for desired benefit, key processes in the growth and development of plants. Such agriregulators may be the future of the agrichemical industry. Value-in-use benefits, such as compositional changes, could result from chemical agriregulators. Chemical agriregulators generated by biotechnology rather than by chemotechnological innovation as in the past are more distant than biotechnology-based diagnostics, microbes, and seeds.

Impact on Production Efficiency

Nutrient input illustrates the potential impact of biotechnology on reducing cost per unit of product (Hardy, 1985c). Nitrogen is a key nutrient for plant growth. For the legume crops, for example, soybeans and alfalfa, a rhizobial microbe-legume plant symbiosis provides annually about 40 million tons of nitrogen nutrient on a global basis. This capability to convert the abundant yet unavailable nitrogen of the atmosphere to nutrient nitrogen is made possible by a complex of genes, called *nif*, that are found in the microbial partner. Restructuring of these genes using biotechnological knowledge and techniques increases the amount of nutrient nitrogen and thereby legume yield in greenhouse tests. Field tests of such improved microbes were first made in 1988 and are continuing in 1989 for legume crops using this type of microbial product. Commercial use may come in the early 1990s.

An even more useful biotechnology product would be the introduction of functional *nif* genes into crop plants to eliminate the need for purchased commercial fertilizer. All crops—cereals, legumes, grasses, even trees—might become nitrogen self-sufficient and extend the impact on nutrient input beyond that of microbes, which are limited to use with legumes. This opportunity is one of the most attractive objectives in all of biotechnology, because it would replace an existing world crop production cost of about \$20 billion for nitrogen fertilizer. Biotechnological advances toward this objective have been outstanding; three of five major technological hurdles have been overcome in recent years. Based on this rate of progress, it is reasonable to suggest that a self-nitrogen-fertilizing plant will be invented by the 1990s and possibly go into commercial use around the turn of the century. This time scale is substantially advanced over those considered realistic in the early 1980s because of the rate of technical advance in this field.

Nitrogen self-sufficient crops are an example of the development of an initial microbial product followed by a seed product, each of which has an impact on production efficiency. Other examples could have been provided, although the potential impact of these products is very large. Even larger possible effects would derive from improvements in photosynthesis—the conversion of solar energy to plant material—but the technical basis for such advances is currently less developed. This latter area will be critical to diverting some crops into nonfood markets, such as energy.

Impact on Value-in-Use

Improvement in the composition or function of food crops can improve value-in-use. The conversion of rapeseed to canola by Canadian scientists provides an example (Downey, 1986). Rapeseed contains two components that prevent use of its oil for food. Using nonmolecular biotechnology techniques, scientists developed rapeseed with reduced toxic components so that the oil could be used for food and the meal for feed purposes. The modified plant was named canola. Canadian margarine is made mainly from canola oil and canola has been designated GRAS (generally recognized as safe) in the United States. The potential farm value of the higher value-in-use, modified rapeseed is about $2 billion.

Many other opportunities exist to increase value-in-use. A joint venture between a development-stage biotechnology company and an established one is marketing a product called VegiSnax, which is based on carrots and celery selected for appropriate characteristics for the higher value-in-use snack market. Other opportunities for enhancing value-in-use include food products with improved appearance, flavor, taste, healthfulness, decreased processing, and natural versus synthetic additives. The potential in this area can best be described as very large.

The concept of value-in-use is also key to the nonfood market. Biotechnology will be used to add value-in-use characteristics to modified or new crops. Work by U.S. Department of Agriculture scientists on kenaf as a source of paper is such an example. The value-in-use of kenaf over trees as a paper source may include a simpler pulping process and the need for less ink for printing. Organizations such as the National Research Council's Board on Agriculture should bring together panels to identify the needs and opportunities for biotechnology-based research and development to produce crops with high value-in-use for nonfood markets. Earlier panels considered these opportunities but in the absence of the new biotechnology capabilities.

CONCLUSION

Technical advances in biotechnology relevant to crop production have been occurring at a rate exceeding that recognized by most except for the involved technologists. Time lines for some major projected impacts are being shortened. Government permission for field research and development has progressed so that it is no longer the major factor limiting progress. All of the major areas of need in crop production agriculture should benefit substantially from biotechnology-based products and processes. Those areas of need are increased food and nonfood productivity—decreased cost of crop production, increased value-in-use crops, and development of crops for nonfood markets—with an objective of environmental neutrality. As countries with food inadequacy continue to move to self-sufficiency, the role of the traditional world breadbasket countries in crop production for food will decline. A major challenge in those breadbasket countries will be the generation of crops with high value-in-use for food but even more so for nonfood markets. Biotechnology can alter the crop and its processing for those markets.

REFERENCES

Akbar, M. J. 1986. We don't need pity: India can look after itself. New York Times, August 3, IV, 3:1.

Boyce Thompson Institute. 1988. Regulatory Considerations: Genetically Engineered Plants. Summary of a workshop held at Boyce Thompson Institute for Plant Research at Cornell University, Oct. 19–21, 1987. Center for Science Information, San Francisco.

Burns, F. J. 1985. A record grain crop is changing China. New York Times, February 17, III, 2:1.

Chemical Week. October 22, 1986. A successful test of gene-altered plants. 66.

Downey, R. K. 1986. New opportunities in oil seed crops. Pp. 71–79 in BioExpo 86. Proceedings of the American Commercial and Industrial Conference and Exposition in Biotechnology, O.R. Zaborsky, ed. Stoneham, Mass.: Butterworth.

Gibbs, M., and C. Carlson, eds. 1985. Crop Productivity—Research Imperatives Revisited. International Conference held at Boyne Highlands Inn, October 13–18, 1985, and Airlie House, December 11–13, 1985.

Hardy, R. W. F. 1985a. Roles of academe, government, and industry for agriculture in a changing world. Pp. 339–345 in Biotechnology in Plant Science, M. Zaitlin and P. Day, eds. New York: Academic Press.

Hardy, R. W. F. 1985b. Biotechnology: Status, forecast, and issues. Pp. 191–226 in Technological Frontiers and Foreign Relations. Washington, D.C.: National Academy Press.

Hardy, R. W. F. 1985c. Applications of nitrogen fixation in agriculture and forestry. Pp. 683–687 in Nitrogen Fixation Research Progress, H. J. Evans, P. J. Bottomley, and W. E. Newton, eds. Dordrecht: Martinus Nijhoff.

Hardy, R. W. F. 1986. Agricultural research in flux. Experiments in university-industry ties. Technology in Society 8:273–276.

Hardy, R. W. F., and D. J. Glass. 1985. Our investment: What is at stake? Issues in Science and Technology 1(3):69–82.

Jones, S. V. 1986. New policy on plants and seeds. New York Times, April 19.

Koncz, C., O. Olsson, W. H. R. Langridge, J. Schell, and A. A. Szalay. 1987. Expression and assembly of functional bacterial luciferase in plants. Proceedings of the National Academy of Sciences U.S.A. 84:131–135.

Marx, J. L. 1987. Rice plants regenerated from protoplasts. Science 235:31–32.

Moffat, A. S. 1986. Toward a biotechnology revolution. Mosaic 17(2):26–39.

Murray, J. R. 1986. The first $4 billion is the hardest. Bio/Technology 4:293–296.

National Research Council. 1986a. What Is America Eating? Washington, D.C.: National Academy Press.

National Research Council. 1986b. Pesticides and Groundwater Quality: Issues and Problems in Four States. Washington, D.C.: National Academy Press.

National Research Council. 1987. Agricultural Biotechnology. Washington, D.C.: National Academy Press.

National Research Council. 1988. Designing Foods: Animal Product Options in the Marketplace. Washington, D.C.: National Academy Press.

Ng, T. K., R. M. Busche, C. C. McDonald, and R. W. F. Hardy. 1983. Production of feedstock chemicals. Science 219:733–740.

Office of Technology Assessment. 1986. Technology, Public Policy, and the Changing Structure of American Agriculture. Washington, D.C.: U.S. Government Printing Office.

Ruttan, V. W. 1986. Increasing productivity and efficiency of agriculture. Science 231:781.

Schmeck, H. M. J. 1987. Scientists transplant grain genes. New York Times, January 13, III, 3:1.

Schneider, K. 1986a. Surplus of food is now worldwide. New York Times, September 9.

Schneider, K. 1986b. Looking abroad to fill our bellies. New York Times, August 3.

Schneider, K. 1986c. Putting a tag on microbes. New York Times, September 15.

Scientific American. 1987. Lighting up. 237:60–62.

Shinozaki, K., M. Ohme, M. Tanaka, T. Wakasugi, N. Hayashida, T. Matsubayashi, N. Zaita, J. Chunwongse, J. Obokata, K. Yamaguchi-Shinozaki, C. Ohto, K. Torazawa, B. Y. Meng, M. Sugita, H. Deno, T. Kamogashira, K. Yamada, J. Kusuda, F. Takaiwa, A. Kato, N. Tohdoh, H. Shimada, and M. Sugiura. 1986. The complete nucleotide sequence of the tobacco chloroplast genome: Its gene organization and expression. EMBO Journal 5:2043–2049.

Yocum, R. 1986. Genetic engineering of industrial yeasts. Pp. 171–181 in BioExpo 86 Proceedings. Stoneham, Mass.: Butterworth.

Biotechnology and Crop Protection

Robert T. Giaquinta

The progressive increase in productivity in most major crops over the past several decades has resulted from several advances in technology and management practices. Collectively these inputs have helped overcome numerous factors that constrain crop productivity. Advances have included genetic-based increases in the yield potential of crops; improved mechanization for more timely and efficient operations; increased supply of water and nitrogen; better matching of crop life cycles to the environment; optimization of planting densities; genetic-based resistance to diseases and insects; and improved weed, disease, and insect control by use of effective and selective crop protection chemicals. Although significant progress has been made in increasing productivity, the fact that average crop yields are only about one-third of record yields suggests that further improvements in productivity can be achieved through continued advances in technology and management practices (Gifford et al., 1984).

For the long term, cogent arguments can be put forth for the need to increase crop yields. For the next decade or two, however, major emphasis must be placed on maximizing economic yield, that is, increasing the efficiency of production by reducing input costs while protecting and preserving the environment. Technologies that meet this challenge are likely to be readily adopted, especially as support prices are removed and worldwide

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competition to become the lowest cost producer of agricultural commodities stiffens and environmental concerns and regulations heighten.

Advances in biotechnology have the potential to augment, as well as change, today's crop improvement and crop protection strategies. (For the purpose of this paper, "biotechnology" refers to the application of genetic and chemical technologies to agricultural problems in crop improvement and crop protection.) In terms of crop improvement, several technical and management innovations are needed for existing crops in order to reduce input costs for production, stabilize yields under varying environmental conditions (i.e., minimize risks), and increase the sustainability of germplasm. In addition, innovations are needed to create new crops and markets for consumers, growers, and agribusinesses. Examples of new crops include high-value crops with improved nutritional (oil, protein, carbohydrate), processing, storage, and marketing qualities. The improvement of crop quality through biotechnology is receiving wide attention and may be the area that holds the greatest potential for consumers, growers, and businesses. This area is addressed elsewhere in this volume. The focus of this paper is the role of biotechnology in crop protection.

Losses in crop production from competing biological systems, such as weeds, diseases, insects, nematodes, and viruses, significantly decrease productivity. Therefore, innovative, cost-effective solutions to these problems warrant high priority. Losses from pests are truly enormous in that worldwide preharvest yields would be reduced by 30 to 50 percent or more without pest control. Moreover, the trend toward more efficient soil-conservation practices of intensive cropping, minimum tillage, and reduced crop rotations may well exacerbate the problems caused by weeds and soil- and residue-inhabiting insects and pathogens. Thus, the need for more efficient, effective, and environmentally safe pest controls in a changing agricultural environment will help drive the adoption of new technical advancements for crop protection.

Although traditional plant breeding has made noteworthy strides in producing crops with genetic-based resistance to many important plant diseases and insects, crop protection chemicals (herbicides, insecticides, and fungicides) remain an essential adjunct and, in some cases, the only means for defending against these pests and the associated losses in crop production.

Biotechnology has several implications for crop protection. It has the potential to change crop protection practices and businesses by reducing the need for chemical inputs, displacing some products, and reducing the value of some crop protection markets. Biotechnology also offers the potential to create new products in crop protection, such as genetically modified plants that are resistant to herbicides, diseases, viruses, and insects. It will also lead to improved biocontrols for weeds, insects, and diseases and to specific diagnostics that can be used in integrated pest management approaches, quality assurance, and breeding (restriction fragment length polymorphisms). In short, biotechnology will lead to a portfolio of solutions for crop protection. These new solutions will be driven by technical advances and will be adopted by agriculture because of marketplace needs, society's expectations, the need for sound integrated pest management practices, and environmental and regulatory issues.

Much has been written about the promises and expectations—real and imagined—of biotechnology for crop protection. Three points, however, are realistic and noteworthy. First, biotechnology *will* have an impact on crop protection strategies and businesses. It appears, however, that the impact will be modest in the near term and will occur on an evolutionary, rather than a revolutionary, time scale. The total U.S. market for crop protection chemicals, for example, is forecasted to increase at a rate of 3 percent per year (from $5.8 billion to $6.8 billion) from 1990 to 1995. In contrast, the crop protection market attributed to biotechnology is predicted to increase 29 percent per year (from $45 million to $160 million) over this same time period. Even though the 29 percent annual increase is impressive, it means that only about 2 percent of the crop protection market will be attributable to biotechnology (Wheat and Bondaryk, 1986). It is reasonable to expect, however, that biotechnology-derived crop protection products will find increasing application in the marketplace beyond 1995 and into the next century.

Second, biological and genetic solutions will complement and augment chemical methods for pest control. It is highly unlikely that genetic-biological controls will replace agrichemicals. For reasons of efficacy alone, chemical controls will continue to be the mainstay of pest control well into the next century. However, there will be a continuing emphasis on chemistry with high environmental safety.

Third, biotechnology will actually facilitate the design, discovery, and development of novel-acting, environmentally safe crop protection chemicals. Advances in technologies such as gene cloning, protein crystallography, computer modeling, and protein engineering and increased understanding of the dynamics of protein structure and function will have profound consequences for the design of future agrichemicals. These next-generation agrichemicals, by necessity, will have novel modes of action, extremely low use rates, high selectivity for target pests, high safety for mammals and nontarget species, high environmental compatibility, and excellent cost efficiency. In this regard, genetics and chemistry are complementary rather than competing technologies in crop protection.

Substantial opportunities exist for the chemical and seed industries to use biotechnology as a tool for the efficient and effective discovery and development of improved crop protection chemicals and improved crop varieties. As discussed in the following section, biotechnology also promises to cre-

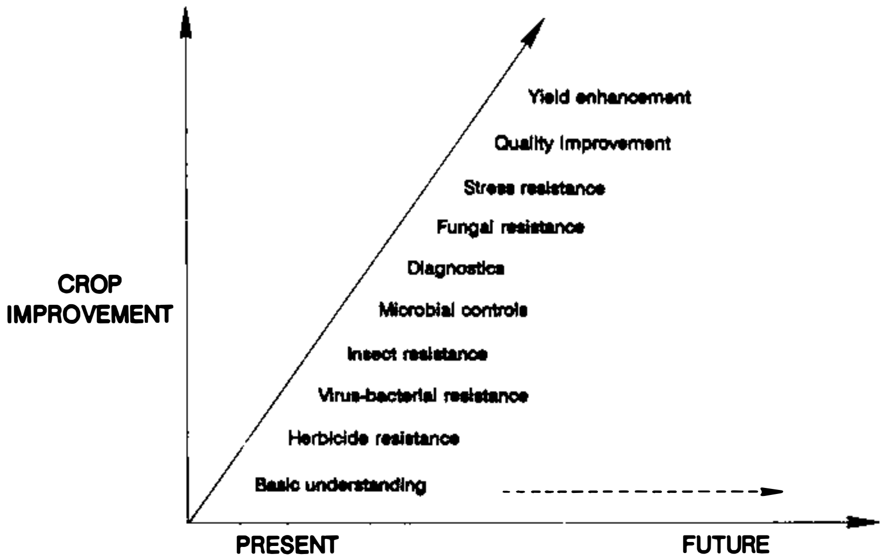

FIGURE 1 Prospect for genetic engineering.

ate novel plants with traits that cannot be derived by traditional chemical synthesis or plant breeding.

PROSPECTS FOR BIOTECHNOLOGY AND CROP PROTECTION

One of the most significant roles of molecular biology in agriculture may well be its use as an unprecedented scientific tool that provides, and will continue to provide, a fundamental understanding of basic processes in plants and pests (Figure 1). Molecular biology techniques have ushered in a new era of investigation and understanding of the structure, function, regulation, and development of genes in plants, fungi, viruses, insects, and nematodes. Understanding the molecular mechanisms underlying the regulation and expression of genes that control form and function will have profound consequences for crop protection and improvement in the twenty-first century.

Early advances in the genetic engineering of plants have resulted from the transfer of single gene traits, such as those coding for resistance to herbicides, viruses, and insects (Figure 1). The development of improved microbial pesticides, such as those derived from *Bacillus thuringiensis* (Bt), will also be among the first products from biotechnology. Similarly, high-specificity diagnostic kits based on either monoclonal antibody or DNA-probe technology will find wide application in agriculture, including detection and identification of plant pathogens as part of an integrated pest management system, molecular "finger printing" of new or proprietary crop varieties, identification-tracking of nonindigenous versus indigenous microbes in the environment, detection and quantitation of chemicals and biologicals in the environment and food chain, and development and registration of new agrichemicals and new crop varieties. All these applications are within the realm of today's technology.

Engineering of plants to achieve multigenic characteristics, such as broad-based resistance to fungal diseases and environmental stresses (temperature, drought, salinity, heavy metals in soils), quality, and yield, is currently beyond our knowledge base and technical capabilities. Several scientific and technical advances must be achieved before such multigenic traits can be engineered into crops, including the identification of those genes that code for complex, agronomically useful traits; the understanding of how those genes are coordinately controlled and expressed; vector design; plant regeneration systems in legumes, cereals, and other important crops; and the understanding of inheritance patterns to introduce and maintain those traits in crops.

The preceding discussion centers on improving crops through recombinant DNA methodologies. Approaches other than gene transfer (and traditional breeding) also exist for the selection of plants with altered characteristics. Resistant plants can be produced, for example, by random mutagenesis via selection of the desired trait at the cellular level, followed by regeneration into whole plants; mutagenesis of seeds, followed by screening for a trait at the seedling or whole plant stage; and screening of plants that have been regenerated from cell culture (somaclonal variation). Although these techniques have been successfully exploited to achieve resistance to herbicides, mineral stresses, and diseases, they have several limitations. These include the difficulty of selecting physiological, morphological, and developmental traits at the cellular level; lack of regeneration systems in many important crops (although significant strides are continually being made in this area); and the need to use labor-intensive and time-consuming backcrossing programs to eliminate undesirable traits caused by random mutagenesis. Nevertheless, plants with commercially significant levels of herbicide resistance have been obtained via cell-culture selection (see following section), and somaclonal variation is proving to be an effective means of selecting crops with improved characteristics.

HOST PLANT RESISTANCE

Traditional plant breeding has made steady and notable progress in developing crops that are resistant to insects, nematodes, and pathogens. Host plant resistance is a proven and economical method for pest control and one that has minimal environmental impact (Croft et al., 1985). The breeding approach relies mainly on the introduction of useful resistant traits from germplasm within a crop species into new cultivars. This traditional approach is limited by at least three factors: (1) lack of useful resistance genes within a species; (2) inability to use resistance genes or gene combinations from species that are not closely related to the desired crop; and (3) the long time frame associated with multiple genetic crosses before the trait can be introduced into a commercially acceptable line. Biotechnology will play a major role in overcoming these limitations, but it will neither replace traditional plant breeding nor reduce its importance. Its role will facilitate breeding by generating genetic diversity (in this case, resistance) within a species; identifying "useful" genes; circumventing genetic barriers to allow gene transfer between widely differing genotypes; and reducing the time of introduction of new varieties. In particular, RFLP technology as a diagnostic breeding tool holds much promise for enhancing the efficacy, reliability, and predictabiliy of developing improved crop varieties.

In the following sections, selected examples of herbicide, disease, and insect resistance are addressed. The intent is not to provide an in-depth review of the literature or technology in these areas. Rather, the examples represent significant technical advances that have the potential to be used in agriculture in the next several years.

Herbicide Resistance

Herbicides account for about one-half of the $20 billion that are annually expended on crop protection chemicals worldwide. Herbicide expenditures in the United States for corn and soybeans alone equal about $1 billion for each crop. On the surface, the capability to introduce herbicide resistance into crops would permit the use of current herbicides (or herbicides under development) on a much broader range of crops than is now possible. Those crops could include the major acreage crops, such as corn, soybeans, cereals, rice, cotton, oilseed rape, and sugar beets, or smaller acreage, high-value specialty crops, such as vegetables. Herbicide-resistant specialty crops may be useful because growers do not have a broad range of existing selective herbicides to use on these crops.

Ideally, an herbicide-resistance strategy for crops should center around an herbicide that has the following 10 criteria:

1. broad-spectrum activity to control all grass and broadleaf weeds,
2. sufficient residual activity to give season-long weed control but not enough residual to cause injury to rotational crops,
3. high mammalian safety,
4. ultralow use rates,
5. flexibility to be used either pre- or postemergence,

6. high environmental safety,
7. high reliability across a variety of soil types and climates,
8. high compatibility with available application equipment,
9. no in-kind competition, and of great importance,
10. low cost.

Not surprisingly, the ideal herbicide defined by these criteria does not exist. Herein lies one of the major pitfalls for those who believe that a crop that is resistant to a single herbicide will solve all weed problems over wide geographical regions. It is reasonable to expect, however, that herbicide-resistant crops will complement existing methods for weed control in more defined situations and will offer value to the grower. Although the "ideal" herbicide does not exist, herbicide-resistant crops, undoubtedly, will be developed for efficacious herbicides that offer low use rates and high mammalian and environmental safety.

A wide array of herbicide-resistance research is being conducted in the private and public sectors. The commercial potential for herbicide-resistant crops and herbicide sales is clearly one of the driving forces. Technological considerations have also been responsible for the broad interest in herbicide resistance. Unlike many other aspects of crop improvement, herbicide resistance can be easily addressed by today's biotechnology. For instance, single genes that code for resistance to specific herbicides can be identified and cloned; vector technology for single gene transfers exists (e.g., disarmed Ti plasmids, electroporation, microinjection, gene "gun" technology); transformed or mutated cells can be easily selected using the herbicide itself as the selection pressure; regeneration techniques for several model plant systems exist; and expression of the trait can be easily screened at the seedling or whole-plant level. For some herbicide-resistant plants, for example, sulfonylurea-resistant tobacco (Chaleff and Ray, 1984) and imidazolinone-resistant corn (Anderson and Georgeson, 1986), the inheritance pattern—a single semidominant or dominant nuclear gene—facilitates the stable introduction and maintenance of resistance in plants.

Selected examples of recent advances in herbicide-resistance research and development follow. The reader is referred to an overview of herbicide resistance by Benbrook and Moses (1986) for a survey of herbicide-resistance research.

Sulfonylureas

The sulfonylurea class of herbicides developed by E. I. du Pont de Nemours & Co., Inc., have ushered in a new era in herbicide technology. These herbicides are characterized by high potency, unprecedented low use rates (some as low as 2 to 10 grams per acre—literally a teaspoon per acre), and high safety to mammals and nontarget organisms (acute toxicity is less than that of table salt). These qualities represent the shape of things to come in herbicide technology. Du Pont scientists have shown that two types of tolerance mechanisms exist in plants for the sulfonylureas. One mechanism is naturally occurring and is responsible for the selectivity of various sulfonylureas in cereals (e.g., "Glean," "Ally," "Express," "Harmony"), rice ("Londax"), and soybeans ("Classic"). Tolerance to sulfonylureas in these crops is due to a metabolic conversion of the parent sulfonylurea to an herbicidally inactive product (Beyer et al., in press). The second mechanism of resistance is based on a genetic alteration in the enzyme acetolactate synthase (ALS) that makes it less sensitive to inhibition by sulfonylurea (Falco et al., 1985). (Acetolactate synthase, the first common enzyme in the biosynthesis of the essential amino acids isoleucine and valine, is the site of action of the sulfonylureas [LaRossa and Schloss, 1984].) Using cell culture selection and regeneration techniques, Du Pont scientists have produced tobacco mutants that are 100 to 1,000 times more resistant to the sulfonylureas than wild-type tobacco (Chaleff and Ray, 1984). Genetic analysis of the plants derived by cell culture showed that resistance was due to a single, semidominant or dominant nuclear gene mutation. Additionally, the biochemical basis for plant resistance was shown to be due to the production of an altered ALS enzyme that was about a thousandfold less sensitive to sulfonylurea inhibition than ALS isolated from the sensitive, wild-type plant (Chaleff and Mauvais, 1984). Scientists at Du Pont and Advanced Genetic Sciences have cloned the gene coding for the resistant ALS and have successfully used that gene to transform commercial tobacco lines. These transgenic tobacco plants express high-level, genetically stable resistance to sulfonylureas. In related studies, seed mutagenesis was used to produce sulfonylurea-resistant *Arabidopsis* plants. Introduction of the resistant ALS gene from *Arabidopsis* into tobacco also conferred high-level, stable resistance to the sulfonylurea herbicides (Mazur and Falco, 1989; C. Sommerville, Michigan State University, and B. Mazur, Du Pont, personal communication, 1986).

Imidazolinones

American Cyanamid's new class of herbicides ("Scepter," "Arsenal," and "Assert") kills plants by inhibiting the same enzyme target site, ALS, as the sulfonylurea herbicides. Scientists at Molecular Genetics, Inc., (Anderson and Georgeson, 1986) have selected corn mutants from cell culture that are highly resistant to the imidazolinone and sulfonylurea chemistry. Resistance is encoded by a single dominant gene, which leads to the production of an ALS enzyme that is insensitive to these herbicides. Pioneer Hi-Bred International, under contractual agreement with American Cyanamid, is currently introducing the resistance trait into commercial corn lines. Assuming that the introduction of the resistance trait is not linked to adverse plant performance, these herbicide-resistant corn lines may be commercially available by 1991. Herbicide resistant canola is under development ty Allelix.

Glyphosate

Monsanto's glyphosate, the active ingredient in "Roundup,~" is a broad-spectrum, postemergence herbicide that blocks aromatic amino acid biosynthesis by inhibiting the chloroplastic enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase in the shikimate pathway. Monsanto scientists have produced glyphosate-tolerant plants by two approaches. One approach involved selecting glyphosate-tolerant cell lines of petunia that overproduced a gene coding for EPSP synthase. Amplification of the EPSP synthase gene was the molecular basis for resistance in this cell line. Introduction of the EPSP synthase gene into cells on a high-expression vector resulted in glyphosate-tolerant petunia plants (Shah et al., 1986). In the second approach, a glyphosate-resistant plant's EPSP synthase gene was introduced into sensitive plants to achieve tolerance (R. Fraley, Monsanto Co., personal communication, 1986).

Calgene scientists (Comai et al., 1985) have achieved glyphosate tolerance in tobacco by selecting and cloning a mutant *Aro A* gene from *Salmonella*, which produces a bacterial EPSP synthase that is insensitive to inhibition by glyphosate. Introduction and expression of this mutant *Aro A* gene in tobacco conferred tolerance to glyphosate.

Phosphinotricin

Scientists at Plant Genetic Systems (PGS) in Ghent, Belgium, have recently introduced high-level resistance to Hoechst's broad-spectrum "Basta" herbicide in potatoes, tomatoes, and tobacco. "Basta" (phosphinotricin), an analog of glutamine, kills plants by inhibiting the plant enzyme, glutamine synthase. Herbicide resistance was achieved by inserting a gene from *Streptomyces* bacteria, which codes for an enzyme (acetyltransferase) that inactivates the phosphinotricin by acetylation. In field tests, the genetically engineered plants survived herbicide rates that were ten-fold higher than the normal rates of "Basta" (Botterman and Leemans, 1988; Newmark, 1987).

Bromoxynil

Calgene scientists have successfully conferred resistance in tobacco to commercial levels of Rhone-Poulenc's bromoxynil herbicide. A gene coding for a specific nitrilase enzyme that converts bromoxynil to a nonherbicidal metabolite was cloned from the bacterium, *Klesbsiella ozaenae*. Transfer of the bromoxynil detoxifying gene into tobacco resulted in nitrilase expression in leaves and high levels of resistance to bromoxynil (Stalker et al., 1988).

Outlook for Use of Herbicide-Resistant Crops

The examples for sulfonylurea, imidazolinone, glyphosate, bromoxynil, and phosphinotricin herbicides represent the most significant and commercially exploitable advances in herbicide-resistance research reported to date. Similar advances will follow for other herbicides.

Technical hurdles still must be overcome before herbicide resistance can be broadly introduced into most crops, but this area of research will continue to advance at a rapid pace. In general, the ability to produce herbicide-resistant crops will not be limited by technology. Herbicide-resistant crops face several uncertainties. For instance, are herbicide-resistant crops really needed? In terms of efficacy, many excellent selective herbicides already exist or are under development for most major agronomic crops, and to a large extent, farmers are satisfied with the weed control they provide. Since it may take 5 to 10 years beyond the technical accomplishment to introduce a herbicide-resistant crop into the marketplace—due to backcrossing, field and yield trials, seed buildup, and market penetration—the need for herbicide resistance in major crops may be lessened further, because more selective and more effective chemicals will also be introduced into the marketplace during this time frame. The trend toward herbicide mixtures for complete weed control may also reduce the need for resistance in major crops. Other relevant questions include: Will herbicide resistance be limited to niche specialty crop markets or will it find selected applications in major crops (e.g., controlling "escape" weeds, increasing the margin of safety to existing selective herbicides, and allowing crop rotations that otherwise could not occur because of residual herbicide activity in the soil)? Will herbicide resistance be cost-effective for the grower? Will the necessity of using specific seed-chemical combinations limit the grower's flexibility to plant other crops or use other herbicides, or make other decisions more difficult for him? Will herbicide-resistant crops change the existing weed spectrum in crops? In addition, herbicide-resistant crops produced by rDNA face the same regulatory and public uncertainties and concerns that all rDNA plants face at this time. The likely answer to the overall question is that herbicide-resistant crops will find *selected* uses in agriculture. This is because herbicide-resistant crops should offer cost-effective, reliable, and environmentally safe weed control and more options to farmers for combatting weeds.

Experimentation on herbicide resistance is shifting from the laboratory arena to that of the marketplace, where its true impact will ultimately be determined. Marketplace considerations aside, herbicide-resistance research has fostered the development of several molecular methodologies and has provided plant scientists with a powerful selection marker that can, and will, be used for many aspects of crop improvement in the future.

Disease-Resistant Plants

Diseases caused by pathogenic fungi, bacteria, and viruses result in significant losses in agriculture. Major progress in disease control has been achieved by using recombinant DNA (rDNA) techniques to produce virus-resistant plants. Cross-protection, the practice of inoculating plants with mild strains of virus to prevent more virulent strains from infecting plants, has been used to prevent yield losses in tomatoes from tobacco mosaic virus (TMV), in citrus from citrus tristeza virus, and in potatoes from potato spindle tuber viroid. This phenomenon of cross-protection was the basis for the production of transgenic tobacco and tomato plants that are resistant to the symptoms caused by TMV infection (Abel et al., 1986; R. Beachy, Washington University, personal communication, 1986). In these experiments a chimeric gene containing a complementary DNA of a TMV coat protein was introduced into tobacco cells on a disarmed Ti plasmid of *Agrobacterium tumefaciens*. The transformed plants produced high levels of virus coat protein and showed a significant delay in the appearance of symptom development following inoculation with TMV. If this strategy of engineering viral coat proteins into plants is applicable to other crops and if it occurs without penalty to yield or plant performance, then this method has significant commercial potential.

Activities are under way to develop plants resistant to bacterial disease. Scientists at Agracetus have used rDNA techniques to produce tobacco plants that are resistant to crown gall disease. This was accomplished by inactivating a cytokinin-producing gene in a T-DNA fragment from *Agrobacterium tumefaciens* and introducing the T-DNA fragment into tobacco. The transformed tobacco was resistant to infection by both *A. tumefaciens* and *A. rhizogenes* in laboratory and field experiments (W. Brill, Agracetus Co., personal communication, 1986). This study represented the first field testing of a rDNA-derived plant.

Advances in the design of plants that are resistant to fungal pathogens is currently limited by our knowledge of many aspects of host-pathogen interactions. Much research is needed to define the genes and gene products in plants and pathogens that confer resistance. Several laboratories are focusing on the role of chitinase and gluconases in disease protection (Broglie, personal communication, 1989). Similarly, recent advances in the development of transformation systems in pathogenic fungi like *Pyricularia oryzae*, the causative agent of rice blast disease, promise to provide new understanding of the molecular determinants of disease and resistance (Parsons et al., 1987).

Insect-Resistant Plants

Insects, like diseases, cause significant losses at all stages of plant development. Researchers at Plant Genetics Systems, N.V., in Belgium (Vaeck et al., 1986) have cloned the protein crystal gene from Bt that directs the synthesis of a nontoxic 130 kd (kilodalton) protein. (Under the alkaline condition of the insect's midgut, the 130 kd protein is proteolytically cleaved to a 60 kd toxin that is insecticidal to certain insects.) Tobacco plants transformed with a chimeric Bt toxin gene expressed a functional Bt toxin and were resistant to damage by *Manduca sexta* (tobacco hornworm) in greenhouse tests. This is a significant first step in the eventual design of crops that are resistant to agronomically important insect pests. Insect-resistant plants based on Bt genes are being actively pursued by scientists at Agracetus and Monsanto. Both companies are field testing Bt-containing cotton in 1989. In addition to the Bt strategy, Agricultural Genetics Company (AGC) is focusing on introducing the cowpea trypsin inhibitor (CpTi) gene as a means of producing insect-resistant plants. The CpTi gene produces a protein that inhibits digestive activity in insects. AGC has licensed the CpTi to Pioneer, Calgene, and BioTechnica Agriculture to assess its utility.

Insects have the remarkable ability to develop resistance to a wide variety of chemicals and single-gene traits. Whether this will limit the utility of introducing Bt or CpTi genes into plants to achieve resistance is an issue that needs to be resolved. The efficacy of these genes in insect control still needs to be established.

BIOCONTROLS

Biocontrol strategies for pest management have received considerable interest because of the low environmental impact associated with this approach (Croft et al., 1985). As noted previously, Bt is being exploited as a biocontrol strategy for insect control in many laboratories; Bt is a gram-positive bacterium that produces endogenous protein crystals during sporulation. The crystals comprise nontoxic proteins of 130 to 160 kd molecular weight that break down to an insecticidal 60 kd fragment within the insect's gut (Vaeck et al., 1986). Many naturally occurring strains of Bt have been isolated that show varying specificities against *Lepidoptera*, *Coleoptera*, and *Diptera* species, and several have been commercially used to control certain insects. Research at several institutions is aimed at understanding the molecular basis of specificity with the intent of designing novel Bt toxins (or hybrid toxins) with improved efficacy and broader spectrum activity. The toxins can be delivered to plants by direct application of either nonliving or living microbes. Another approach examined by researchers at Monsanto involved cloning the Bt toxin gene in a root-colonizing soil bacterium, *Pseudomonas* species, to protect roots against feeding by soil-borne insects (R. Fraley, Monsanto Co., personal communication, 1986).

Advantages of the microbial toxin approach include high specificity to pests versus nontarget organisms, nonpersistence of the biological toxicant in the environment because of biodegradability, and the reduction in chemical load into the environment. However, microbial pesticides have several disadvantages that currently preclude their wide use in insect control. Several of these disadvantages, not too surprisingly, result from the aforementioned attributes. Microbial toxins, such as Bt, have a very narrow spectrum of insect control, which severely limits their usefulness in the field, where several insect pests can contribute to crop damage. Additional disadvantages include the slow-acting versus fast "knock-down" insecticidal activity (the latter eliminates early damage); instability in the environment, which necessitates multiple applications; lack of reliability; high cost; and regulatory considerations, particularly for rDNA-derived microorganisms or nonindigenous organisms (Bondaryk, 1986). Nevertheless, research in several laboratories is aggressively addressing these shortcomings, and it is reasonable to predict that insecticidal toxins will continue to find new applications in agriculture.

Biological strategies for controlling plant pathogens center on control of pathogens with natural enemies, such as hyperparasites, viruses, and predators; protection of plant surfaces with nonpathogenic epiphytes that are antagonistic to the pathogen; and enhancing plant resistance by inoculating plants with nonpathogens. Specific examples include the use of nonpathogenic strains of *Agrobacterium radiabacter* that produce a bacteriocin, Agrocin-84, which controls sensitive pathogens, and plant growth-promoting rhizobacteria, which colonize the rhizosphere and suppress root pathogens by producing antibiotics and siderophores (Croft et al., 1985). Another example is Ecogen's "Dagger G" biofungicide. This product, based on a naturally occurring *Pseudomonas* which was isolated from soil in the Mississippi Delta, controls damping off diseases caused by *Rhizoctonia* and *Pythium* pathogens. In weed control, biological controls have centered on weed pathogens (mycoherbicides) and weed-feeding arthropods. Mycoherbicides include Mycogen's "Casst," based on *Alternasia cassiae*, for sicklepod control; Ecogen's "Collego," based on *Colletotrichum gloeosporoides*, for northern joint vetch control; and Abbott's "Devine," based on *Phytophthora* palmivora, for strangle vine control. Although biological control for weeds may find application in nonintensively managed agricultural systems, or in specialty niche markets, it is questionable whether this strategy could compete with chemical controls in terms of efficacy and weed spectrum in major acreage crops. Biological controls are receiving much attention in the private, public, and government sectors. They may find their application where chemical controls are lacking, where chemistry is expensive or impractical, where chemicals are restricted, and in highly managed systems such as greenhouses, nurseries, and gardens or lawns.

CROP PROTECTION CHEMICALS

Today, crop protection chemicals represent the principal means for controlling all pest groups in virtually all crops. Chemical controls represent a significant input into modern production systems, and as such, a major part of agribusiness. They will continue to play a pivotal role in crop protection into the foreseeable future.

Most, if not all, crop protection chemicals have been discovered by empirical evaluation of chemicals for biological activity. Chemical leads resulting from a screening program are then optimized by concerted structure-activity efforts. The empirical approach has been highly successful, as evidenced by the existence of a number of effective products in the marketplace. It is becoming more difficult, however, to discover agrichemicals by this approach. In 1950, for instance, 1 out of approximately every 2,000 chemicals that were evaluated resulted in a new product. In 1970, the success rate decreased to 1 out of 7,500 chemicals, and in 1986 it stood at about 1 out of 20,000. By the end of the century, the empirical approach may necessitate screening upwards of 100,000 compounds for every new class of agrichemicals that is introduced into the marketplace. The decrease in discovery efficiency has been accompanied by increased development costs, which today range from $20 million to $40 million per product.

Biotechnology research will facilitate the discovery and development process for crop protection chemicals by:

- Identifying key metabolic processes and target sites for novel-acting chemistry;
- Biorationally designing inhibitors of key enzymes and receptors;
- Designing chemicals that regulate developmental processes through direct effects at the gene level;
- Identifying and improving the efficacy of natural products and allelopathic chemicals;
- Employing fermentation techniques to produce microbial-derived products (e.g., avermectins);
- Using plant or microbial cultures or enzymes for the synthesis of com-

plex molecules or to accomplish specific chemical synthesis steps that cannot be accomplished readily in the laboratory; and

• Using biotechnology techniques to improve the efficacy and efficiency of the residue identification and toxicology testing required for product registration.

Gene-cloning techniques already play a pivotal role in enzymology and analysis of protein structure-function relationships. The ability to clone, sequence, and overproduce genes and gene products in quantities sufficient for biochemical, biophysical, and structural analyses has implications for the design of mechanism-based enzyme inhibitors. Similarly, molecular techniques are providing new insights into the dynamics of protein folding and flexing, both of which have consequences for chemical design.

Many developmental processes involve the interaction of specific regulatory proteins with DNA. Molecular techniques coupled with computer modeling, computational techniques, and x-ray crystallography will provide understanding of key aspects of these regulatory protein-DNA interactions, including the nature of electric fields, docking sites, conformational changes, and ion redistributions. Similarly, recombinant DNA and site-directed mutagenesis (the insertion of synthetic DNA into a gene to produce a modified protein) will find application in the design of plants that have exquisite selectivity for specific chemicals. Peptide synthesis will aid in the discovery and production of synthetic peptides that mimic naturally occurring, bioactive natural products, such as insect neurotransmitters and second messenger molecules in plants and pests. The increasing fund of knowledge resulting from molecular biology is setting the stage for a new era in the design of crop protection chemicals.

New technical advances will clearly foster the discovery of new chemical controls. We must recognize, however, that new technology alone will not ensure adoption of new products in the marketplace. Issues relevant to next-generation agrichemicals will probably be similar to the practical issues facing today's chemistry—cost, efficacy, product compatibility, reliability, environmental safety, maturing markets, regulatory policy, development costs, and the farm economy.

SUMMARY

Biotechnology has the potential to affect all areas of crop protection. New techniques and knowledge will lead to the discovery of better and more environmentally compatible chemical and genetic means for controlling pests and disease. This will be accomplished by improving existing methods of control and by creating entirely new solutions to problems in agriculture. Biotechnology cannot stand alone, however; it is but one arrow in our quiver. The only successful approach to crop protection will be an integrated approach based on additional research aimed at alleviating environmental concerns, maximizing host plant resistance to pests, discovering novel crop protection chemicals, improving biological controls, and improving management practices. Advances in these areas hold great promise for increasing the efficiency of food and fiber production and for preserving our natural resources in the decades ahead.

REFERENCES

Abel, P. P., R. S. Nelson, B. De, N. Hoffmann, S. G. Rogers, R. T. Fraley, and R. N. Beachy. 1986. Delay of disease development in transgenic plants that express the tobacco mosaic virus coat protein. Science 232:738–743.

Anderson, P. C., and M. Georgeson. 1986. An imidazolinone and sulfonylurea tolerant mutant of corn. J. Cellular Biochemistry (Supplement)10C.

Benbrook, C. M., and P. B. Moses. 1986. Herbicide resistance: Environmental and economic issues. Pp. 27–54 in Proceedings of BioExpo 86, O. R. Zaborsky, ed. Stoneham, Mass.: Butterworth.

Beyer, E. M., Jr., M. J. Duffy, J. V. Hay, and D. D. Schlueter. In press. Sulfonylurea herbicides. In Herbicides: Chemistry, Degradation and Mode of Action, P. C. Kearney and D. D. Kaufman, eds. New York: Marcell Dekker.

Bondaryk, R. P. 1986. Microbial pesticides. In International Forefront Biotechnology Portfolio, Section 3B. Cambridge, Mass.: Arthur D. Little Decision Resources.

Botterman, J., and J. Leemans. 1988. Engineering herbicide resistance in plants. Trends in Genetics 4:219–222.

Chaleff, R. S., and C. J. Mauvais. 1984. Acetolactate synthase is the site of action of two sulfonylurea herbicides. Science 224:1443–1445.

Chaleff, R. S., and T. B. Ray. 1984. Herbicide-resistant mutants from tobacco cell cultures. Science 223:1148–1151.

Comai, L., D. Facciotti, W. R. Hiatt, G. Thompson, R. E. Rose, and D. M. Stalker. 1985. Expression in plants of a mutant *Aro A* gene from *Salmonella typhimurium* confers tolerance to glyphosate. Nature 317:741–744.

Croft, B. A., R. J. Cook, and D. R. MacKenzie. 1985. Biological constraints. Pp. 177–195 in Crop Productivity—Research Imperatives Revisited. An international conference held at Boyne Highlands Inn, October 13–18, 1985 and Airlie House, December 11–13, 1985. M. Gibbs and C. Carlson, eds.

Falco, S. C., R. S. Chaleff, K. S. Dumas, R. A. LaRossa, K. J. Leto, C. J. Mauvais, B. J. Mazur, T. B. Ray, J. V. Schloss, and N. S. Yadav. 1985. Molecular biology of sulfonylurea herbicide activity. Pp. 313–328 in Biotechnology in Plant Science, M. Zaitlin, P. Day, and A. Hollaender, eds. New York: Academic Press.

Gifford, R. M., J. H. Thorne, W. D. Hitz, and R. T. Giaquinta. 1984. Crop productivity and photoassimilate partitioning. Science 225:801–808.

LaRossa, R. A., and J. V. Schloss. 1984. The sulfonylurea herbicide sulfometuron methyl is an extremely potent and selective inhibitor of acetolactate synthase in *Salmonella typhimurium*. J. Biological Chemistry 259:8753–8757.

Mazur, B. J., and S. F. Falco. 1989. The development of herbicide resistant crops. Ann. Rev. Plant Physiology 40:441–470.

Newmark, P. 1987. Plant genetic systems get Basta resistance. Bio/Technology 5(April):10.

Parsons, K. A., B. Valent, and F. G. Chumley. 1987. Transformation of *Magnaporthe grisea* using the *A. nidulans arg B* gene. Proc. Nat. Acad. Sci., USA 84:4161–4165.

Shah, D. M., R. B. Horsch, H. J. Klee, G. M. Kishore, J. A. Winter, N. E. Tumer, C. M. Hironaka, P. R. Sanders, C. S. Gasser, S. Aykent, N. R. Siegel, S. G. Rogers, and R. T. Fraley. 1986. Engineering herbicide tolerance in transgenic plants. Science 233:478–481.

Stalker, D. M., K. E. McBride, and L. D. Malyj. 1988. Herbicide resistance in transgenic plants expressing a bacterial detoxification gene. Science 242:419–423.

Vaeck, M., H. Hofte, A. Reynaerts, J. Leemans, M. Van Montagu, and M. Zabeau. 1987. Engineering of insect resistant plants using a *B. thuringiensis* gene. Pp. 355–366 in Molecular Strategies for Crop Protection, C. J. Arntzen and C. Ryan, eds. UCLA Vol. 48. New York: Alan R. Liss.

Wheat, D. W., and R. B. Bondaryk. 1986. Biotechnology in agriculture: Issues and strategies for commercialization. In International Forefront Biotechnology Portfolio, Section 3B. Cambridge, Mass.: Arthur D. Little Decision Resources.

Impact of Prospective New Technologies on Crop Productivity: Implications for Domestic and World Agriculture

Randolph Barker

We are now entering what Wittwer (1985) describes as a "golden age in agricultural science." As a result of recent advances in the biological sciences, technological innovations are on the horizon that will likely allow significant gains in crop productivity. Whether these gains are achieved, however, will depend not only on the development of technologies in the laboratory, but also on what is economically feasible and how the new technologies are perceived by the public sector. Moreover, as with all advances, the benefits will be unevenly distributed. This being the case, it is clear that researchers have not yet adequately investigated the fundamental question: Technology for what purpose and to serve whose ends (Buttel, 1986b).

The focus of this paper is on advances in the biological sciences that make it possible to solve problems that conventional methods either could not address or had solved with limited success. This kind of research, including basic and applied aspects, is typically termed biotechnology. The term is used here in a generic sense to include such areas as tissue and anther culture and wide crossing as well as recombinant DNA technology.

Progress has been more rapid in the animal than in the plant sciences. In fact, biotechnology is unlikely to produce major gains in crop productivity for another 10 to 20 years. Thus, it is too early to assess the potential impact of gains due to a specific technology, but certainly not too early to speculate on the general direction and consequences of those changes.

This paper identifies some areas in which gains in crop productivity are likely to occur and speculates on how those gains will affect U.S. and world agriculture. The first section indicates how the current bias in research funding and in the institutional structure of research will influence decisions with respect to the choice of technology to be developed. The second section discusses the rate of progress in various technological innovations and the impact, either direct or through product substitution, on crop productivity. The final section examines the likely effects of these advances on U.S. competitiveness in the world market.

BIAS IN RESEARCH

The priority given to research depends on available funding, the goals of the institution, and the preferences of individuals, all of which are linked. Two important factors, priority for animal over plant research and the emergence of the private sector as the primary funding source for both research and dissemination of new technologies, have influenced the direction of research in biotechnologies.

Basic Animal Versus Plant Research in Biotechnology

Public sector funding for major categories of research is, to a large degree, politically determined, and in the United States, the emphasis is on human health issues rather than on food production. This is reflected in the top-heavy government allocation of funds for biotechnology research to federal health agencies (Table 1). It is difficult, of course, to determine how much research conducted by the National Institutes of Health (NIH) is applied to animal science problems.

The fact that plant molecular biology in particular has been neglected is not strictly a matter of funding. Plant cells are difficult to manipulate because the cell walls are hard to penetrate and contain four to five times as much genetic information as do animal cells. Animal tissue research, on the other hand, depends on the comparatively simple procedures of fermentation and genetic manipulation of bacteria to produce pharmacological products. As a result, animal science innovations, such as bovine growth hormone, are already being tested. Such advances do not require molecular knowledge of the biological processes of animals. Technological advances that lead to increases in crop productivity will also initially occur in areas in which molecular knowledge of the plant is not required.

Public and Private Sector Complementarities

The emergence of biotechnology has been accompanied by a change in the institutional structure of agricultural research. We are now in the midst of a rapid change in the division of labor between public and private research (Buttel, 1986b). This will have a major impact on the kinds of technologies that are developed.

Historically, agriculture has relied on public investment in both basic

TABLE 1 Funding Levels for Biotechnology and Agriculturally Related Biotechnology Research by Selected Sources

Source	Amount ($U.S. millions)
Agriculturally related biotechnology	
U.S. Department of Agriculture	
Agricultural Research Service	24.5
Cooperative State Research Service	
Competitive grants	30.0
Hatch Act and special grants	18.4
State agricultural experiment stations[a]	
State	16.2
Industry	5.4
Private Industry[b]	150.0
All other biotechnology[c]	
Environmental Protection Agency	1.5
Food and Drug Administration	2.6
National Institutes of Health	1,849.5
National Science Foundation	81.6

[a]Nonfederal support; fiscal year 1984 data (National Association of State Universities and Land-Grant Colleges, 1985).
[b]Estimation based on data from the Agricultural Research Institute (1985).
[c]Fiscal year 1985 (General Accounting Office, 1986). Funding by non-USDA federal agencies may include some agriculturally related biotechnology research.

SOURCE: National Research Council (1987).

and applied research because the private sector could not easily capture the benefits from new technological developments, such as improved varieties, cultivars, or cultural practices. Ruttan (1982) attributes much of the past success in maintaining growth in agricultural productivity to the "articulation" and "decentralization" of the U.S. agricultural research establishment. The close links among various parts of the system—basic research, applied research, extension, private industry, and farmers—were enhanced by the decentralization of authority to the state and local levels.

There were signs in the early 1970s that the alliance described was losing its support and its relevance. In this period, two influential critiques of U.S. agriculture were published (Buttel, 1986a). One, Hightower's (1973) *Hard Tomatoes, Hard Times*, criticized the agricultural research system on the grounds of social inequity and justice, arguing that the university land-grant system had become a publicly subsidized research arm of agribusiness and the large farmer. The second report, prepared by the Pound committee (NRC, 1972), argued that public agricultural research was highly insular and largely divorced from the frontiers of knowledge in the basic biological sciences. Ten years later the Winrock report (Rockefeller Foundation, 1982) reemphasized many of the conclusions of the Pound report and recommended greater participation in agricultural research by scientists outside the land-grant system and the U.S. Department of Agriculture (USDA). Against this background of growing concern, we can now look more directly at the impact that advances in the biological sciences have on the structure of the agricultural research system.

The public sector has rapidly responded to the new challenges of biotechnology. The estimated number of biotechnology faculty (full-time equivalents) at the state agricultural experiment stations increased from 283 in 1982 to a projected 520 in 1986, roughly 4 to 8 percent of total faculty in the system (National Association of State Universities and Land-Grant Colleges, 1985).

Biotechnology has also helped introduce an important new family of basic science disciplines to the agricultural research establishment, including molecular and cell biology, biochemistry, and cytogenetics (Table 2). It is increasingly difficult to argue that basic research is neutral or unbiased and that most scientific discoveries are serendipitous, thereby obviating the need to set research priorities. It is imperative that all tiers of the research system maintain close communication. Most of the research supported by non-USDA federal agencies, however, is conducted in universities and laboratories that are not a part of the traditional agricultural research network. Moreover, there may also be a qualitative difference between USDA-funded research and that supported by other agencies. Comparing competitive grants programs, the annual USDA support level is about half that of the National Science Foundation (NSF) and a quarter of that of NIH. Thus, NIH tends to attract the best scientists. Until recently, USDA provided almost no funds for competitive grants, a reflection of the low priority that federal government placed on funding basic research in agriculture in the 1960s and 1970s (Bonnen, 1983).

A distinguishing feature of many of the new biological technologies is that the process or products are often patentable. Such legal actions as the Plant Variety Protection Act of 1970, which established the right of the private sector to obtain patents for novel life forms, greatly stimulated private investment in agricultural research. Since the mid-1970s, private sector investment in biotechnology has grown sharply. Public and private sector investment in all biotechnological research related to agriculture (including research funded by non-USDA federal agencies) is now between 5 and 10 percent of the total investment in agricultural research, although

TABLE 2 Tiers in Science and Biotechnology Development

Tiers and Subfields	
1. Basic Biological Sciences	3. Technological Invention
Molecular biology	Plant breeding
Cell biology	Plant pathology
Biochemistry	Entomology
Cytogenetics	Animal breeding
	Animal nutrition
2. Agricultural/Biological Sciences	
Plant physiology	4. Technology Transfer
Animal physiology	Seed industry
Soil microbiology	Chemical and fertilizer industry
Soil chemistry	Veterinary medicine
	Extension services

some would argue that private sector investments are understated. Not all private investments in biotechnology have proved profitable, however, because a considerable gestation period is normally required before new biotechnology products reach the marketplace. The private sector increasingly recognizes that its own progress in biotechnological development depends on the rate of progress in publicly supported basic research.

In basic biological research, an alliance is emerging between public sector researchers and private sector technologists. Although many of the research participants do not belong to the traditional agricultural research establishment, they should be viewed as a complement to, rather than a substitute for, the publicly supported agricultural research establishment. In fact, advances in basic biological research will increase the demand for technology generated by both the public and private sectors.

The growing importance of the private sector in technology development raises some important questions for public sector research. What goals should the public sector pursue? What potentially high-payoff opportunities exist that will not be undertaken by the private sector? What research will benefit the clientele—both producers and consumers—that supports the agricultural colleges and research stations?

The land-grant universities are finding it increasingly difficult to address these questions because they have less control over research budgets, a growing portion of which come from competitive grants and private industry funding. Some important public sector initiatives outside the land-grant system are linking basic research to technology development, such as the Michigan Biotechnology Institute and the programs for biotechnology research on rice funded by the Rockefeller Foundation. The ultimate success of these programs remains to be determined. At present, however, private sector goals are setting the course for technological invention (the third tier in Table 2), and this will undoubtedly affect the initial direction of technological advances to enhance crop productivity.

Despite these changes, the primary source of scientific manpower continues to reside in the public sector research establishment. The traditional U.S. agricultural research establishment has a comparative advantage in education and research capacity that needs to be encouraged and developed. Basic support and structure should be assured by public funding that does not rely too heavily on competitive grants.

ADVANCES IN CROP PRODUCTIVITY

Advances in the biological sciences, including tissue and anther culture, wide crossing, recombinant DNA, and biocontrol, provide researchers greater flexibility in problem solving while complementing traditional plant-improvement and crop-management techniques. As a rule, problems that are difficult to solve using conventional techniques are still troublesome, even with the use of more advanced techniques.

The appropriate choice among techniques is a matter of economic concern. What will be the economic benefits and how will the benefits be shared? What will the research cost, and in particular, what will be the gestation period for technological development and dissemination? New technologies are adopted when producers expect a gain in crop productivity and a resulting lower unit cost of production. This may be due to an increase in yield, a decrease in cost, or a change in quality and, hence, in the value of the commodity. The particular manner in which gains are achieved, however, will have an important effect on how the benefits are distributed among producers.

The following section discusses the potential for development of several specific types of biotechnology, the applicability to specific categories of crops, and finally, the potential impact of biotechnology through commodity substitution.

Biotechnological Advances in Agronomy

For the purpose of discussion, biotechnological advances in agronomy can be grouped into five categories: (1) plant protection, (2) product quality, (3) environmental constraints, (4) nitrogen fixation, and (5) biomass. The categories are listed in terms of increasing length of the gestation period. Biotechnological innovations in the area of plant protection and product quality will be available in the next 5 to 10 years, but those in nitrogen fixation and biomass are likely to take considerably longer. Within each of the categories, however, some technologies will be developed much more rapidly than others.

Plant Protection

Most researchers seem to agree that technologies offering improved plant protection will be among the first biotechnologies released for adoption. The most rapid progress is predicted for the development of herbicide-resistant crops (Florkowski and Hill, 1985) because resistance is controlled by a single gene, tissue culture can be used to identify resistant strains, and there appear to be significant benefits that the private sector can realize. Whether herbicide-resistant varieties will prove to be less costly than conventional weed control is open to question, but a large market is anticipated. The technology probably will be ready for adoption in some crops in five years or less.

New technologies may also be developed relatively quickly for insect and disease control. Crop loss due to insects and diseases can be reduced through cultural, biological, chemical, or resistance-breeding methods. Relatively little research is devoted to cultural or biological methods because the private sector cannot easily realize profits. Chemical methods, the most widely used form of control, are favored by private industry, although an increased emphasis is being placed on the development of disease- and insect-resistant varieties because excessive pesticide use contributes to product contamination and groundwater pollution. The short-term costs of resistance-breeding methods to farmers could be even higher than those incurred using chemical control. Alternatively, in some cases biotechnological innovations could be used to enhance chemical methods.

The time required to develop resistant varieties will vary widely depending on the nature and difficulty of the problem. In the area of diseases, for example, progress is likely to be rapid for viral problems and slow for fungal problems. Techniques have already been developed that make it possible to immunize plants against viral attack, but more knowledge of the genetics of both the host and pathogen and of host-pathogen interactions is needed before progress can be made in breeding for resistance to fungi. If success can be achieved, the impact on crop productivity is likely to be large relative to control of other forms of disease. This is because fungi cause severe crop damage, chemical control methods are costly, and attempts to breed for resistance to date have proved only partially successful.

In summary, within the area of plant protection itself, the easy biotechnological solutions are likely to be available fairly soon, but they will have a relatively low payoff in terms of gains in crop productivity. For the more complex problems, biotechnologies probably will not be available for some time to come.

Product Quality

Biotechnology is likely to have an early impact on product quality in terms of marketing, processing, and nutrition. General Foods, for example, is funding research to produce rice varieties with a starch content more suitable to the company's processing needs. Researchers use tissue culture techniques and somoclonal variation to identify improved lines. A number of attempts have been made to raise the protein level of plants through conventional breeding practices, but with little success. Although breeders can raise the percentage of protein, yield invariably declines.

Environmental Constraints

Selection and breeding for varieties that are either resistant to or escape environmental stresses are perhaps as old as agriculture itself. For example, drought conditions in the lower Yangtze and lower Huai river valleys during the crop year 1011–1012, led Emperor Zheng Zong of the Song Dynasty to order that 30,000 bushels of Champa rice be brought from Fujian Province and distributed to farmers in drought-stricken areas, together with instructions for proper methods of cultivation (Barker and Herdt, 1985). The early tropical and subtropical varieties of rice could not be grown above 36 degrees north latitude, but by the nineteenth century, rice was grown in Japan at 46 degrees north latitude, and today it is grown in China at 53 degrees north latitude.

Other major cereal grains are also grown over a wider environmental range. The wheat area, for example, has been expanded to the Gangetic Plain in India, and wheat is now grown on millions of hectares in West Bengal and Bangladesh. Maize is grown in cold climates in the United States and Europe and in dry climates in North Africa, where only sorghum and millets were previously grown.

Considerable research is being conducted to develop plants that are more tolerant of environmental stresses, such as drought, frost, heat, and salinity. Substantial progress could be made in some of these areas in the next 20 years, and the impact on crop productivity could be very large, particularly in the developing countries. But the rate of progress will depend on the level of public sector investment in basic research and technology development.

Nitrogen Fixation

Nitrogen fixation is one of the most discussed topics in biotechnology because its development would enable farmers to use atmospheric nitrogen in place of expensive, oil-dependent nitrogen fertilizer. The economic viability and potential importance of this technology will depend on the price of nitrogen fertilizer, which in the long run is certain to be considerably higher than it is today.

In symbiotic nitrogen fixation, bacteria in the rhizosphere of the plant convert atmospheric nitrogen to nitrate, primarily in association with leguminous plants. Managing rhizobium bacteria through improved inoculum could significantly increase the yield of leguminous plants (Florkowski and Hill, 1985). Initiating nitrogen fixation in other organisms could lead to a symbiotic relationship with crops such as corn, but yields would likely be reduced because of the energy expended to maintain the bacteria. Hardy (this volume) is optimistic about progress in the development of nitrogen self-sufficient plants. He states that due to recent technological advances, it is reasonable to suggest that self-nitrogen-fertilizing plants will be invented by the early 1990s.

Biomass

The yield potential of plants can be improved through heterosis, or through improved photosynthetic efficiency. Yield gains through heterosis occur by creating hybrids, such as hybrid corn. Recently, the Chinese have achieved a 15 to 20 percent improvement in yield because of heterosis in hybrid rice varieties. To date, attempts to use hybrid wheat commercially have been unsuccessful for technical reasons, but when the fundamental mechanisms underlying heterosis are understood, it may be possible to breed directly for heterosis without creating hybrids. Alternatively, hybrids could be developed that are apomictic or have the capacity for asexual seed production (Rockefeller Foundation, 1986).

Potentially, photosynthetic efficiency may be enhanced in some plants by improving the CO_2 fixation pathway, but development of this technology is far in the future.

Crops

In this section, biotechnological developments are examined for four crop categories: (1) horticultural crops, (2) industrial and plantation crops, (3) cereal grains and grain legumes, and (4) roots and tubers. The crops are listed according to length of gestation period before new technologies will be available, but as with the biotechnology categories noted previously, there will be a great deal of variability within each of the crop categories. As indicated earlier, technologies with a high potential payoff to private sector investors will likely be developed first.

Horticultural Crops

There are a wide range of high-value fruits and vegetables for which gains in crop productivity will be made through biotechnological innovations. Typically, large amounts of chemicals have been used for pest control. The emphasis in crop improvement will be on producing resistant varieties, varieties with higher quality (such as the high-solids tomato), and varieties with stress tolerance. The initial objective will be to breed varieties with a single added gene or trait that changes the basic plant characteristics as little as possible.

Bananas provide an example of a crop for which public investment in biotechnological development could provide significant improvements in disease control. Black Sigatoka, a new fungal leaf-spot pathogen, was identified in Honduras in 1972 (Carlson, 1986). It greatly increased the cost of disease control and currently threatens the export banana industry in the Americas. Black Sigatoka has also spread to the plantain crop in Central and West Africa, and it may destroy a crop that is an important staple food in the diet of some 40 million Africans. Using techniques required for the selection and recovery of genetic variability from tissue culture, it might be possible to develop resistant clones. A private company, such as United Fruit, is unlikely to undertake such research, however, because of the tremendous up-front research costs and the uncertainty of success. Also, an improved Cavendish clone would represent a one-time sale because it is not legally protectable. (The Cavendish is a popular banana cultivar; its clone would be propagated through asexual or vegetative reproduction, which requires no seed.)

Industrial and Plantation Crops

Industrial and plantation crops are an important source of export earnings for many developing countries. This category includes tree crops, such as coconut, palm oil, cocoa, and coffee; fibers; and sugar cane. Research investment by private multinational groups can have a major impact in this area, and improvements can often be made with proven tissue culture techniques. Consider the case of palm oil in Malaysia. Palm oil accounts for close to 15 percent of the world market for edible oils and fats. Unilever and other private companies have provided research assistance to the Malaysian palm oil industry in an effort to produce superior palm oil plants through cloning. Rapid increases in crop productivity have allowed Malaysia to capture more than 80 percent of the world market.

Cereal Grains and Grain Legumes

Cereal grains and grain legumes present more challenging technical problems to researchers. Easy-to-apply tissue culture techniques offer limited opportunity for major gains in crop productivity. It will be at least another 10 years before appropriate techniques have been developed and adequate knowledge is available on important agronomic traits that will allow recombinant DNA to be applied successfully. The most significant gains will first be achieved with corn because more is known about the basic genetics of corn, and because innovations marketed in the form of hybrid seed offer a much higher return on private investment. By contrast, progress with rice, a much less important crop in the developed world, will be slow because less is known about rice genetics and there is little incentive for private sector investment in research. These factors motivated the Rockefeller Foundation to fund a major biotechnology program on rice.

Roots and Tubers

Although there is considerable potential for improvement in roots and tubers using tissue culture techniques, most of these crops have a low market value. In addition, the plant seed materials are extremely difficult to store and distribute. The exception is the potato, which has an important place as a food staple and a source of starch in the developed world and is rapidly gaining prominence as a preferred food source in some developing countries. Research on the development of true seed potatoes now makes it possible to ship disease-free potato seed around the world. In the developed world, research is under way to develop potatoes with resistance to major pests, such as the golden nematode. However, biotechnological research on roots and tubers has been minimal compared with that on other commodities.

Commodity Substitutions

Historically, commodity substitution has been an important source of productivity gain, but the gain in one commodity always comes at the expense of another. Direct substitution of one crop for another can occur as a crop gains wider adaptability to environmental conditions. As previously noted, for example, corn is being substituted for sorghum and millets in some of the drier portions of Africa.

Another even more important form of substitution occurs as a result of change in end-product use. A familiar example is the substitution of vegetable fats (margarine) for animal fats (butter), which was accelerated by the shortage of butter during World War II. More recently, liquid corn sweetener has replaced sugar and now accounts for approximately 50 percent of the total market for caloric sweeteners in the United States. The development of corn sweeteners was stimulated by the protectionist U.S. sugar policy, which maintained domestic sugar prices on an average four times the world price level.

Today, where dairy proteins have been traditionally used, soya, other vegetable proteins, and casein (a low-cost dairy product) are rapidly taking their place (Junne, 1986). Well-known examples are imitation coffee creamers and cheese substitutes. Soya and other vegetable proteins are still at a disadvantage when it comes to taste and color, but biotechnology-developed flavoring may overcome objectionable tastes.

Considerable sums have been invested in the United States and Canada to develop an improved rapeseed (canola) to compete with other sources of edible oil. In Europe, barley is being used as a new source of starch. The genetic flexibility of this crop makes it possible to improve the characteristics of barley starch sufficiently to compete with other starch forms (Junne, 1986). In yet another area of food technology, research is being conducted to synthesize cocoa butter, which if successful would reduce the demand for cocoa imports from tropical countries.

In summary, research in biotechnology will change the comparative advantage among commodities as cheap sources of high-quality protein, starch, and sweeteners and a range of other items for food and industrial purposes become available. The direction of these changes will be hard to predict and will be influenced by both economic and political factors.

IMPLICATIONS FOR U.S. AND WORLD AGRICULTURE

A major concern in this country is the competitiveness of U.S. agricultural products and the role of U.S. agriculture in satisfying the world's food needs. Put in its simplest terms, will the world export market grow and will the United States maintain or increase its share of that market? Considering the wide range of commodities and potential technological changes, plus the maze of government policies that affect technology development and trade, the issue becomes very complex.

Total productivity (measured in terms of gross value of output divided by gross value of input) in U.S. agriculture and that of the countries of the European Economic Community (EEC), our main competitors, has grown at about 2 percent per annum over the past decade. Total productivity in Asia and Latin America has grown at zero to 1 percent, and India and most of the countries in Africa are experiencing negative growth rates. On the other hand, there have been substantial increases in investment in agricultural research in the developing countries, particularly for food crops. There have also been significant gains in productivity growth in the cereal grains in developing countries, largely as a result of the introduction of green-revolution type technology, including improved seeds, fertilizers, and irrigation.

A distinguishing feature of the new biotechnology is that it is extremely knowledge intensive. Both for this reason and because technology or product development will occur primarily in the private sector, the new technologies will be relatively capital intensive and very management intensive. Farmers—generally those with large farms—with superior management ability and access to information and data processing will be able to use the new biotechnologies most effectively (Kalter et al., 1984; Office of Technology Assessment, 1984).

Knowledge, although it is costly to acquire, is not easily patentable. This fact has implications for the future cost of and access to information. In addition, the public sector pipelines through which advanced scientific knowledge or biotechnology can flow are poorly developed. For export crops, access to biotechnology can be provided by multinational groups. For the main food crops, access to biotechnology can come through the International Agricultural Research Centers and through national programs in the larger countries, such as India or Brazil. At present, however, the links among these institutions and advanced laboratories in the developed world are weak, and funding to strengthen those links must come largely from donor agencies in the developed countries. Evidence suggests that the gap in productivity growth between developed and developing countries will likely widen. With success in biotechnology research, the comparative advantage in production of many commodities could shift toward the developed countries. Should U.S. agriculture be concerned about this?

A growing body of evidence indicates that agricultural and economic development in developing countries can lead, in many situations, to an increase in demand for U.S. farm products (Bachman and Paulino, 1979; Kellog, 1985; Lee and Shane, 1985; Mellor, 1986; Paarlberg, 1986; Saduolet and de Janvry, 1986). This occurs as a result of rising incomes and relatively high income elasticities of demand for food products in countries where either the end products or the inputs, such as livestock feed, cannot be produced domestically. Demand for U.S. agricultural exports in some of the more advanced developing countries, such as Brazil, Taiwan, and Malaysia, grew rapidly during the 1970s and, together with strong demand from the centrally planned economies, led to an unprecedented export boom. Since the early 1980s, however, a number of factors have contributed to the slump in U.S. farm trade. Will we return to the export boom days of the 1970s, and what role will biotechnology play in this?

Consider the case of two agricultural economies, Malaysia and the Philippines; one has prospered and the other has fallen on hard times. Even before the expansion of oil palm production, Malaysia was extremely successful in linking its research efforts in the rubber industry with those of the developed countries to remain on the cutting edge of technological advances. Despite growing demand for rubber substitutes, Malaysia maintained a comparative advantage in rubber production by increasing crop yields and improving product quality. Palm oil offered a comparative advantage over rubber in Malaysia in terms of lower labor requirements and increased labor productivity. Again, the developed–developing country research partnership paid off, and export earnings from agriculture have continued to boost incomes and provide foreign exchange to meet the growing demand for agricultural imports.

In terms of dollar earnings, sugar cane and coconut were the two major export crops in the Philippines. Under the Laurel-Langley agreement, which ended in 1974, the Philippines had a preferential tariff and an annual export quota for more than 1 million metric tons of raw sugar. With the advent of corn sweeteners (spurred by U.S. price supports for sugar), U.S. demand for sugar dropped sharply in the 1980s, and by 1985 the Philippine quota had dropped to one-fifth the previous level.

Coconut and palm oil are direct substitutes for each other. Expansion of palm oil production helped to depress world oil prices, including coconut oil prices. The coconut industry has made little technological progress and has lost ground to the more efficient palm oil industry. Over the past decade, the Philippine government appears to have squandered large sums of money that ostensibly were collected from sugar cane and coconut producers for investment in research. As a consequence of the subsequent decline in income, in the early 1970s, the New Peoples Army shifted its base of operations out of Central Luzon, where government investment in infrastructure and rice technology had raised crop productivity and incomes, to the economically depressed sugar cane and coconut areas.

These two cases can be regarded as extremes, but they illustrate how access or lack of access to technology in specific crops and domestic U.S. farm policies can influence foreign exchange earnings and demand for U.S. farm exports in developing countries. Demand for exports has generally declined as a consequence of slowed worldwide economic growth. The recovery of export markets will depend on general economic conditions. A number of developing countries, feeling the pinch in reduced export earnings, have recently devalued their currencies to promote export growth. There are increasing risks in the export market, however. Advances in biotechnology leading to the production of substitutes in the developed countries, coupled with protectionist price and trade policies in those same countries, are likely to reduce import demand for a number of major developing-country exports. This in turn will dampen the demand for U.S. exports. How the many forces affecting trade volume will work out on balance is difficult to predict, but if the trends are of sufficient magnitude, both developed and developing countries could move to a higher level of self-sufficiency in agricultural production.

CONCLUSION

The United States now appears on the verge of what has been referred to as a biorevolution. A major concern is whether the past level of growth in agricultural productivity can be sustained and whether productivity gains will maintain the competitiveness of U.S. agriculture. Since little is known about the rate at which the new technology will become available or about the impact it will have on productivity, it is difficult to develop a definitive picture of future productivity growth (Ruttan, this volume). The papers in this volume suggest that it may be difficult to match the rapid productivity gains of the past, which were achieved largely through labor substitution in agriculture. As with all technological innovations, the benefits will not be evenly distributed. The dislocations associated with rapid technical change in agriculture are not a new phenomenon. The farm adjustment problem in both U.S. and world agriculture has been with us for a long, long time and is a fundamental part of the development process.

What distinguishes the biorevolution from earlier technological revolutions, however, is the expanded role of the private sector in agricultural research, the fact that the new technology is knowledge intensive, and the potential speed and magnitude of change due to agricultural innovation. Thus, the question, "Who benefits?," will be of paramount concern. The public sector must not only anticipate the kinds of changes that will take place, but carefully define its goals and priorities in biotechnology research and determine the institutional and policy changes needed to attain those goals.

REFERENCES

Agricultural Research Institute. 1985. A Survey of U.S. Agricultural Research by Private Industry, III. Bethesda, Md.

Bachman, K. L., and L. A. Paulino. 1979. Rapid Food Production Growth in Selected Developing Countries: A Comparative Analysis of Underlying Trends, 1961–1976. Research Report No. 11. Washington, D.C.; International Food Policy Research Institute.

Barker, R., and R. W. Herdt, with B. Rose. 1985. The Rice Economy of Asia. Washington, D.C.: Resources for the Future Press.

Bonnen, J. J. 1983. Historical sources of U.S. agricultural productivity: Implication for R&D policy and social science research. Am. J. Ag. Econ. 65:958–966.

Buttel, F. H. 1986a. Biotechnology and agricultural research policy: Emergent issues. Pp. 312–347 in New Directions for Agriculture and Agricultural Development, K.A. Dahlberg, ed. Totowa, N.J.: Rowman and Allenheld.

Buttel, F. H. 1986b. Biotechnology and public agricultural research policy. Pp. 123–156 in Agricultural Science Policy in Transition, J. Rhodes, ed. Bethesda, Md.: Agricultural Research Institute.

Carlson, P. S. 1986. Somatic Cell Genetics: Developing World Applications. Crop Genetics International, Dorsey, Md. Photocopy.

Florkowski, W.J., and L.W. Hill. 1985. Expected Commercial Applications of Biotechnology in Crop Production: Results of the Survey. Department of Agricultural Economics, AE 4605. Urbana: University of Illinois.

General Accounting Office. 1986. Biotechnology: Analysis of Federally Funded Research. (GAO/RCED-86-187). Washington, D.C.

Hightower, J. 1973. Hard Tomatoes, Hard Times. Cambridge, Mass.: Schenkman.

Junne, G. 1986. Implications of Biotechnology for Agriculture in the European Economic Community. Contribution to the Second International Conference, Biomedical and Agricultural High Technology. Columbus, Ohio, November 12–14.

Kalter, R. J., R. Milligan, W. Lesser, W. Magrath, D. Bauman, A. McGuirk, E. Andrysick, and M. Grosh. 1984. Biotechnology and the Dairy Industry: Production Costs and Commercial Potential of Bovine Growth Hormone. Department of Agricultural Economics, A.E. Research 84-22. Ithaca, N.Y.: Cornell University.

Kellog, E. 1985. University involvement in international agricultural development activities: Important issues for public education. Speech given at Annual Meeting of the Association of U.S. University Directors of International Agricultural Programs, Athens, Ga., May 31.

Lee, J. E., Jr., and M. Shane. 1985. United States Agricultural Interests and Growth in the Developing Economies: The Critical Linkage. Economic Research Service, Washingon, D.C.: U.S. Department of Agriculture.

Mellor, J. W. 1986. The new global context of agricultural research-implications for policy. Paper prepared for Consultative Group on International Agricultural Research, International Centers Week, Washington, D.C., November 3–6.

National Association of State Universities and Land-Grant Colleges. 1985. Emerging Biotechnologies in Agriculture: Issues and Policies. Progress Report IV. Washington, D.C.

National Research Council. 1972. Report of the Committee on Research Advising to the U.S. Department of Agriculture. Washington, D.C.: National Academy Press.

National Research Council. 1987. Agricultural Biotechnology: Strategies for National Competitiveness. Washington, D.C.: National Academy Press.

Office of Technology Assessment. 1984. Commercial Biotechnology. Washington, D.C.

Paarlberg, R. L. 1986. United States Agriculture and the Developing World: Partners or Competitors? Washington, D.C.: Curry Foundation.

Rockefeller Foundation. 1982. Science for Agriculture. New York.

Rockefeller Foundation. 1986. Conference on "Apomixis." Bellagio, Italy, April 21–26.

Ruttan, V. W. 1982. Agricultural Policy Research. Minneapolis: University of Minnesota Press.

Saduolet, E., and A. de Janvry. 1986. Less-developed country food security strategies and demands for imports. A. J. Ag. Econ. 68:5.

Wittwer, S. H. 1985. Crop productivity—Research imperatives: A decade of change. Pp. 1–6 in Crop Productivity—Research Imperatives Revisited, M. Gibbs and C. Carlson, eds.

The Present and Future Roles of Biotechnology in Animal Production

Thomas E. Wagner

Animal products account for one-half of all U.S. agricultural revenues. But within the past decade, increased foreign competition, a marked decrease in the implementation of new technology, and increased consumer concern about health hazards associated with the overconsumption of some animal products have seriously threatened this segment of our agricultural economy. During this same period, advances in biotechnology have offered the promise of dramatic improvements in the quality, healthfulness, product range, and economics of production of animal products. The greatest single challenge facing U.S. animal agricultural policy is to ensure the full and rapid implementation of biotechnological advances as they become mature technologies. Only through a futuristic strategic plan, one that emphasizes the positive aspects of biotechnology implementation and focuses on weaving biotechnology into the very fabric of U.S. animal agriculture, can the near- and long-term viability of this important part of our economy be ensured.

Four areas of technology will have the most significant impact on animal agriculture in the next two decades: (1) recombinant peptide hormones and other growth enhancers in livestock; (2) advanced cellular engineering techniques that fundamentally change the basis of animal reproduction; (3) direct gene transfer in animals to develop totally new and dramatically improved strains of transgenic livestock; and (4) gene transfer to develop a system of "molecular farming," which will permit the production of a wide variety of nonfood protein in animals.

THE USE OF PEPTIDE GROWTH HORMONES TO INCREASE ANIMAL PRODUCTIVITY

During the 1970s, advances in microbial recombinant genetics made possible the cloning and expression in bacteria of a wide variety of mammalian genes. Included in this group of genes were several of the animal growth hormone genes. As a result of this new technology, substantial quantities of these growth hormone proteins were available during the late 1970s and early 1980s, and scientists were able to undertake detailed study of the effects of exogenous added growth hormone on the growth performance of livestock.

Growth hormone is a protein, produced in very small quantities in the pituitary gland of young animals, that accelerates growth and metabolism. This peptide is both an anabolic and a catabolic hormone in that it stimulates growth rate and muscle accretion and concurrently decreases adipose tissue growth (Etherton et al., 1986, 1987). The positive effects of growth hormone on muscle and bone growth are mediated by the insulin-like growth factor I (IGF-I) (Etherton and Kensinger, 1984), but the effects on adipose tissue are direct effects (Walton and Etherton, 1986).

In extensive tests with swine, daily injections of recombinant growth hormone clearly demonstrated the efficacy of this agent for enhancing growth and carcass quality. Animals injected with 140 μg/kg of body weight showed an increase in muscle mass of 24 percent, a decrease in the amount of feed required for 1 unit of body weight gain of 24 percent, and most dramatically, a decrease in carcass lipid of 68 percent (Etherton et al., 1986).

The National Center for Health Statistics has indicated that between 1976 and 1980, 34 million adult Americans were markedly overweight. Among this population, diabetes mellitus is 2.9 times higher than among the normal-weight population, the prevalence of hypertension and elevated cholesterol is 5.6 and 2.1 times higher, respectively, and mortality rates are up to 3.9 times higher. The Joint Nutrition Monitoring Evaluation Committee of the U.S. Department of Agriculture and the U.S. Department of Health and Human Services has identified 10 problem nutrients in the U.S. diet, 7 of which originate from animal products. The highest on this list are food energy, total fat, saturated fatty acids, cholesterol, and sodium. The American Heart Association, the American Cancer Society, the National Academy of Sciences' Committee on Diet and Cancer, and the National Institutes of Health all recommend a substantial reduction in dietary fat, particularly from animal sources (less than 30 percent of calories should come from fat).

Both for the national health and the economic health of the animal industry, livestock producers must produce animal products that contain far less fat, but these producers must accomplish this goal with a concomitant decrease in production costs to retain their economic viability in the current agricultural economic environment. It is highly fortuitous that such an agent as growth hormone, which both decreases the fat content of livestock and provides greater efficiency in food utilization and, thus, decreases production costs, has become available at this time of crisis for animal agriculture. Although growth hormone and the other protein enhancers of growth performance that will surely arise from the current in-depth study of the mechanisms of animal growth are certainly not, by themselves, the answer to the problems in animal agriculture, they may well provide the first step to recovery.

In addition to their importance in decreasing animal production costs and animal fat, growth hormones provide a very attractive replacement for the steroid hormones and subtherapeutic antibiotics being used in animal production. Not only are these growth promoters far less effective than growth hormone, they have given rise to increasing consumer concern about the residue they leave in animal products. Because of these concerns, the countries of the European Economic Community have banned the use of steroids in farm products after 1988. It is of utmost importance for U.S. animal agricultural interests to explain to the consumer the marked difference between the protein growth hormones and low molecular weight chemicals like steroid growth promoters and antibiotics. Unlike the small molecular weight chemical substances currently used, proteins, like growth hormone, have a half-life within the animal of less than a few minutes, which eliminates any possibility of residue in food products. Efforts to educate the consumer about the residue-free nature of growth hormone are crucial so that these growth hormones are not confused with the residue-producing steroid growth promoters.

In addition to its advantageous effects on animal growth and carcass quality, growth hormone stimulates milk production in the cow. Bovine growth hormone (bGH) administered through several complete lactations to dairy cattle showed increases in milk production as high as 40 percent (Bauman et al., 1985). Unfortunately, bGH does not seem to increase the feed-conversion ratio in milk production (Bauman et al., 1985).

Because growth hormone must be supplied and administered regularly, the use of this protein in both meat-producing and dairy animals is most suited to concentrated confinement agriculture, such as that practiced in the United States and Europe.

CELLULAR ENGINEERING OF GAMETES AND EMBRYOS TO ENHANCE ANIMAL REPRODUCTION

Parallel to the rapid development of recombinant genetics and molecular biology have been the remarkable advances in the area of cellular developmental biology. Many of the significant advances in animal agriculture resulting from biotechnology will come from the joint application of technology flowing from these two, quite different areas of science. Advances in cellular engineering have already suggested bold new alternatives to current methods of animal reproduction.

Reproduction of livestock and genetic improvement of animal breeds is being accomplished through selective matings of superior examples within a breed type or between breed types to take advantage of the positive aspects of heterosis. In some species and breed types (e.g., dairy cattle), the use of cryo-preserved gametes, artificial insemination, and embryo transfer has become an accepted and common means of using elite progenitor animals. These cellular technologies have been advanced slowly during the past several decades so that only crude cellular engineering techniques, such as embryo twining, are now being used in specialized elite breeding programs. But major advances in the 1980s in in vitro oocyte maturation and fertilization, lineage engineering, parthenogenesis, and cloning suggest the beginning of a revolution in animal reproduction as significant—or more significant—than the current revolution in molecular genetics.

Although a male animal may produce sufficient gametes to generate a very large number of offspring (naturally or through artificial insemination), the female produces only a single or relatively small multiple ovulation during each estrous cycle, which markedly limits reproductive capacity. Not only is it impossible to make effective use of a female to improve the species significantly, but the contribution of an elite breeding pair is limited by the reproductive performance of the female. This significant problem in animal reproduction may have been substantially overcome by recent advances in in vitro oocyte maturation and fertilization. Moor and coworkers (Staigmiller and Moor, 1984) have shown in sheep that the large store of oocytes present in the ovaries of the female may be matured in a feeder cell culture system to mature eggs that may be in vitro fertilized and develop to term. A significant number of lambs have been born using this procedure, and experiments are under way to adapt this technology to all other livestock species, which would make possible the generation of potentially thousands of offspring from a single elite breeding pair.

Although cloning from the tissue of existing animals seems only a distant possibility, rapid advances have been made in cloning from embryonic tissue. By transferring the nuclei of later-stage embryos into the cytoplasm of oocytes, Willadsen (1986) has produced clonal lambs. Because this technology may be used in repeated sequence, it suggests the real possibility of generating an almost continuous line of identical animals. Using very different techniques, it has been demonstrated that the germ cells of a female mouse may be maintained and propagated in a clonal fashion through the use of parthenogenetic chimeras (Surani et al., 1977). In these experiments, unfertilized oocytes were induced to develop early embryos and these parthenogenetic embryos merged with normal embryos to generate mosaic mice in which portions of tissue, including the ovaries, derived from the genotype of the oocyte donor female without contribution from a male. Therefore, some of the eggs ovulated by these parthenote chimeras would be virtually identical to the original donor female. These technologies may be applied to livestock to achieve continuous generation of germ plasm from an elite female.

Progress in understanding the basic cellular and molecular mechanism of early mammalian embryonic development has been rapidly accelerating (Surani et al., 1986), and it seems likely that even more elegant methods for producing and reproducing highly homogeneous, elite lines of farm animals will be available in the near future. Unfortunately, U.S. scientists in this field lag researchers in other countries, and England is the clear leader in this area of biotechnology. The technology itself and its resultant products should be equally applicable to all forms of agriculture and to all regions.

DIRECT GENE TRANSFER IN ANIMALS AND THE DEVELOPMENT OF TRANSGENIC LIVESTOCK

As a direct result of the interaction between the advances in cellular developmental biology and molecular biology, methods were developed at the beginning of this decade that make possible the direct transfer of cloned genes into the germ line of mammals (Wagner et al., 1986). The advent of gene transfer technology, which makes possible the introduction of well-characterized cloned genes into the permanent genetic make-up of mammalian species, including laboratory mice (Wagner et al., 1986) and domestic farm animals (Wagner and Jochle, 1986), holds the promise of providing a new methodology for the genetic improvement of livestock. Using this recombinant genetic procedure, greater genetic improvement may soon be achieved in a single gestation period than has been possible using classical genetic selection over a period of decades.

The introduction of growth-hormone-expressing genes into livestock species is a good example of the application of this technology to animal agriculture. When synthetic fusion genes composed of a strong constitutive promoter and the structural gene for either human (Palmiter et al., 1983) or bovine growth hormone (Wagner and Jochle, 1986) are introduced into the germ line of mice, the resulting growth-hormone transgenic mice have enhanced growth performance and carcass qualities to even a greater extent than do animals injected with the growth hormone protein (Wagner and Jochle, 1986).

As described earlier, the advantages of administered growth hormone in livestock and dairy production are clear, but these advantages have a price.

The cost of production and especially of purification of recombinant proteins from microbial suspensions places a significant cost on such agents. A substantial portion of any increased profits to farmers will go toward paying these manufacturing costs as well as the marketing and research costs of the product. All of this suggests that a better mode of use of the growth hormone system may be through the permanent genetic alteration of farm livestock, using animals that are transgenic for the expressing growth hormone gene. But, along with their obvious advantages in effectiveness, cost, and profit share to the farmer, transgenic animals also may have some significant drawbacks. Any change in the permanent genetic make-up of a living organism must be compatible with all aspects of that organism's life cycle. Although genetic engineering, which increases the level and duration of growth hormone production within an animal, clearly and dramatically increases growth rate and feed efficiency, it also has some negative side effects on reproductive performance. By prolonging the animal's growth period, puberty is delayed, which results in a less-than-ideal breeding animal. To develop transgenic animals that demonstrate the positive traits for growth but minimal negative effects, it will be necessary to regulate the time of expression of the transgenes. Development of regulated transgenic animals is a future step for biotechnology, but rapid progress in that direction has occurred in the past several years (Wagner and Jochle, 1986; Wagner et al., 1986).

Gene transfer in farm animals for optimizing growth, that is, maximizing animal protein-production capacities, is an important first goal for this new technology. It offers an attractive alternative to the continued or periodic administration of growth hormone, growth-hormone releasing hormone, or of other growth promotion products; it entirely avoids residue problems and has no environmental impact. Simultaneously, it provides a first demonstration of this technology's potential, feasibility, and practicality. As such, it can serve as an object lesson for future developments.

Probably beginning in the late 1990s, transgenic livestock carrying transgenes to confer increased growth performance, disease resistance, and reproductive traits will begin to take their place beside conventional livestock on U.S. farms and ranches. The net effect in productivity and economic competitiveness from the use of these animals is likely to be substantial. But the United States, despite its lead in science and technology in this area, can expect strong competition in developing and implementing this technology because it is so applicable to regions where agriculture is less concentrated. Also, the regulatory climate in the United States may restrict rapid implementation of transgenic livestock.

MOLECULAR FARMING WITH LIVESTOCK

The rapid development of recombinant gene transfer in livestock will, in addition to increasing productivity, efficiency, and economic advantage, offer livestock agriculture the opportunity to develop totally new products. Because transgenic animals may be produced that contain functioning genes from virtually any source, natural or synthetic, and coding for any desired protein product, these potential products need not be what we now term animal products or food. Over the next several decades, the potential ability to produce high-value, nonfood products in livestock may be the most economically important aspect of biotechnology implementation for animal agriculture.

The genes that code for the production of proteins in animals are complex molecular information packets, each coding not only for a protein structure (structural sequences) but also for the regulation of expression of that protein within the animal (promoter/regulatory sequences). Examples include the bovine casein gene and chicken ovalbumin gene code for the production of the principal milk protein and egg white protein, respectively. Both of these proteins are produced in substantial quantities within specific tissues and organs of the producing animal. The tissue specificity (e.g., the cow's udder for casein and the chicken oviduct for ovalbumin) and the level of gene expression are both regulated by DNA regions flanking the structural sequences (Wagner et al., 1986). Although the specific sequences regulating these genes have not as yet been fully elucidated, regions of other tissue-specific regulated genes have been isolated and well characterized (Dean et al., 1983). These tissue-specific regulatory sequences may be used to direct the expression of other genes to the tissue targets of these regulatory elements. Therefore, by using the regulatory elements of genes, such as the ovalbumin or casein genes, to direct the expression of other genes to tissues, where these gene products may be recovered in milk or egg white, it may soon be possible to develop transgenic animals containing these genetic constructs that become virtual factories for the production of valuable nonfood proteins. Animal systems are among the most efficient protein-producing systems in nature and may be the most effective way to produce many proteins for industrial or pharmaceutical use.

Because it is logical to pursue high-value applications first, the earliest products of biotechnology have been aimed at the human and animal health markets. Most of these products are proteins, such as insulin, growth hormones, interferons, monoclonal antibodies, and blood proteins. It follows that such products are also likely candidates for molecular farming. Many production methods for biological proteins are currently used to produce these proteins: extraction from live tissues, for products such as human serum albumin, antihemophilic factor, and porcine or bovine insulin; fermentation of recombinant bacteria, for hormones such as human growth hormone produced by Genentech and human insulin produced by Eli Lilly; animal cell culture in vivo, for the production of monoclonal antibodies in mouse ascites fluid; in vitro mammalian cell culture, also for the production of monoclonal antibodies; and chemical synthesis, for peptides, such as salmon calcitonin sold by Armour for the treatment of osteoporosis and

Paget's disease. Compared with these other technologies, molecular farming offers the major advantage of a highly competitive production cost brought about by two major elements: the low cost of raw materials (e.g., animal feeds) and the high concentration of product expected in the harvest. In addition, the machinery for downstream processing has already been perfected (e.g., milking machines, dairy processing, and automated egg harvesting).

Although the initial products of molecular farming may be protein pharmaceuticals or other high-value and low-volume proteins, in the longer term the economy of animal recombinant protein production may lend itself to lower value recombinant proteins, such as food additives or industrial proteins. These potential new markets could have a major positive effect on the agricultural economy several decades from now. Unlike transgenic animals used in the traditional mode for the production of food, animal molecular farming requires a highly sophisticated interaction between the agricultural sector and the industrial sector. Such interaction is most easily accomplished in highly industrialized nations and regions where agriculture is also an important segment of the economy, such as in the United States. Emerging nations with a strong agricultural base may also choose such systems to support the development of their industrial sector. Maintaining a strong lead in areas of biotechnology such as molecular farming may be important to both the agricultural and industrial segments of the U.S. economy.

CONCLUSION

The four technologies discussed in this paper represent key areas in the developing field of animal biotechnology. Each will have a major impact on animal agriculture in the next several decades. These technologies and other biotechnologies of perhaps equal importance will change the face of livestock farming and ranching to a greater extent than most would currently suspect. The future U.S. agricultural position worldwide will depend more on the ability of U.S. agriculture to implement these advances in biotechnology than on any other single factor.

Although it is of utmost importance to evaluate the safety and real value of each new technology prior to permitting its general use, it is crucial that a regulatory climate that stifles the development and implementation of agricultural biotechnology not be allowed to develop. An agricultural policy that seeks a balance between an active program of biotechnology development and a reasoned regulatory environment can take advantage of the leading position of the United States in biotechnology to strengthen our agricultural economy. Within such a positive environment, livestock agriculture can look to a new era of real prosperity based on increased production efficiency and new products.

REFERENCES

Bauman, D. E., P. J. Eppard, M. J. DeGeeter, and G. M. Lanza. 1985. Responses of high-producing dairy cows to long-term treatment with pituitary somatotropin and recombinant somatotropin. J. Dairy Sci. 68:1352–1362.

Dean, D., B. J. Knoll, M. E. Riser, and B. O'Malley. 1983. A 51-flanking sequence essential for progesterone regulation of an ovalbumin fusion gene. Nature 305:551–554.

Etherton, T., and R. Kensinger. 1984. Endocrine regulation of fetal and postnatal meat animal growth. J. Anim. Sci. 59:511.

Etherton, T., J. Wiggins, C. Chung, C. Evock, J. Rebhun, and P. Walton. 1986. Stimulation of pig growth performance by porcine growth hormone and growth hormone-releasing factor. J. Anim. Sci. 63:1389–1399.

Etherton, T., J. Wiggins, C. Evock, C. Chung, J. Rebhun, P. Walton, and N. Steele. 1987. Stimulation of pig growth performance by porcine growth hormone: Determination of the dose-response relationship. J. Anim. Sci. 64:433–443.

Palmiter, R. D., G. Norstedt, R. E. Gelinas, R. E. Hammer, and R. L. Brinster. 1983. Metallotionein-human GH fusion genes stimulate growth of mice. Science 222:809–814.

Staigmiller, R. B., and R. M. Moor. 1984. Effect of follicle cells on the maturation and developmental competence of ovine oocytes matured outside the follicle. Gamete Research 9:221–230.

Surani, M. A. H., S. C. Barton, and M. H. Kaufman. 1977. Development to term of chimeras between diploid parthenogenetic and fertilized embryos. Nature 270:601–602.

Surani, M. A. H., W. Reik, M. L. Norris, and S. C. Barton. 1986. Chromosomal determinants of mouse development. Gene. 97:123–136.

Wagner, T. E., and W. Jochle. 1986. Recombinant gene transfer in animals: The potential for improving growth in livestock. Pp. 293–314 in Control and Manipulation of Animal Growth, P. J. Buttery, N. B. Haynes, and D. B. Lindsay, eds. London: Butterworth.

Wagner, T. E., X. Z. Chen, and W. B. Hayes. 1986. Mammalian gene transfer and gene expression. Pp. 319–350 in Molecular and Cellular Aspects of Reproduction, D. S. Dhindsa and O. P. Bahl, eds. New York: Plenum Press.

Walton, P., and T. Etherton. 1986. Stimulation of lipogenesis by insulin in swine adipose tissue: Antagonism by porcine growth hormone. J. Anim. Sci. 62:1584.Willadsen, S. M. 1986. Nuclear transplantation in sheep embryos. Nature 320:63–65.

Willadsen, S. M. 1986. Nuclear transplantation in sheep embryos. Nature 320:63–65.

Impact of Emerging Technologies on Animal Protection

David E. Reed

Translating biotechnology into products has been difficult. When the recombinant DNA (rDNA) and monoclonal antibody (MAB) technologies were first developed, there were extravagant promises of new products. In particular, vaccines and therapeutics for veterinary use were to become safer, cheaper, and more efficacious and, consequently, were to reduce the cost of meat production. It has taken much longer to develop products than predicted and, in many cases, biotechnology projects for use with food animals have been abandoned as too costly for continued development. This paper discusses the impact of these emerging technologies on our ability to protect food animals from disease.

VACCINES AGAINST VIRAL DISEASES

The research success with producing bovine somatotropin in bacteria by rDNA methods led to predictions of similar success in producing viral vaccines in limitless quantities. Scientists uniformly have succeeded in cloning and expressing viral surface proteins. Among the biotechnology companies, essentially all the viruses of economic importance in food-producing animals have been extensively researched. In most cases, however, the millions of dollars spent in research have not led to products. The exact reasons for these failures are various, but they involve the difficulty in coping with the large molecules that represent the immunizing portions of the viruses.

Recombinant DNA Viral Subunit Vaccines

Given enough research resources, it is now, or soon will be, technically feasible to produce viral subunit vaccines using rDNA technology. A possibly overriding issue, however, is the cost of the research necessary to complete development of working, practical vaccines. The magnitude of the research task cannot be overestimated. Development of an rDNA vaccine for foot and mouth disease (FMD) in cattle, for example, requires that the immunizing subunit be completely and rigorously defined and the gene for that subunit cloned and expressed. To make a practical vaccine, the protein chemistry, immunology, and rDNA research as well as the vaccine development and the clinical testing must be repeated for each type of FMD virus and, possibly, for each subtype of virus because the final FMD vaccine product must be multivalent. Subunit vaccine research is expensive and was especially so in the early 1980s, the early days of rDNA, when hundreds of industry scientists and technicians were conducting the basic molecular virology research required to make veterinary vaccines.

It is important to understand that the current U.S. market for vaccines for food animals is only a $100 million business and that the viral vaccine component of that business is about 40 percent. It is doubtful that a market of that size is sufficiently large for industry to continue to fund the basic research needed to complete development of rDNA subunit vaccines. Given our current knowledge of the cost of the research and development, when any sort of financial model is applied to the research, the dollar values of the products fail to justify their continued development. The dollar loss from viral diseases in food animals in the United States alone, however, is large, and when rinderpest and FMD viruses are added to the losses worldwide, the figure becomes enormous. It seems that the fundamental error of the biotechnology firms was assuming that the product sales from technologically derived products would key from the dollar losses from disease rather than from the smaller product sales dollars. In retrospect, it seems to have been an arrogant point of view, one that assumed complete success and complete worldwide replacement of "old technology" with "high technology."

It is probable that some of the rDNA subunit viral vaccines will be developed to the point of commercialization within a few years. Considerable research remains to be done before this can happen, however. The major current barriers to successful development are not regulatory, but barriers of nature. One of the early promises of the rDNA technology, for example, was production of viral subunit vaccines through inexpensive fermentation of recombinant *Escherichia coli* bacteria. An example of successful research is the cloning and expression of a bovine papilloma virus (BPV) capsid protein in *E. coli*. In this case, the product is a killed *E. coli*-BPV recombinant bacterin. The product has been tested in extensive experimental immunogenicity trials in cattle and found to be highly efficacious in preventing warts (DeLorbe et al., 1987).

The more common examples have been ones of failure. At Molecular Genetics, scientists attempted to make an rDNA vaccine against parvovirus, a major cause of abortion and infertility in swine. They were successful in expressing porcine parvovirus structural proteins in *E. coli*. These proteins, when used to immunize animals, would produce antibody against parvovirus, but, unlike protein obtained from the virus, a vaccine from the viral protein produced from *E. coli* failed to protect animals (J. M. Halling, Molecular Genetics, Inc., personal communication, 1986; Smith and Halling et al., 1984). When they attempted to prepare a vaccine against pseudorabies virus, a porcine herpesvirus, they found that it took more than 1,000 times more *E. coli*-produced viral protein than authentic viral protein to immunize a pig (J. L'Italien, T. Zamb, A. Robbins, and R. Marshall, Molecular Genetics, Inc., unpublished data, 1985–1986).

If rDNA approaches to subunit vaccines are to be successful, their efficacy must increase. The most certain and straightforward approach in most cases is to introduce the genes for the viral immunogens into mammalian cell expression systems rather than bacterial expression systems. These expression systems are capable of producing viral protein that is immunologically equivalent to authentic viral protein but, in most cases, the proteins cannot yet be expressed at economically feasible levels.

Recombinant DNA Live Virus Vaccines

Recombinant DNA research has been successful in two areas of live virus vaccine development: (1) production of live virus vaccines in which a virulence gene has been deleted and (2) production of live virus vaccines that are genetic recombinants between, for instance, vaccinia virus (the virus that was used to eradicate smallpox) and the immunizing subunit genes of another virus.

In the first area, the rDNA methods for deleting virulence genes should replace the traditional methods of attenuation, such as mutagenesis, multiple cell culture passage, temperature selection, and passage in nonhost animals. The only example of a commercially available live virus vaccine modified by rDNA techniques is a porcine herpesvirus vaccine in which the viral thymidine kinase (TK) gene has been deleted (Kit et al., 1985).

The TK^- live virus vaccine has a safety advantage over the TK^+ vaccines because it is less neurovirulent. However, the live virus vaccines, as a class, remain less safe than the nonliving vaccines because the efficacy of the live virus vaccine depends on replication of the vaccine virus in the host animal. Unfortunately, just as the virus's ability to grow in the host is correlated with its ability to cause disease, there also is a close correlation between the virus's ability to grow in the host and its ability to immunize. This means that the most efficacious vaccines are as a rule the least attenuated and the least safe. It is likely that rDNA methods will be able to identify virulence factors that can be deleted without damaging the ability of the virus to replicate in (and immunize) the host. Virus virulence, however, is usually not limited to a single gene, and in many cases, the ability of the virus to replicate is inextricably linked to its pathogenicity.

The live virus vaccines, conventional or genetically modified, carry an additional safety hazard beyond the hazard of the vaccine virus infection in the host. In comparison to the killed vaccines, the live virus vaccines are much more likely to carry contaminating pathogenic viruses or mycoplasmas.

Success with the recombinant vaccinia approach has been commonly reported. A good example of the efficacy of a live vaccinia recombinant vaccine is found in work with Rift Valley fever virus (RVFV). A recombinant vaccinia virus carrying the genes for the G1 and G2 glycoproteins conferred 90 to 100 percent protection to mice challenged with virulent virus after receiving a single dose of vaccine (Collett et al., 1987). In contrast, a RVFV subunit vaccine prepared from *E. coli*-produced G2 protein conferred only 56 to 70 percent protection.

Because the vaccinia virus is somewhat pathogenic for humans, the recombinant vaccinia approach is burdened with safety risks beyond that of conventional live virus vaccines. It is unclear whether regulatory clearance will be forthcoming for vaccinia recombinants, and that poses a significant barrier. If we choose to commercialize vaccines with no safety risk, we will choose not to commercialize recombinant vaccinia vaccines. In the developed nations, the safer, more expensive vaccines are affordable. In the less developed countries, there may be no choice but to use the less expensive and less safe modified live and rDNA live vaccines. The small percentage of failures of safety is outweighed by the benefits of affordable disease prevention. It is a difficult ethical problem. Certainly there will be individual casualties, but there also may be population benefits from commercializing inexpensive new vaccines in the developing nations. From an ethical standpoint, however, it would be unseemly to promote for the developing nations the use of the less safe (but less costly) products that, for safety reasons, we will not use ourselves. We can afford the safer vaccines. Many other nations cannot.

VACCINES AGAINST BACTERIAL DISEASES

Because the genomes of bacteria are much larger than the viral genomes, the rDNA technology has been more difficult to apply to bacterial diseases of food animals. The notable exception, however, is commercial development by rDNA techniques of vaccines containing *E. coli* pilus proteins (the proteins responsible for adherence of the *E. coli* bacteria to the intestinal wall) and enterotoxin (one of the proteins responsible for inducing diarrhea).

Bacterial vaccines that are in the research stage include those against pneumonia in cattle and pigs. But because the precise immunizing portions of the bacteria have not yet been identified, commercial introduction of vaccines against bacterial pneumonia is not imminent. This is unfortunate because the need for higher efficacy and higher safety in vaccines is most evident in the vaccines against Pasteurella pneumonia in all species. A respected poultry disease researcher who had been retired from poultry research for nearly 20 years recently returned to his old haunts and claimed that the quality of poultry Pasteurella vaccines had not changed since he left the field—and he wondered why, given all our fancy technology. The same problems of lack of efficacy are reported with the Pasteurella vaccines for cattle (Martin et al., 1980).

MONOCLONAL ANTIBODY PRODUCTS

There is only one monoclonal antibody (MAB) product currently being sold for the prevention of animal disease, the MAB against the K99 pilus of *E. coli* (Sherman et al., 1983). The disease caused by K99+ *E. coli* is colibacillosis, a severe and often fatal diarrheal disease in newborn calves. The MAB product is given in a single oral dose to calves at birth. The MAB prevents disease, presumably by blocking the pilus-dependent attachment of K99+ *E. coli* to the intestinal wall.

The MAB technology has just begun to have an impact on food animal production. Because the markets for veterinary biologicals (vaccines and antibody products) are small relative to the market for human biologicals, however, adoption of the MAB technology for food animal protection is likely to be slow.

MIDDLE TECH VERSUS HIGH TECH

It is clear that scientists and administrators in the public and private sectors have expected too much too soon from the rDNA technology. It is time to reassess the technology and the needs. The research goals must be linked to products to improve livestock performance and not linked to a particular technology. For example, we must first ask what is needed in an FMD vaccine before we decide that rDNA technology can improve the product. One of the great promises of the rDNA technology was lower cost vaccines. In the case of FMD, the cost of the vaccine has not been the major problem. The most pressing problems with FMD vaccines have been safety problems caused by allergic reactions and incomplete inactivation of the virus. Other technologies besides rDNA can be used to solve these safety problems.

An entire area of technology has not been adequately used by the veterinary biologics industry—the "middle tech" that became commonplace while the "high tech" rDNA technology was being developed. The U.S. Department of Agriculture, for example, is encouraging the veterinary biologics industry to develop in vitro assays to replace the current laboratory and host animal tests. Most of the needed assay procedures are in place, but they are in the hands of the rDNA technocrats and are *not* being used by the veterinary biologics industry. As an example, the common PAGE (polyacrylamide gel electrophoresis) assay for protein purity and quantity for the most part is not used by those in veterinary biologics, yet it could be readily adapted for assessing the potency and purity of the veterinary bacterial and viral products. The ELISA (enzyme-linked immunosorbent assay) is readily adaptable for use in in vitro potency assays and has been available for more than 10 years, but it is infrequently used by the veterinary biologics industry. Adopting in vitro assays would lead to considerable enhancement of the quality and, especially, the reproducibility of the products. The in vitro assays can and should replace the laboratory or host animal potency assays, and it is difficult to understand why the industry has been so slow to adopt such assays.

As another example of the benefits to be gained from middle tech, affinity chromatography technology has provided the tools to make vaccines of unprecedented purity. By using MAB immunoaffinity chromatography purification technology, Molecular Genetics, for example, is developing a vaccine for a herpesvirus that afflicts pigs. Beyond the obvious safety benefits of a highly pure product and the efficacy of being able to use an in vitro potency assay, the product has additional advantage of being compatible with a serologic test for pseudorabies. Because pseudorabies is a controlled disease, any animal that is serologically positive is subject to restrictions on sale or shipment. A diagnostic test that detects serologic response to a virus surface protein *not* included in the vaccine will detect infected pigs but will not detect pigs vaccinated with the affinity-purified protein vaccine. It is likely that a similar approach could be used to improve a number of veterinary vaccines. Especially attractive candidates for this purification technology are the controlled diseases of cattle (e.g., brucellosis, foot and mouth disease, and bluetongue) and those vaccines that have safety problems because of impurities. The affinity purification technology is not costly and can be run in very large scale.

PROSPECTS FOR TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES

A final comment is in order on the possibilities of transferring the emerging biotechnology to the less highly developed nations. Certainly there is considerable need in the developing nations for the products from the high tech and middle tech areas. The prospects for transferring either the technology or the fruits of the technology appear to be somewhat bleak, however. Numerous conventional vaccines, for example, are available against serious food animal diseases, such as pneumonia and diarrhea. These vaccines are commonly used in the developed nations but are rarely used elsewhere. Many of the developing nations do not possess either the distribution infrastructure or the economic base to use these vaccines. When scientists at Molecular Genetics proceeded to develop a RVFV vaccine, they presumed they were developing it not only for the protection of humans who might be working in the virus-endemic area of sub-Saharan Africa, but also for protection of sheep and cattle, which are severely afflicted by this disease (Collett et al., 1987). With a technologically based vaccine such as the one developed for Rift Valley fever, however, the company sees no clear entry into Africa. There is probably no country in Africa that has both the technologic base to accept such a product and a political climate that would permit transfer of the technology. If the transfer of technologically based products to developing countries is to occur, it will require the help of international agricultural organizations.

REFERENCES

Collett, M. S., K. Keegan, S. L. Hu, P. Sridhar, A. F. Purchio, W. H. Ennis, and J. M. Dalrymple. 1987. Pp. 321–329 in The Biology of Negative Strand Viruses, Mahy and Kolakofsky, eds. Mineola, N.Y.: Elsevier.

DeLorbe, W., W. P. Pilacinski, M. A. Lum, W. Cooney, R. F. Marshall, and D. E. Reed. 1987. Modern approaches to new vaccines: Prevention of AIDS and other viral, bacterial, and parasitic diseases. Pp. 431–434 in Vaccines 87, R. M. Chanock, R. A. Lerner, F. Brown, and H. Ginsberg, eds. Cold Spring Harbor, N.Y.: Cold Spring Harbor Laboratory.

Kit, S., M. Kit, and E. C. Pirtle. 1985. Attenuated properties of thymidine kinase-negative deletion mutant of pseudorabies virus. Am. J. Vet. Res. 46(6):1359–1367.

Martin, S. W., A. H. Meek, D. G. David, R. G. Thomson, J. A. Johnson, A. Lopez, L. Stephens, R. A. Curtis, J. F. Prescott, S. Rosendal, M. Savan, A. J. Zubaidy, and M. R. Bolton. 1980. Factors associated with mortality in feedlot cattle: The Bruce County beef cattle project. Can. J. Comp. Med. 44(January):1–10.

Sherman, D. M., S. D. Acres, P. L. Sadowski, J. A. Springer, B. Bray, T. J. G. Raybould, and C. C. Muscoplat. 1983. Protection of calves against fatal enteric colibacillosis by orally administered *Escherichia coli* K99-specific monoclonal antibody. Infection and Immunity 42(November):653–658.

Smith, S., and S. M. Halling. 1984. Expression of canine parvovirus-beta-galactosidase fusion proteins in *Escherichia coli*. Gene 29:263–269.

Emerging Agricultural Technologies: Economic and Policy Implications for Animal Production

Robert J. Kalter and Robert A. Milligan

A number of emerging agricultural technologies promise developments that, if realized, will increase productivity and reduce the per-unit production costs for animal and plant products. In the area of animal production, ongoing research in the areas of biotechnology, computers, information systems and processing, robotics, and controlled environments will provide numerous practical applications. With the management skills and practices necessary to integrate the application of these technologies, this research may accelerate the rate of agricultural productivity over the next 20 years beyond any level previously observed.

It is likely, however, that technological change will have differential economic impacts on the various facets of U.S. agriculture, with respect to both degree and timing. It is impossible to forecast with a high degree of accuracy the multitude of implications likely to arise, their magnitude, or their exact implications for public policy. At best, we can attempt to foresee trends and important policy concerns. This paper examines some of the possible implications of one major productivity-enhancing technology pertinent to animal production and reviews the resulting concerns for public policy. The analysis is aimed at providing insight into possible future trends that will be sparked by this and other technological innovations.

In the near future, enhanced protein deposition in animals, as a result of new chemical or biotechnology-created products, is most likely to lead to major productivity enhancements. Examples of protein synthesis regulation

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resulting from products being developed for commercialization are major increases in milk production from mature dairy cows and brood animals of other species; increased growth of mammary secretory tissue in dairy heifers; reduced ratios of fat to muscle in swine, beef cattle, and poultry; and improved feed efficiency in all animal species.

If such products are given regulatory approval for on-farm use, a number of major economic adjustments could result. Total nutrient requirements necessary to produce animal products for human consumption would decline. Improved fattening and milk-production efficiency might, for any given animal species, cause a reduction in the size of the national herd necessary to produce a given amount of animal product. Livestock feed requirements and the acreage of agricultural land necessary to produce that feed would decrease. Lower derived demand for animal feed could cause reduced prices for harvested crops, which would lower land values. Lower animal production costs would, in turn, result in lower consumer prices, and lower prices would lead to an increase in the quantity of animal products demanded (all else remaining constant). Regionally, productivity improvements could alter patterns of production and agricultural land use. Finally, by modifying the ratio of fat to muscle, the quality of product produced from meat animals could be improved and consumer acceptance could be increased. All of these potential adjustments have major implications for farm and food policy.

TECHNOLOGY COST VERSUS PRODUCTIVITY RESPONSE

It is well known that regulation of protein deposition in animals can be accomplished, at least in part, by administering supplemental dosages of certain hormones, particularly growth hormones and somatotropin-like products, or by feeding chemicals of the beta-adrenergic agonists family. The approach that most closely approximates natural processes in the animal, thereby reducing or eliminating unwanted side effects, is the use of hormones (either natural or synthetic reproductions). Unfortunately, the cost of using natural protein hormones extracted from animals at slaughter is economically prohibitive for commercial use. Only the advent of biotechnology has permitted consideration of synthetic protein hormonal products designed to control protein deposition.

By identifying the gene responsible for producing regulating hormones in the animal, modern biotechnology has created the possibility of isolating that genetic material, transferring it to ordinary bacteria cells, and reproducing those cells using standard fermentation techniques. The bacteria produce the hormone that is signaled by the transferred genetic material. The resulting substance can then be isolated, purified, and made available for commercial use.

Cost of Technology

In the long run, genetic alteration of the animal, using scientific techniques, may lead to increased natural production of the required hormones by the animal, thereby eliminating the need for synthetic production and external administration of the substances.

In the near term, the cost of producing synthetic hormonal proteins is of key interest in considering questions of commercial impact. Clearly, high production costs, and the resulting price to farm operators, would tend to restrict or even eliminate the adoption and use of such substances. Fortunately, the production technique is well known and easily evaluated by cost engineering analysis (Peters and Timmerhaus, 1980).

This type of evaluation was recently conducted for the product known as bovine somatotropin, or bovine growth hormone (bGH), which is widely expected to be used to increase milk production in dairy animals (Kalter et al., 1985). That study estimated plant capital and operating costs and subjected them to a comprehensive evaluation of economic and financial feasibility. Particular attention was paid to the size of the production facilities required and to whether costs for producing the product would vary with the size of the facility needed. The estimated cost of production was clearly related to plant size, indicating that substantial economies of size would exist. At dosages likely to be recommended for use in dairy animals, however, less than 100 pounds of pure hormone would be needed to inject 1 million animals per day. Facilities capable of this scale of output are likely to have production costs well under $4.00 per gram and probably under $2.00 per gram. With daily dosage rates at the milligram level, production costs are likely to be relatively low per value gained in efficiency. For dairy animals, this figure should be under $0.05 per animal per day. Although optimal dosages and delivery systems will vary across species, the selling price of hormonal-type products, even with marketing margins added, should permit their commercial introduction and contribute to rapid adoption at most foreseeable market prices for animal products. Adoption speed will be further enhanced by the fact that this technology requires little or no up-front capital investment by the farm operator; only a daily operating cost is involved. The principal retardant to adoption will be the improved management practices required to attain and sustain productivity increases.

Impact on Productivity and Feed Efficiency

Somatotropin acts by altering nutrient partitioning to direct more nutrients for milk synthesis in lactating cows or for muscle development in growing animals (Bauman and McCutcheon, 1986). The gain in efficiency in dairy cows occurs because of a dilution of maintenance costs. Cows treated with somatotropin have an increased nutrient requirement to support the increased milk yield. Because cows do not have excessive body fat, they obtain the extra nutrients by increasing voluntary intake. Thus, the gain in feed efficiency for dairy cows occurs because nutrients used for maintenance constitute a smaller portion of total nutrient consumption.

Growing animals treated with somatotropin have an increased rate of growth so that a portion of the increase in feed efficiency also occurs because of a dilution of maintenance. However, a major portion of the gain in feed efficiency occurs because more nutrients are used for lean tissue accretion (at a cost of 1 to 2 kcal net energy per unit of gain) and fewer are used for body fat accumulation (at a cost of 6 to 9 kcal per unit of gain). Because the protein requirement for lean tissue growth is greater than that for body fat accretion, however, the use of somatotropin will require an increase in the dietary protein requirement per unit of gain. Overall, one observes a remarkable increase in feed efficiency of growing animals treated with somatotropin as well as an increase in the carcass percentage of lean meat.

Although experimental work is still in progress, enough is known to make tentative judgments concerning the possible effects of protein deposition products on animal production (McCutcheon and Bauman, 1985). Research trials using bGH with lactating dairy cows have the longest history. Improvements in milk yield have reached 40 percent in the last two-thirds of lactation (Bauman et al., 1985) and, based on use of bGH during full lactation, could achieve 30 percent under optimal management conditions. Increases in feed efficiency, defined as total energy input per unit of milk output, have been somewhat variable (Baird et al., 1986; Bauman et al., 1985; Chalupa et al., 1986; Hutchison et al., 1986; Soderholm et al., 1986), at least partially because of the small numbers of cows in the experiments. Results, when adjusted for changes in body weight, indicate that the increases are explained by diluting the maintenance requirements over the larger production. When feed efficiency increases by diluting maintenance requirements, a 25 percent increase in milk production from a cow producing 6,500 kg of milk per year results in a corresponding increase in feed efficiency of 8.7 percent.

Since the output of growing and finishing beef, swine, and broilers is the animal itself, an improvement in feed efficiency is a direct response to use of growth hormones. Meltzer (1987) concludes that, based on early research in swine, improved feed-to-gain ratios of 10 to 20 percent are attainable. More recent research has achieved feed efficiency improvements of from 30 to 50 percent during the last 60 days of the fattening cycle (Boyd et al., 1986; Etherton, 1986). Gains of this magnitude did, however, require higher protein rations than have been considered optimal in commercial practice. Tests on beef cattle have been far fewer but early results have shown growth-efficiency gains of up to 21 percent (Fabry et al., 1985). Of equal interest for both swine and beef cattle is the fact that these efficiency gains were achieved in conjunction with major reductions in backfat (in swine those reductions have reached as high as 70 percent). Results for broilers have been the most disappointing to date with less than a 5 percent improvement in efficiency.

For all species, the results noted must be treated with caution. All experimental results to date are from carefully controlled tests that were usually conducted under ideal conditions. The efficiency gains reported will average far less when new products are used in production agriculture because on many farms the quality of management is already limiting animal production. If a farmer is currently feeding a diet that is inadequate in protein, for example, the use of somatotropin will not yield any performance response in lactating cows or growing pigs and cattle.

IMPLICATIONS FOR PRODUCTION COSTS

Supply of a commodity is conventionally increased (or decreased) in response to an increase (or decrease) in market price. Such changes result from movements along the supply curve. But economists also talk about "supply shifters," events that alter the supply curve. Perhaps the most common supply shifter is technological change. A supply shift due to technological change means that after adjustments to the new technology have occurred, the total supply of the product is greater at each price than prior to the commercial introduction of the technology. This results from increases in productivity and efficiency since, in equilibrium, returns will be the same before and after the technological change.

To measure the extent of a supply-curve shift, one must determine the magnitude of price decline at each quantity supplied. At the level of the individual farm firm, the question becomes: At what price level would returns be the same after the technological change as before it? This section examines the price decline for dairy cows, beef, and swine resulting from various levels of technological change and the provision of constant supply to the market. It is assumed that, as is true in equilibrium, price equals the cost of production when all costs, including operator inputs, are included. Poultry production is not considered because research results to date have indicated response rates that would not support commercial introduction of a protein synthesis product.

Dairy Cows

The inputs for milk production can be classified into three categories: (1) feed, (2) inputs directly related to the volume of milk per cow, and (3) inputs that are invariant to production per cow. Inputs in the third category include those that are directly related to the number of cows and those that are fixed for the given facilities. Production responses from products affecting protein deposition affect each item differently. The cost per unit of those inputs that are directly proportional to milk production does not change. The cost of inputs that are constant per cow declines proportionally to the increase in production. The impact of feed cost is twofold. First, required nutrients decline proportionally to increased feed efficiency. Second, the average price per unit of feed fed may change (increase) due to changes in rations.

In Table 1 the cost of production, and therefore the equilibrium price of milk, is given under various assumptions concerning production response as a result of hormones and feed-efficiency improvements. The cost of supplemental hormone dosages is, however, not included. Low, medium, and high scenarios for animal response are constructed. The equilibrium price of milk falls by 11 to 15 percent as a result of the new technology. However, reasonable expectations regarding hormone cost ($1.17 per hundred kg of milk) would decrease this drop to between 6 and 11 percent. Feed-cost savings, alone, are insufficient to cover the assumed cost of somatotropin. However, those reductions plus savings due to the spread of constant per-cow costs over the greater output account for the price drop.

Meat Animals

There are three potential effects of growth hormone on profitability of meat animal production. First, protein hormones have a positive impact on feed efficiency due to dilution of maintenance in dairy cows and shifts in nutrient partitioning in growing animals. Second, the rate of gain increases. This can result in either a larger marketable animal, a shorter production period, or both. Third, the quantity and perhaps the quality of salable meat will be enhanced. Quantity increases result from the reduction in the amount of fat that would normally be trimmed. Fat reductions may also result in enhancements to meat quality.

The three responses affect the equilibrium price differently. The increase in efficiency affects only the cost of feed. The reduction in production time affects the costs that are fixed. The cost per kilogram of meat will decline proportionally to the increase in rate of gain. The change in salable meat increases the sale value of the animal.

The price decline for beef and hogs is somewhat less than that for milk (Table 1) for three reasons. First, it is assumed that the hormone is used only during the fattening phase and that feeder prices remain unchanged. Thus, the cost-of-production data refer only to a portion of the animal's life cycle. Additional studies could result in hormone use starting at lower

TABLE 1 Equilibrium Price (Cost of Production) With and Without Hormone Usage for Dairy Cows, Beef, and Hogs

Commodity	Current[a] Price, Without Hormone	Low Range[b] Equilibrium Price, With Somatotropin ($/hundred kg)	Low Range[b] Percent Change	Medium Range[c] Equilibrium Price With Somatotropin ($/hundred kg)	Medium Range[c] Percent Change	High Range[d] Equilibrium Price With Somatotropin ($/hundred kg)	High Range[d] Percent Change
Milk	26.58	23.70	–10.8	23.13	–13.0	22.62	–14.9
Beef	144.57	137.29	–5.0	134.66	–6.9	132.10	–8.6
Hogs							
Protein 14%	110.92	102.73	–7.4	99.69	–10.1	96.76	–12.8
Protein 20%	—	104.6	–5.7	101.47	–8.5	98.42	–11.3

[a]Based on the U.S. average using 1985 data (U.S. Department of Agriculture, 1986).
[b]Assumes a 15 percent productivity improvement and an 8.7 percent feed-efficiency improvement for dairy cows, and a 15 percent feed-efficiency improvement and a 10 percent increase in the rate of gain for beef and hogs. Excludes actual cost of the hormone.
[c]Assumes a 20 percent productivity improvement and an 8.7 percent feed-efficiency improvement for dairy cows, and a 20 percent feed-efficiency improvement and a 15 percent increase in rate of gain for beef and hogs. Excludes actual cost of the hormone.
[d]Assumes a 25 percent productivity improvement and an 8.7 percent feed-efficiency improvement for dairy cows, and a 25 percent feed-efficiency improvement and a 20 percent increase in rate of gain for beef and hogs. Excludes actual cost of the hormone.

body weights. This is particularly critical for beef since the U.S. Department of Agriculture (1986) budgets assume feeders of almost 300 kilograms. Second, the increase in rate of gain is much smaller than the production per cow in dairy. (The gain in protein deposition is about the same as the response in lactating cows. Because fat accretion is lower, however, the overall increase in body weight gain is less that the lactational response.) Third, a change to a higher protein ration to optimize hormone performance (Boyd et al., 1986) will increase feed costs and reduce the economic benefits of the product. For hogs, a comparison of the last two rows in Table 1 documents the latter effect.

Regardless of these differences, the impact on production cost of this single product is substantial. It alone appears to be capable of improving feed efficiency to a level long enjoyed by poultry producers. Note again that the values listed in Table 1 for beef and hogs do not include the cost of the hormone. Such a cost is difficult to determine at this time since optimal dosage levels have not been determined. The cost of the hormone will, however, reduce the production cost decrease and, consequently, have implications for response in demand. It is also critical to remember that research to date indicates that the quantity of marketable meat increases when growth hormone is used. The meat could, therefore, command a higher price.

IMPLICATIONS FOR PRODUCT DEMAND

Lower prices as a result of a technology-induced shift in the supply function are but one aspect (albeit an important one) of the interplay of market forces caused by a disruption of equilibrium conditions. Another important response is the resulting impact on quantity demanded. In searching for a new market equilibrium, one would not normally expect consumption patterns to remain constant. Although the demand for animal products is price inelastic, studies have shown that it is not perfectly inelastic (for a given change in price). Thus, some increased demand will occur with an improvement in production efficiency and the resulting reduction in production cost (and, hence, market prices). The degree of price elasticity is, of course, an important question that bears directly on the economic implications of introducing products that enhance protein production of animals.

Conceptually the issue is not as simple as the magnitude of the product's "own" elasticity value (that is, the responsiveness of the quantity of a product consumed to changes in its price). The relationship between demands for various types of meat may also be of interest. If the price of pork drops, will the result be an increase in demand for pork and a compensatory reduction in the demand for beef and broilers? Technically this result is referred to as the cross-elasticity of demand for a product or the percentage change

TABLE 2 Own and Gross Elasticity Values for Major Commodities at Retail and Farm Levels

	Milk		Beef		Chicken		Pork	
Commodity	Retail	Farm	Retail	Farm	Retail	Farm	Retail	Farm
Milk								
George and King[a]	–0.346	–0.324	0.006	0.004	0.002	0.002	0.005	0.003
Heien[b]	–0.539	–0.505	0.024	0.016	–0.006	–0.005	0.016	0.009
Haidacher et al.[c]	—	—	—	—	—	—	—	—
Beef								
George and King	0.003	–0.003	0.644	–0.417	0.068	0.053	0.083	0.048
Heien	–0.012	–0.011	–0.956	–0.618	0.012	0.009	0.030	0.018
Haidacher et al.	—	—	–0.660	–0.427	0.040	0.031	0.120	0.070
Chicken								
George and King	0.005	0.005	0.197	0.127	–0.777	–0.602	0.121	0.071
Heien	–0.002	–0.002	0.350	0.226	–0.797	–0.618	0.299	0.174
Haidacher et al.	—	—	0.160	0.104	–0.580	–0.449	0.280	0.163
Pork								
George and King	0.005	0.005	0.076	0.049	0.035	0.027	–0.413	–0.413
Heien	–0.009	–0.008	0.364	0.236	0.095	0.074	–0.511	0.298
Haidacher et al.	—	—	0.160	0.104	0.100	0.078	–0.730	0.426

[a]George and King (1971).
[b]Heien (1982).
[c]Haidacher et al. (1982:Table 7, p. 16).

in the quantity of *X* taken, divided by the percentage change in the price of *Y*. Positive cross-elasticities imply that goods are substitutes for each other. Thus, a decrease in price will not lead to a commensurable increase in consumption; thus, decreasing total expenditures on the commodity. Commodities that are complements will exhibit negative cross-elasticity. The larger the cross-elasticity, the greater the degree of substitutability or complementarity.

It is necessary to recognize, however, that elasticity values measured at the point of retail sales are not the same as those applicable at the farm level. Since marketing margins will not normally change as a result of a technological change at the farm level, the percentage change in consumer prices will be less than the measured change in production costs. As a result, farm-level elasticities will usually be lower than their counterparts at the retail level.

In Table 2 values are given for the own and cross-elasticities of milk, beef, chicken, and pork, at both the retail and farm levels, as calculated by three econometric studies over a span of more than a decade. As expected, the own values are all inelastic (less than one) and the cross-elasticity values indicate that the products in question are substitutes for each other. Thus, a decrease in price will not lead to a commensurate increase in consumption; thus, decreasing total expenditures on the commodity. The degree of substitutability is relatively small in most cases; the relationship between chicken and red meat exhibits the largest values. Note, moreover, that the fact that animal products are substitutes implies that consumption gains by one will take place partially at the expense of other products.

Mathematically, knowledge of the demand and supply elasticity values would enable an approximation of the new equilibrium level for price and quantity consumed after the effects of a technological change had worked their way through the economy. Unfortunately, an additional element would appear to complicate this estimation in the case of protein deposition products. Up to this point, the discussion has focused on a movement along the demand curve in response to lower prices. Like shifts in supply curves due to technological change, however, shifts in demand functions can also occur as a result of, among other things, changes in product quality. In the case of meat products, hormone supplements have been demonstrated to cause dramatic changes in carcass quality by reducing fat content (Bauman and McCutcheon, 1986; Boyd et al., 1986). In some experimental trials, backfat in hogs has been reduced by 70 percent. Similar effects are expected for beef animals. The degree to which this affects actual cuts of meat is still uncertain. Positive shifts in consumer demand are possible if quality improvements are perceived.

On the basis of the estimates of lower production costs, the applicable supply and demand elasticities, and the fact that animal products are substitutes for one another, only small increases in quantity consumed for any given animal product could be expected as a result of the adoption of protein synthesis products. The implications of changes in product quality and the subsequent shift in demand functions, however, are unknown. Forecasts based on past experience are unlikely to yield much insight into this issue since it reflects a structural change not represented by previous market conditions. Only actual experience will determine whether demand for animal products will shift sufficiently against other food products to expand markets. Judgment would argue against major changes since development of quality improvements in competitive products cannot be expected to stand still. In a dynamic, competitive world, comparative advantages are usually small and temporary.

TECHNOLOGICAL CHANGE AT A TIME OF EXCESS RESOURCE CAPACITY

Despite a long-term decline in farm numbers, farm operators, marginal land use, and more recently, land values, U.S. commercial agriculture continues to experience excess capacity, overcapitalization, and an overabundance of committed resources (as evidenced by its inability to achieve rates of return comparable to those of other sectors of the economy). Additional new technology will only add to this continuing problem. The previous evaluation appears to give little comfort to those concerned about excess capacity and low returns on investment. If feed-efficiency improvements of 30 percent in hogs and beef are attainable, any increase in consumer demand would be swamped by short-run shifts in supply. The relevant policy issue seems to center on the gulf between society's desire to achieve the broad social benefits offered by adoption of new cost-reducing technologies and the equity implications for those in agriculture who, as a result of their immobile resource endowments, will be materially harmed by the adoption of technology.

Design of appropriate public policies in this environment, however, requires a better understanding of the forces affecting change and their possible effects on existing resource commitments. Land use is a key factor in this equation. Improvements in animal productivity could have an immediate impact on the demand for land, land values, and the central policy question posed here.

Feed Utilization

An estimate of total 1984 feed requirements, by source, is presented in Table 3 for each of the major animal species. Feed requirements are then forecasted in Table 4 on the basis of the improved feed efficiencies discussed previously and an assumed continuation of current demand levels (and, thus, lower herd numbers) for animal-derived products. The resulting values are based on commercial availability of hormonal products for all species and their full (100 percent) adoption by commercial farm operators. The forecasted changes in feed consumption should be interpreted with caution, however, because none of the hormonal supplements have been approved for commercial introduction and numerous technical parameters relevant to their use must still be determined. For example, the optimal time period over which animals would be provided supplemental dosages of protein synthesis products is not known with certainty. Thus, the average improvement in feed-to-gain ratios is difficult to determine with any degree of precision. For purposes of this analysis, it was assumed that hormone administration would take place over the entire lactation period for dairy animals (Bauman and McCutcheon, 1986), over the fattening period for cattle (cattle on feed) and poultry, and over the last 60 days of the life cycle for fattening hogs (Boyd et al., 1986; Etherton, 1986). It was further assumed that 30 percent of the feed concentrates consumed by swine raised for pork are fed prior to the last 60 days of the fattening cycle and that the

TABLE 3 Feed Consumption by Major Types of Livestock and Source (million metric tons)

Livestock	Feed Grains: Corn	Feed Grains: Other[a]	Food Grains[b]	High-Protein Feed: Soybean Meal	High-Protein Feed: Other[c]	Other Feed[d]	Harvested Roughages: Hay	Harvested Roughages: Other[e]
Dairy animals	20.5	5.3	1.3	1.7	0.6	3.8	39.5	36.4
Cattle on feed	18.8	9.7	3.1	0.8	1.1	0.9	22.4	8.5
Broilers	11.4	0.6	0.9	4.0	1.3	2.0	—	—
Hogs	38.2	2.7	1.4	4.6	1.1	2.0	—	—
Total	88.9	18.3	6.7	11.1	4.1	8.7	61.9	44.9

NOTE: Reflects consumption from October 1, 1984, to September 30, 1985.

[a]Sorghum, oats, and barley.
[b]Wheat and rye.
[c]Animal and grain proteins and non-soybean oil meals.
[d]Drymilling by-products, fats and oils, alfalfa meal, molasses, screenings, salt, minerals, and urea.
[e]Silage, beet pulp, and straw.

SOURCE: U.S. Department of Agriculture (1985).

protein content of feed would increase to 20 percent (from the currently recommended 14 percent) during hormone administration.

Requirements across the four species for feed and food grains, harvested roughages, and other feed decrease dramatically. For the mid-range scenario this reduction ranges from 10 to 21 percent. However, the requirement for higher protein feeds, like soybean oil meal, increases the need for these crops by 24 to 45 percent. The values are not substantially different for the low- or high-range scenarios. The two species causing the largest impact are cattle and hogs.

The 21 percent drop in corn requirements and the 45 percent increase in need for soybeans (mid-range scenario) stems directly from the assumption that hog rations will require enhanced protein content to achieve optimal feed-to-gain ratios with hormone supplements. Note that rations for beef cattle remain unchanged since animal science research has not yet considered this issue. The results contrast sharply with those obtained for unchanged hog rations; an assumption used by the authors in a previous paper (Kalter and Milligan, 1986). When hogs are left on a 14 percent protein ration, required feed from all sources falls from 10 to 16 percent for the

TABLE 4 Forecasted Feed Consumption Resulting From Protein Synthesis Regulation (million metric tons)

	Feed Grains		Food	High-Protein Feed		Other	Harvested Roughages	
				Soybean				
Livestock	Corn	Other	Grains	Meal	Other	Feed	Hay	Other
Low range								
Dairy animals	18.72	4.84	1.19	1.55	0.55	3.47	36.06	33.23
Cattle on feed	15.98	8.25	2.64	0.68	0.94	0.77	19.04	7.23
Broilers	10.89	0.57	0.86	3.82	1.24	1.91	—	—
Hogs	26.88	1.90	1.25	10.43	2.50	1.79	—	—
Total	72.47	15.56	5.94	16.48	5.23	7.94	55.10	40.46
Percent change	–19	–15	–11	+49	+28	–9	–11	–10
Medium range								
Dairy animals	18.72	4.84	1.19	1.55	0.55	3.47	36.06	33.23
Cattle on feed	15.04	7.76	2.48	0.64	0.88	0.72	17.92	6.80
Broilers	10.89	0.57	0.86	3.82	1.24	1.91	—	—
Hogs	25.83	1.83	1.20	10.03	2.40	1.72	—	—
Total	70.48	15.00	5.73	16.04	5.07	7.82	53.98	40.03
Percent change	–21	–18	–15	+45	+24	–10	–13	–11
High range								
Dairy animals	18.72	4.84	1.19	1.55	0.55	3.47	36.06	33.23
Cattle on feed	14.10	7.28	2.33	0.60	0.83	0.68	16.80	6.31
Broilers	10.89	0.57	0.86	3.82	1.24	1.91	—	—
Hogs	24.79	1.75	1.16	9.62	2.30	1.65	—	—
Total	68.50	14.44	5.54	15.59	4.92	7.71	52.86	39.54
Percent change	–23	–21	–17	+41	+20	–11	–15	–12

NOTE: Based on feed-efficiency improvements of 8.7 percent for dairy animals; 15, 20, and 25 percent, respectively, for cattle on feed, hogs, and beef; and 5 percent for poultry (broilers only) from October 1, 1984, to September 30, 1985. Assumes hogs are fed a 20 percent protein ration for last 60 days of fattening and that 70 percent of total feed consumption occurs while on hormones.

mid-range scenario. Research appears to indicate, however, that improvements in feed-to-gain ratios will be less without the higher protein ration. Thus, the implications for cropland usage heavily depend on a combination of the required management practices and technical parameters involved, and the economic circumstances at the time of use. If more salable meat is available per animal, fewer total animals, and therefore less feed, will be required. This would further reduce feed-grain acreage below that discussed here.

Changing feed requirements will cause a web of modifications in key market values. Without a general equilibrium model of the agricultural sector neither the magnitude nor, in some cases, direction of the changes can be clearly forecast. Even with such a model, the level of forecast uncertainty would be extremely high because of the associated structural changes that will take place. In some cases, required feed reductions can only lead to lower prices for key crops, reduced land values, and reduced acreage committed to the raising of such crops. In other instances (e.g., soybeans), the reverse may be true.

In light of this uncertainty, changing acreage needs for key crops as a result of increased efficiency in dairy, beef, and swine production are only guesses (Table 5). The calculations are averages based on 1983 yields, except for corn and soybeans (see note, Table 5). The total acreage reduction is small (5 million to 10 million acres) compared with the total land area devoted to farming (1.02 billion acres) in the United States. The impact is more significant on individual crops; substantial reductions in corn, feed-grain, and hay acreage and a major increase in soybean acreage are possible as a result of the changing animal-feed requirements.

Each of the values in Table 5 is based on the assumption that a modification in the protein content of feed rations for swine will be required with the introduction of protein synthesis products. Should this prove not to be the case, a very different result would be obtained. For the mid-range response scenario, overall acreage requirements would be reduced by 14.5 (as opposed to 7.4) million acres. Requirements for all crops decrease, but that for corn would be only 4.5 million acres, and soybean acreage would fall by 2.1 million compared with an increase of 8 million assuming high-protein feed. For both assumptions these values may be conservative, since one would expect the least productive land to exit first in any production cutback or more intensive cultivation of existing acreage in any expansion.

PUBLIC POLICY IMPLICATIONS

The potential impacts of protein deposition products discussed in the preceding section provide only a glimpse of the possible ramifications that may stem from the commercial introduction of these products. Improved

TABLE 5 Estimated Acreage Changes (in million acres) Resulting From Changing Animal-Feed Requirements

Scenario	Feed Grains: Corn	Feed Grains: Other[a]	Food Grains[b]	Soybeans	Roughage: Hay	Roughage: Other[c]	Total
Low range	–6.4	–2.6	–0.7	+8.7	–3.2	–0.4	–4.6
Mid range	–7.2	–3.2	–0.9	+8.0	–3.7	–0.4	–7.4
High range	–8.0	–3.7	–1.1	+7.2	–4.2	–0.5	–10.3

NOTE: Corn grain yields in 1983 averaged only 81 bushels per acre, but they were 113 and 108 bushels per acre, respectively, in the two previous years. Thus, an average of 101 bushels per acre was used in the analysis. Similarly for soybeans, yields were 30.1, 31.5, and 25.3 bushels per acre in 1981, 1982, and 1983, respectively, for an average of 29 bushels per acre.

[a]Sorghum, oats, and barley.
[b]Wheat and rye.
[c]Silage, beet pulp, and straw.

productivity in agriculture has always been associated with price, acreage, consumption, and product-quality effects. The magnitude and speed with which these impacts could occur has, however, no historical antecedent. More important, the indirect implications of these new management tools may carry farm-level and aggregate consequences that are more far-reaching than any of the concerns discussed here. Concerns as diverse as marketing relationships, structural trends in farming, pressure on public policy instruments, financing mechanisms for agriculture and food processing, and rural community development could be heavily influenced by dramatic breakthroughs in products that enhance productive efficiency.

As a result, the next 15 years will be exciting but perilous times for agricultural policy. Developing new technologies will continue to improve farming productivity and efficiency, often at spectacular rates from the biological perspective. But these changes will not come uniformly, in either time or degree, across the various agricultural components and farms. This variability, along with the links between sectors, will create substantial uncertainty for policymakers. Incomplete research on technical factors (e.g., requirements for optimal management practices) that accompany technology adoption will make forecasting even more difficult.

In general, the resulting economic impacts will be less than the causal biological changes. Regulatory approval often will be the determining factor in the timing of new product introductions. Management will be a key element in determining the rate of adoption and ultimate performance obtained. At low response rates, many of the technologies will, in fact, be uneconomic for commercial agriculture. Meltzer (1987) suggests, for example, that the response to porcine hormone must be at least a 5 percent feed-efficiency improvement, at current product prices, to obtain adoption. But many technological innovations are synergetic. Thus, the total impact of new technology introductions may be greater than the sum of the parts.

At the farm-firm level, the successful adoption of the new technologies will be directly correlated to the management capabilities of the farm managers. This will mean that the already large differences in productivity and profitability between top managers and below-average managers will increase. The new technologies, therefore, will place increased economic pressure on businesses with below-average management even if economic conditions facing the industry are unchanged. Since a higher proportion of smaller farms are poorly managed, the new technologies will increase the concern from and about the small farm.

The uncertainties associated with these technologies, other uncertainties, and the continuing overcapacity problems facing agriculture will result in periods of low profitability and asset restructuring, such as is currently occurring. In an uncertain market, decision makers need the capability to adjust rapidly as new information is obtained. But the market for public policy does not respond rapidly to changing circumstances; nor does existing public policy necessarily provide the proper incentives for the private sector to take advantage of changing economic or technical events. The speed and flexibility associated with decentralized, private decision making may be the strongest argument for public deregulation of agriculture. In essence, the best policy may be no policy.

Continuation of price support programs only provides incentives to defeat other options designed to remove excess capacity from farming (such as land conservation efforts or mandatory acreage reduction requirements). Not only are many of these programs voluntary, but they become ineffective as farmers idle their poorest land and crop their remaining acreage more intensively.

In the short run, such a policy would accelerate the restructuring of assets in the food industry. Major equity losses could be expected since in these situations market prices cannot support debt service that seemed entirely reasonable before the uncertainties intervened. To ease this transition, a one-time buy-down of lender and owner assets may now be called for as a far less expensive long-run solution to our overcapacity problems. Without a debt forgiveness program, two unacceptable alternatives are available: enact price or income support programs to enable debt service or let the market work and force excessive numbers of producers (including top producers) into default. Without intervention, the latter policy results in top producers losing their farms; lenders also lose when the sale of the assets does not cover the indebtedness. On the other hand, a debt forgiveness policy would encounter major implementation problems related to determining who qnalifies for a write-down and at what level.

If a viable debt reduction policy could be developed for use during periods of unusual and unexpected economic stress, protection could be provided to leading farm managers. The added flexibility would give agriculture the capability to adjust to the future so that society can reap maximum benefit from cost-reducing, quality-enhancing changes to production methods.

It is also important to remember that farm operators will continue to be displaced from agriculture. For too long we have used agricultural policy in an attempt to prevent this displacement and then virtually ignored those who have been displaced anyway. It is time to treat agricultural problems with agricultural policy and social problems with social policy.

Perhaps with the number of farm operators at a historic low, an approach that would allow society to deal with social problems directly rather than through costly income-maintenance programs is possible. For the long term, unemployment insurance for farmers, retraining programs for those desiring to leave the industry, and expanded public support for management and technical training of farm operators wishing to stay on the land may be the options on which public policy should focus.

REFERENCES

Baird, L. S., R. W. Hemken, R. J. Harmon, and R. G. Eggert. 1986. Response of lactating dairy cows to recombinant bovine growth hormone (rbGH). J. Dairy Sci. 69(Suppl. 1):118.

Bauman, D. E., and S. N. McCutcheon. 1986. The effects of growth hormone and prolactin on metabolism. Pp. 436–455 in Proceedings, VI International Symposium on Ruminant Physiology: Control of Digestion and Metabolism in Ruminants, L. P. Milligan, W. L. Grovum, and A. Dobson, eds. Englewood Cliffs, N.J.: Prentice-Hall.

Bauman, D. E., P. J. Eppard, M. J. De Geeter, and G. M. Lanza. 1985. Responses of high producing dairy cows to long term treatment with pituitary- and recombinant-somatotropin. J. Dairy Sci. 68:1352.

Boyd, R. D., D. E. Bauman, D. H. Beermann, A. F. Neergaard, L. Souza, and W. R. Butler. 1986. Titration of the porcine growth hormone dose which maximizes growth performance and lean deposition in swine. Paper presented at the Annual Meeting of the American Society of Animal Science, Kansas State University, July 29–August 1.

Chalupa, W., B. Vecchiarelli, P. Schneider, and R. G. Eggert. 1986. Long-term responses of lactating cows to daily injections of recombinant somatotropin. J. Dairy Sci. 69(Suppl. 1):151.

Etherton, T. D., C. M. Evock, C. S. Chung, P. E. Walton, M. N. Sillence, K. A. Magri, and R. E. Ivy. 1986. Stimulation of pig growth performance by long-term treatment with pituitary porcine growth hormone (pGH) and a recombinant pGH. J. Anim. Sci. 63(Suppl. 1):219.

Fabry, J., L. Ruelle, V. Claes, and E. Ettaib. 1985. Efficacity of exogenous bovine growth hormone for increased weight gains, feed efficiency, and carcass quality in beef heifers. J. Anim. Sci. 61(Suppl. 1):261–262.

George, P. S., and G. A. King. 1971. Consumer Demand for Food Commodities in the United States with Projections for 1980. Monograph No. 26. California Agricultural Experiment Station, University of California Division of Agricultural Sciences, Berkeley: Giannini Foundation of Agricultural Economics.

Haidacher, R. C., J. A. Craven, K. S. Huang, D. M. Smallwood, and J. R. Blaylock. 1982. Consumer demand for red meats, poultry, and fish. Economic Research Service, GES 820818. Washington, D.C.: U.S. Department of Agriculture.

Heien, D. 1982. The structure of food demand: Interrelatedness and duality. Am. J. Ag. Econ. 64(2):213–221.

Hutchison, C. F., J. E. Tomlinson, and W. H. McGee. 1986. The effects of exogenous recombinant or pituitary extracted bovine growth hormone on performance of dairy cows. J. Dairy Sci. 69(Suppl. 1):152.

Kalter, R. J., and R. A. Milligan. 1986. Protein synthesis regulation in animals: Major economic implications. Paper presented at Symposium on Food and Animal Research, Lexington, Kentucky, November 2–4, 1986.

Kalter, R. J., R. A. Milligan, W. H. Lesser, W. B. Magrath, L. W. Tauer, D. E. Bauman, A. McGuirk, E. Andrysick, and M. Grosh. 1985. Biotechnology and the dairy industry: Production costs, commercial potential, and the economic impact of the bovine growth hormone. Agricultural Economics Research 85–20. Department of Agricultural Economics, Cornell University Agricultural Experiment Station, New York State College of Agriculture and Life Sciences. Ithaca, N.Y.: Cornell University.

McCutcheon, S. N., and D. E. Bauman. 1985. Application of hormones produced by recombinant DNA technology to increasing animal productivity. Pp. 130–140 in Reviews of Rural Science and Biotechnology and Recombinant DNA Technology in the Animal Production Industries, R. A. Long, J. S. F. Barker, D. B. Adams, and K. J. Hutchinson, eds. Sydney: University of New England.

Meltzer, M. I. 1987. Repartitioning agents in livestock: Economic impact of porcine growth hormone. Master's thesis, Cornell University, Ithaca, New York.

Peters, M., and K. Timmerhaus. 1980. Plant design and economics for chemical engineers. New York: McGraw-Hill.

Soderholm, C. G., D. E. Otterby, F. R. Ehle, J. G. Linn, W. P. Hansen, and R. J. Annexstad. 1986. Effects of different doses of recombinant bovine somatotropin (rbSTH) on milk production, body composition, and conditions score in lactating cows. J. Dairy Sci. 69(Suppl. 1):152.

U.S. Department of Agriculture. 1985. Feed Outlook Yearbook. Agricultural Economics Report 298. Washington, D.C.

U.S. Department of Agriculture. 1986. Economic Indicators of the Farm Sector, Costs of Production, 1985. Economic Research Service, Report ECIFS 5–1. Washington, D.C.

Innovation in Agriculture

Howard A. Schneiderman

In providing an overview of current and future innovation in agriculture, this paper advances the view that agriculture has made the transition from a resource-based to a science-based industry, that continued innovation in good times and bad is crucial to enhance the productive efficiency and environmental acceptability of agriculture, and that biotechnology and genetic engineering are keys to agricultural innovation.

The focus of the paper is on U.S. agriculture, but the application of the innovations described will surely be global. Moreover, the innovative technologies are far less capital intensive and more environmentally friendly than most other technologies that enhance the efficiency of production and should be readily applicable by developing nations.

A key aim of U.S. agricultural research is to make U.S. farming a more profitable, reliable, and durable business, one that is able to compete in both domestic and world markets. Unless that happens, the U.S. farmer and the industries and institutions that serve U.S. agriculture—the U.S. Department of Agriculture (USDA), the land-grant universities, the Monsantos, the Pioneer Hi-Breds, and the Mycogens—will not have markets for their goods and services.

Only some of the problems facing U.S. agriculture will be solved by technological innovations like biotechnology or computers. Nonetheless, technological innovations are crucial to enable the U.S. farmer to compete in the world's agricultural marketplace for both U.S. and worldwide markets, and they are crucial to enable the nation to realize the economic potential of plants and livestock as annually renewable sources of wealth. The efficient and profitable production of agricultural goods must remain a durable, core industry in the United States.

Although technological innovations are crucial to enhance the efficiency of U.S. agricultural production, they will not revitalize agriculture unless farm business management, farm policy, the USDA, land-grant universities, extension services, and the many private sector businesses that serve agriculture are also innovative. We need innovative new partnerships among research universities, industry, and government to ensure the rapid application of new science to agriculture. We need innovative teaching of twenty-first century precision agriculture by both the research universities and the extension services. We especially need an innovative farm policy to enable U.S. agriculture to adjust to the changes caused by national and international economic forces. And we need innovative institutions to help protect the income of farm people from the costs resulting from the integration of U.S. agriculture into world markets.

MAJOR RESEARCH THRUSTS

Three of the key needs driving agricultural research today are

- Increased efficiency of production,
- Environmentally friendly crop chemicals, and
- Enhanced crop quality.

This section outlines the scope of these research thrusts and identifies areas of research in which U.S. companies are making major research investments for the future.

Increased Efficiency of Production

To compete in world markets with developing countries that have cheap labor and cheap land, and with developed countries that have sophisticated technology, U.S. farmers will have to reduce the real costs of producing their crops. Our emphasis for several decades was on quantity of production—yield—and much less thought was given to efficiency of production. Today, we need technologies focused on efficiency, on reducing the cost per unit of output produced, in contrast to the maximum-production strategies of the 1960s and 1970s.

Since the early 1900s, U.S. farmers have relied on ever bigger machines and more chemicals to enlarge their crops—and income. But the new trend is toward "*precision agriculture*." More and more successful farmers will aggressively adopt new technologies to reduce the real costs of production. The economic incentive to lower input costs will also lower the use of chemicals in agriculture as well as the amount of tillage.

We will see technologies to reduce the need for fertilizers, which constitute one of the highest input costs. Slow- and controlled-release fertilizers will be developed for major crops. We may also see the application of genetically engineered root-colonizing and soil microbes as substitutes for fertilizer.

We will see a variety of technologies to reduce field operations. Reduced-till and no-till farming will increase with the development of more efficient herbicides, fungicides, and insecticides and more efficient formulations and delivery systems for crop chemicals and seeds. We will also see improved water management practices and innovative approaches to controlling erosion.

Biotechnology

Biotechnology promises to have an enormous impact on crop production. Plant breeding has already provided plants with resistance to major diseases and some insect pests, and with enhanced yields. But genetic engineers can rapidly accelerate plant breeding and offer new ways to protect crops and enhance yields, to make crops hardier and less dependent on the input of chemicals, fertilizer, and the energy needed for tilling. Genetic engineers provide new tools with which the plant breeder can significantly enhance the efficiency of crop production and make farming more reliable and more profitable. Plant breeders remain the key agents of change but their genetic-engineering partners increase their effectiveness.

Since 1983, when scientists originally developed the capability of plant transformation for petunia and tobacco, over a dozen vegetable and commercial crop plants have been transformed in various laboratories. By 1990, genetic engineers will have conferred commercially desirable properties, such as resistance to pests, pathogens, stress, and herbicides, on many major crops, including soybeans, rice, corn, wheat, canola, sorghum, cotton, and alfalfa. They have already genetically engineered plants to resist insects, viruses, and Roundup® herbicide (glyphosate).

The potential advantages to the farmer are manifold. For example, when researchers have genetically engineered cotton to resist both caterpillars (e.g., the pink bollworm) and beetles (e.g., the bollweevil), it will dramatically affect the growing of cotton. No longer will cotton farmers have to spray their fields six or more times each growing season with a conventional insecticide. The input cost savings should be large, and the opportunity to reduce the load of conventional insecticides in the environment is significant.

The greatest potential of biotechnology for short-term productivity gains that will affect the U.S. farmer's bottom line are herbicide- resistant crops. Seed companies have been breeding crops for herbicide resistance for several decades. Genetic engineering permits the rapid acceleration of such breeding programs. Within a decade, crops resistant to more effective, less expensive, and more environmentally friendly herbicides will be widely used by farmers.

Researchers, as noted earlier, have already genetically engineered several crops to have resistance to Roundup® herbicide (glyphosate), which is an effective, broad-spectrum, environmentally friendly herbicide. There are numerous instances in which glyphosate-resistant crops will result in substantially lower weed control costs. In the future we will likely see vastly increased development and use of environmentally friendly, broad-spectrum herbicides with little built-in crop selectivity. Crop selectivity will be achieved by genetically engineering resistance into crops.

The process of genetically transforming plants has become much more rapid, and many major crop varieties can now be effectively transformed for herbicide resistance. These herbicide-resistant crops will provide farmers not only increases in efficiency of production but also important opportunities for new crops and new rotations where weed-control problems had previously prevented crop changes.

In addition to pest and herbicide resistance, biotechnology within 10 years holds the attractive prospect of developing crops that are more tolerant of heat, frost, and other stresses. Crops with these performance features will certainly increase the reliability and efficiency of crop production. They will also extend the geographical range of crops and provide farmers with wider crop choices. We may not see orange groves in Iowa, but some of the changes could be quite dramatic.

Another attractive prospect of genetic engineering is to help halt the decline in the genetic diversity of crops, which makes most modern agriculture vulnerable to attack by rapidly evolving plant disease and pest organisms. While traditional breeding often narrows the genetic variability of a crop species, genetic engineering has the potential to bring much greater diversity to crops. Virtually any desirable trait—whether found in a bacterium, a weed, or even an animal—can now be used to improve plants. During the next two decades, genetic engineering will provide the plant breeder with a precise and powerful tool to create new germplasm, to introduce important new diversity into key crops quickly, and ultimately, to introduce new crops.

Biotechnology can be the instrument of another green revolution. It has the potential to bring about major, previously unachievable advances in crop productivity and quality. It also promises to increase genetic diversity and make crops hardier—less subject to pests, disease, stress, and bad weather.

Information Technology

Farmers need to adopt information tools to enhance productive efficiency and to be economically successful. Computer systems will become increasingly user-friendly. Information technology will become widespread in the office and in the field as farmers integrate computers into their overall operations. Agriculture will become high precision in field management, marketing, and financial management. Initially, crop consultants will play a large role, but more and more farmers and businessmen will come to use artificial intelligence systems that mimic the logic of experts to obtain expert advice and to hone their management skills.

Environmentally Friendly Products

Environmentally friendly products will be a key force, especially when they can make a producer more efficient. We will see increased development and use of environmentally friendly crop chemicals and related products. Breakthroughs in weed control, like glyphosate, and herbicides, like the sulfonylureas and imidazolinones—applied in grams per acre instead of pounds per acre—will come into increased use. These products are safe for humans and wildlife because fish, insects, and mammals (including humans) lack the biochemical pathways upon which these herbicides work. Increased development of new, fast-acting, postemergence herbicides that are broken down rapidly in the soil can also be expected.

New formulation systems will also be introduced that direct a crop chemical to its target, require smaller amounts of chemical, and protect nontarget organisms. More and more delivery systems will take the form of closed containers that eliminate all mixing operations that expose humans to crop protection chemicals. The applicator or farm worker will not have any direct contact with the product.

The ultimate in environmental friendliness will be crops that have been genetically engineered with natural defenses against pests and diseases and new generations of microbial crop protection products and enhancers of production efficiency. Scientists at Monsanto, for example, have been able to transfer a gene for a naturally occurring insecticide, called *Bacillus thuringiensis* protein, or Bt, from one soil microbe into another microbe that lives in natural association with the roots of plants. The objective of the research is to provide a natural protection for the roots against certain insects that feed on them. A strategy such as this has tremendous potential—and minimal environmental impact. Unhappily, Monsanto was not given clearance to field test its new microbial crop protection system, although these genetically engineered microbes, like the genetically engineered crops, pose no unprecedented or unique environmental concerns.

These uses of biotechnology in agriculture can also play a vital role in restoring the durable productivity, the tilth, of our soils and in enhancing the quality of our groundwater.

Drive for Crop Quality

Another major focus of the modern precision farmer will be a drive for crop quality. To stay ahead of mass production in less developed countries, U.S. and European farmers will seek to differentiate their products through superior quality. Examples will include

- Crops with higher protein content;
- Oil crops that produce better quality, less saturated edible oils (i.e., specialty oils) in higher yields;
- Wheat crops with better milling and baking qualities and barley crops with better brewing qualities; and
- Feed crops with higher nutritional values and better digestive qualities.

Biotechnology—the genetic engineering of crops—can accelerate the development of value-added varieties and the drive for quality. Changes in consumer demands will also accelerate the drive for quality. These several demands for quality create important market opportunities.

Strong arguments can also be made for increased crop diversity. We need a prudent number of new crops to fuel U.S. agriculture and forestry. Some efforts have been begun, for example, with kenaf, an annual hibiscus and a cousin to cotton, which is a source of fiber for making paper and paperboard. In the South particularly, the crop appears to be competitive with standard commercial crops and is capable of producing greater quantities of fiber per hectare than pulp wood and at about half the cost. Kenaf can yield from 25 to 45 metric tons dry weight of stems per hectare annually. In the October 24, 1986, issue of the *Austin American-Statesman*, the front page featured an article about kenaf and a comment from a research director of a large farm complex that "a farmer that knows how to grow cotton knows how to grow kenaf." Another attractive new crop candidate for U.S. farmers is oil seed rape, or canola, which is already widely grown in Canada and elsewhere.

Other crop possibilities also exist, but in each case, a market has to be created for the product. It is a "chicken-or-egg" problem that requires partnership between the public and private sectors and innovative planning. Thought should be given to diverting some of the resources that are now used to support research on commodity crops to the development of new farm and forest products. It is difficult to encourage crop shifting unless there are a reasonable number of new crops to shift to.

The ability to genetically engineer plants promises to enlarge the mission of agriculture in other ways. Today, agriculture focuses principally on food and fiber. But if we can genetically engineer plants to produce animal proteins, other prospects emerge. What if we were able to genetically engineer plants to produce human insulin or human blood factors for hemophiliacs or a vaccine for hepatitis or other diseases? This now appears to be possible. Perhaps some of the high-value-added crops of the 1990s will be plants that produce drugs to counteract human diseases or other animal proteins. Perhaps we will be harvesting human insulin and other human drugs from the "north forty."

Increased Efficiency of Livestock Production

It has been known for years that bovine somatotropin, a natural protein produced by the cow's pituitary gland, stimulates milk production, but the traditional source for the substance, pituitaries from cow carcasses, was not a practical means of obtaining a commercial product. Genetic engineering, however, has enabled us to transfer the cow gene for the protein into a bacterium that can produce bovine somatotropin in large enough quantities for testing and commercialization. Extensive tests on dairy cows have already shown that bovine somatotropin improves productive efficiency and reduces the input costs of the dairy farmer. A dairy farmer with, say, 70 or 80 cows can produce as much milk as he previously could with 100 cows, use 15 percent less feed to produce that milk, and finally, have a chance to be more profitable. Monsanto is continuing research on this product and intends to develop it and gain approval from the Food and Drug Administration for a commercial product for the dairy farmer by as early as 1989–1990.

A similar porcine somatotropin could boost feed efficiencies in commercial hog operations by up to 20 percent while speeding the rate of weight gains and producing leaner animals. The pork chops of the future will be high in protein and very low in fat. Nutritionists and consumers the world over would likely applaud and pay a premium for that kind of improvement in meat quality.

IMPORTANCE OF INNOVATION

The commodity crop surpluses that exist today have prompted some critics to suggest a moratorium on agricultural research and technology development, particularly biotechnology. "Why invent something that will increase productivity," they ask, "when we have more than we can sell or use today?"

The answer is straightforward. If we do not continue to innovate, we will be forced out of business. We are not alone on this planet in producing commodity and other agricultural products. The capacity of U.S. agriculture to retain its domestic markets and to expand its foreign markets depends on continued declines in the real costs of production and the development of differentiated quality-added and value-added products. U.S. agriculture has achieved its preeminence in the world by innovating, by substituting knowledge for resources. This innovation must continue despite the problems that our agricultural economy faces today.

Genetic engineering is the most important advance in agricultural science in this century. It can enhance both the productive efficiency of agriculture and the quality of our environment. It has the potential to increase the economic competitiveness of U.S. agriculture. Yet, there is an effort afoot to stop the application of genetic engineering to agriculture. The public has been encouraged to be apprehensive about genetic engineering and biotechnology and to adopt the view that genetic engineering is dangerous, unnatural, and in some way an infringement on "divine copyright." This concern threatens to delay the application of biotechnology to agriculture in the United States and has impeded the pursuit of this science in universities. Indeed, it was not until June 1987 that a genetically engineered plant was allowed to flower and go to seed.

There is no reason to assume, guess, or hypothesize that changing a single gene in a plant by genetic engineering and planting its seed in a field would cause an environmental problem. To convert a corn plant into a weed, for example, would require hundreds of genetic changes, because corn simply does not have weedy characteristics. It is absurd to pretend that we are living in a pristine forest and to say that we should not change anything. In the end, using biotechnology to control plant pests and to raise the agricultural productivity of areas we have decided to cultivate may be the best way to leave other parts of the world unaltered. Let us not forget that the surpluses of agricultural commodities today are as ephemeral as are the surpluses of oil today. The population of the world will double during the next 30 years and so will humanity's need for food. One cannot redesign human beings for greater fuel economy the way one redesigns cars! Hence, as far as food is concerned, for the long term we have two planetary choices: plow up the rest of the world or greatly increase the productivity of existing farm acreage.

Biotechnology offers U.S. farmers and farmers everywhere the best chance to increase their productive efficiency and profitability in an environmentally friendly way. What alternatives are proposed by those who wish to ban the application of genetic engineering to plant and animal agriculture?

The public's concern about recombining genes for agriculture underscores the failure of scientists and other influential leaders to educate the public about the naturalness of genetic recombination and genetic engineering. It is worth remembering that honeybees, farmers, and animal breeders have been recombining the genes of various organisms for millenniums, and those organisms freely roam the planet. Thus, genetic recombination is a key process in nature as well as in genetic engineering. Moreover, genetic engineering gives us an intimate view of how nature operates and allows us to work with nature. It has taught us to address nature in her own universal language, the genetic code, and nature has responded by producing proteins we have asked her to produce, like enzymes that dissolve blood clots, or proteins that improve the productive efficiency of livestock operations. Genetic engineering is a marvelous Rosetta stone. Nature is finally scrutable and, at long last, human beings can work in harmony with nature.

During the next decade, our knowledge of genetic engineering will increase far more rapidly than in the past, and we will have the capability to apply it to more and more unsolved but urgent problems. But scientists will not be allowed to apply genetic engineering to agriculture without public support and without the support and interest of the nation's leaders. We need rational, science-based regulations that allow commercial development while meeting the goals of environmental protection and that permit the safe, purposeful release of modified genetic material. Leaders in universities, government, and industry must actively participate in demystifying genetic engineering so that the public will accept this science as a natural, gentle science whose goal is to prevent pestilence and disease, to improve the productive efficiency and economic viability of U.S. agriculture, and to enhance the quality of human lives.

In a luminous essay published in *Science* magazine, Gerard Piel, chairman of the board of *Scientific American*, made the following observation:

> The work of the scholar and scientist is bound to challenge and make obsolete first this and then that special interest in established ways of making and doing things. The freedom to conduct the supreme public business of the advancement of human understanding must be protected, therefore, by defenses as absolute as social institutions can provide.

Piel concludes: "The best institution we have devised to secure that freedom is the university" (*Science*, September 5, 1986:1056–1060).

But where have the presidents and chancellors of our great research universities been in this debate? Where is the larger academic establishment? Where is the American Civil Liberties Union when the advancement of science, "the supreme exercise of citizen sovereignty," is being suppressed? Indeed, why have organizations such as the Business Roundtable—whose members are the leaders of the United States' greatest corporations—kept silent, since our nation's economic competitiveness is being placed at risk? Where are the congressmen and senators who worry about economic competitiveness? Why has the most well-informed and influential scientific press in the world allowed a few ideologues to make a national science policy that has no basis in science? It is one thing to believe in "equal time." But "equal time for nonsense" will bring the world's work to a halt.

Surely, the whole world need not frame the debate around the narrow view of a few genetic McCarthyites.

Unless the many concerned individuals and groups take a stand and speak out, government regulators, Congress, and the courts will slow the development and application of genetic engineering to agriculture in this country and ensure that we lose a larger and larger share of both domestic and international markets for our agricultural products.

When these individuals and groups do take a stand and speak out to the people about genetic engineering, it will hasten the building of consensus, upon which our democratic society depends. This volume should help to trigger such a public policy initiative.

If we do not adopt new technologies, like biotechnology, that can significantly increase the efficiency of production and ensure product quality, it could permanently cripple U.S. agriculture. The day we limit the use of new technologies is the day we start to bring in massive quantities of Argentine wheat and Brazilian soybeans and become a nation that imports larger and larger quantities of food.

It is also important to recognize that these new technologies will hasten the restructuring of U.S. agriculture whether or not they are adopted by U.S. farmers. For the technologies will certainly be adopted in other agricultural countries and this will increase their productive efficiency, reduce the cost of their goods, and make off-shore commodity products more attractive to users in the United States than high-priced local products.

A country or an industry can survive for a relatively short period of time by erecting barriers to competition and by not investing in innovation. But eventually that country or that industry will have to adopt new technology to survive—examples are the steel and auto industries, which may have waited too long to change.

If the application of biotechnology to agriculture in the United States is delayed for years, the United States will be in the position of producing superb prototype technology for the rest of the world to apply. For both the individual farmer and for the nation as a whole, the choice is clear: either be an innovative farmer or compete with one. Biotechnology can provide U.S. agriculture with an innovative edge.

Technical Change in Agriculture: An Overview of the Effects of Public Policies

Susan M. Capalbo

It is widely believed that the introduction of new technologies results in increased productivity and welfare gains. Baumol and McLennon (1985) recently concluded that "productivity growth is in every sense a long-run issue . . . there is probably nothing more important for changes in a nation's economic welfare in terms of developments spanning periods as long as a half century or more." The aptness of their conclusion is evident in the United States, where increased productivity has been a source of real economic growth throughout the twentieth century. For the agricultural sector, productivity growth has been most dramatic since World War II (Figure 1). Whether measured using crop yields per acre, aggregate output per unit of labor, or an index of aggregate output to an index of aggregate input, the rate of growth of agricultural productivity since the 1940s is substantially greater than in the period leading up to World War II. Moreover, the agricultural sector did not experience the collapse in productivity growth that characterized the nonfarm sectors in the 1970s (Table 1).

Economic theory indicates that changes in productivity can occur as a result of shifts in the production technology—that is, shifts in the maximum volume of output that can be produced with a given volume of inputs—or from changes in the economic incentives facing producers that cause a change in the mixes of inputs and outputs. Direct shifts in the production technology are primarily due to technological advances. The technology available to farmers is developed largely through private and public research and development (R&D) activities, the latter being funded by state and federal agencies. Indirect shifts result from the changes in the mixes of inputs and outputs, holding the state of knowledge constant. These changes are induced by market conditions, supply-management policies, and government regulations that affect the quantities or prices of inputs used or outputs produced.

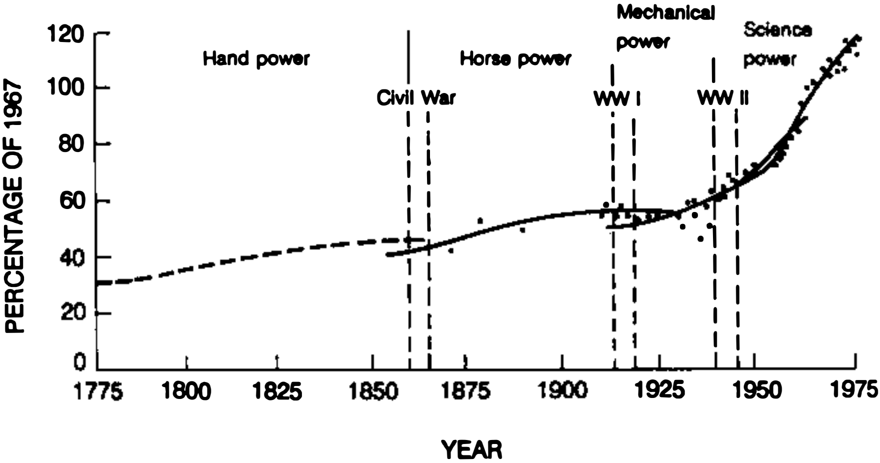

FIGURE 1 U.S. agricultural productivity growth during the past 200 years. Source: U.S. Department of Agriculture.

This paper focuses on how government policies affect productivity growth and technical change in the agricultural sector. More specifically, it examines the evidence on the impacts of R&D spending on productivity and provides a conceptual analysis of the impacts of a subset of government programs that are unique to agriculture.[1] In assessing the effects of government policies on productivity, it is helpful to distinguish between technological development and innovation, the latter being the adoption of a new technology. The innovation or adoption phase is influenced by the economic climate within which users of the technology operate. Unless it is adopted by producers, the output of research activities will not show up in the measures of productivity or technical change.

Viewing technical change as internal to the economic system enables one to examine how economic variables affect the pace and direction of technical change and how that is manifested in the measures of productivity growth. Understanding of these questions could provide some insight into what policies should be changed if the farm sector is to benefit fully from scientific and technical expertise. In addition, a better understanding of the relationship of public policies to rates and patterns of innovation would facilitate altering the distributional and structural consequences of technical change by changing the policies that influence the development and adoption of new technologies.[2]

In general, the goals of R&D policies are related to enhancing technological progress; the goals of agricultural commodity policies and input restrictions are achieving income enhancement, market stability, and so forth, although those policies may indirectly influence technical change. One can only analyze the success of the R&D policies in achieving technological progress in the context of the host of other programs affecting the behavior of agricultural producers. Thus, one must be able to analyze how economic policies whose goals are unrelated to technical change may nevertheless affect the rate and direction of such change.

The paper proceeds as follows: the first section focuses on the nature and extent of government policies, primarily the public sector R&D programs, aimed at inducing direct shifts in production technology. The indirect sources of productivity change, such as supply management policies and environmental regulations, are discussed in the second section. The final section draws conclusions concerning the role of agricultural policies in affecting the observed changes in productivity.

R&D AND PRODUCTIVITY GROWTH

In the United States, government policies to stimulate technological advances in agriculture date back to the mid-1800s. The federal- and state-supported experiment stations and the agricultural extension services are associated with the establishment of the land-grant universities. It is well known that these research programs have been successful and have "necessitated" further government intervention to rescue the farmers from the market consequences of large food surpluses. As Nelson (1982) observes, "interestingly, the response [to the food glut] . . . was to establish a food-price support system, and try to get land out of cultivation, rather than to slow down the governmentally fashioned engine of success."

The technology available to farmers today is developed through R&D in the private and public sectors. (Evenson [1982] discusses the evolution and characterization of private and public R&D spending.) With respect to

TABLE 1 Total Factor Productivity Growth

Period	Private Nonfarm Business[a]	Manufacturing[a]	Farm Sector[b]
1953–1968	1.75	1.93	0.94
1968–1973	1.14	2.84	1.24
1973–1979	0.32	0.85	1.95

[a]Bailey (1986).
[b]Capalbo and Vo (1988).

technology development, the bulk of the private sector output is produced outside the farm sector, primarily by the input supply firms, that is, the farm machinery and farm chemical industries. Ruttan (1986) also notes that new technologies in agriculture are, for the most part, the product of R&D by public sector institutions and private sector suppliers of technical inputs to agriculture.

Although data on private R&D spending are somewhat limited, most estimates show that this component has been an increasing percentage of total R&D monies. Evenson (1982) reports that private sector spending accounted for roughly 25 percent of total R&D spending in the 1950s, 40 percent in the 1960s, and nearly 50 percent in the 1970s. The Cooperative State Research Service (1984) reports that roughly 54 percent of 1982 agricultural R&D was funded by the private sector. The public R&D component includes both federal (U.S. Department of Agriculture) and state (State Agricultural Experiment Station) units. In 1982, of the remaining 46 percent of total R&D expenditures, 29 percent was federal monies and 17 percent was state monies.

What have been the impacts of R&D funding on the productivity of the U.S. farm sector? To address this question one needs to identify how R&D could affect the production process, that is, how it could shift the production function for agricultural products and thus contribute to productivity growth.

Quantifying returns to public sector investment in R&D is difficult because of the fundamental nature of R&D processes, in which outputs are often unobservable, and because of the dichotomy between the development and adoption processes, which separates the output of the R&D process from the outputs and effects exhibited in the production sector. For example, a substantial amount of productivity growth is basically occurring in the intermediate (chemical) input sector, but it is manifest in the agricultural production sector in terms of higher yields and so forth. One could argue, then, that an increase in agricultural productivity due to improvements in purchased inputs should be attributed to the intermediate input sector and not necessarily to the agricultural production sector.[3] Taking this one step further, the productivity of R&D might be approximated by the difference in productivity in the farm production sector, which has a set of well-defined outputs, using an unadjusted versus a quality-adjusted index of purchased inputs from the R&D, holding constant all other factors.

Griliches (1979) outlined two approaches that have been used to characterize the contribution of R&D expenditures to productivity growth: historical case studies and econometric estimates of production functions. Griliches indicates that the case studies tend to concentrate on the successful set of innovations, and thus it is not clear what conclusions can be drawn regarding the contribution of all R&D expenditures.

The econometric approach specifies productivity to be a function of all past (lagged) R&D investments. An estimate is obtained regarding the marginal contribution of R&D to productivity growth. This approach also provides an estimate of the total effect of a particular R&D investment, including the contributions of other investments induced by it.[4]

Some of the difficulties in using the econometric approach are related to measurement problems. The output of the sector performing the R&D is difficult to observe—as noted earlier, the output of government R&D is manifest indirectly in the output of the farm sector. Consider the following example: Suppose a pesticide is developed that works effectively on severe pest problems. Under this scenario, yields during a severe pest infestation will be lower relative to yields during a low pest period, but those lower yields will be associated with high rates of pesticide applications. This would actually lead to a decline in the productivity measure. Thus, in the absence of a variable to adjust for infestation levels, pesticide productivity may be mismeasured.

Evenson (1967), Norton and Davis (1979), and Peterson and Hayami (1977) also present reviews of the methodology used to quantify agriculture R&D effects and to summarize empirical results. Schultz (1953) was one of the first researchers to estimate a supply function effect. He estimated the value of the inputs saved in agriculture over the period 1910–1950 as a result of the adoption of new technologies. This shadow value, which amounted to nearly $9.6 billion per year, was interpreted as a net economic benefit and compared with R&D expenditures, which totaled only $7 billion over 40 years. Peterson (1971) updated the Schultz study through 1967 and found that the marginal rate of return to agricultural research and extension in the early 1960s was over 40 percent; the return over the 1915–1960 period was approximately 21 percent.

In a case study of hybrid corn, Griliches (1958) also calculated a very high rate of return to R&D—700 percent per year. The value of the observed increased corn production, adjusted for changes in costs of production, was used as a proxy for the value of the returns to this particular R&D. A later study by Peterson (1967) on returns to poultry research reported a much lower return, approximately 17 percent per year, from the early 1900s through the 1950s.[5] Returns to the tomato harvester provide a third example. Schmitz and Seckler (1970) reported an internal rate of return of between 8 and 1,288 percent, depending on which assumptions were made concerning the opportunity cost of the displaced resources.

Table 2 presents a summary from selected studies of the rates of return for agricultural research in the United States. One conclusion that can be drawn from the empirical evidence on returns to R&D is that, while the studies are consistent in painting a picture of a highly productive agricultural R&D sector, the returns are sensitive to methodology and data.

TABLE 2 Summary of Selected Studies of Productivity or Returns to Agricultural Research in the United States

Study	Commodity	Time Period	Rate of Return
Methodology: Values of inputs saved[a]			
Griliches (1958)	Hybrid corn	1940–1955	35–40
	Hybrid sorghum	1940–1957	20
Peterson (1967)	Poultry	1915–1960	21–25
Schmitz and Seckler (1970)	Tomatoes	1958–1969	16–46
Peterson and Fitzharris (1977)	Aggregate	1937–1942	50
		1947–1952	51
		1957–1962	49
		1957–1972	34
Methodology: Econometric			
Griliches (1964)	Aggregate	1949–1959	35–40
Peterson (1967)	Poultry	1915–190	21
Evenson (1968)	Aggregate	1949–1959	47
Bredahl and Peterson (1967)	Cash grains	1969	36
	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
Cline (1975)	Aggregate	1938–1948	30.5
		1949–1959	27.5
		1959–1969	25.5
		1969–1972	23.5
Evenson et al. (1979)	Aggregate	1968–1926	65
		1927–1950	95[b]
		1927–1950	110[c]
		1948–1971	45[c]
Norton (1981)	Cash grains	1969	31
		1974	44
	Poultry	1969	27
		1974	33
	Dairy	1969	56
		1974	66
	Livestock	1969	30

[a]This is equivalent to Evenson's (1982) "imputation" studies, which rely on direct methods to associate economic effects with program costs, as distinguished from statistical or economic studies that estimate the economic effects of R&D programs using regression techniques. The latter set of studies enables one to calculate marginal production from research investment.
[b]Applied or technology-oriented R&D
[c]Basic or science-oriented R&D.

SOURCE: Adapted from Evenson et al. (1979), Evenson (1982), and Weaver (1986).

In interpreting the rates of return obtained, it is important to distinguish between the private and the social rate of return. The former is the rate of return to the firm carrying out the R&D; the latter is the rate of return to society. Often the firm that undertakes the R&D cannot appropriate many of the benefits, and thus the social rate of return may be considerably higher than the private rate of return. Many of the rates presented in Table 2 are social rates of return.

Equally important to remember when interpreting the social rates of return presented in Table 2 is the fact that few, if any, of these studies have incorporated social costs in their calculations. The social costs of agricultural research may include environmental damages and/or human health risks associated with the new technologies. Recent research is aimed at adjusting rates of returns to agricultural research to reflect social costs as well as social benefits (see Batie, 1988; Capalbo and Antle, 1989).

Once an innovation is adopted, the level of potential output that can be produced from a given set of inputs is altered. If the innovation is not neutral with respect to all inputs, the adopted innovation results in a change in the mix both of inputs and of outputs. This is commonly referred to as the biases of technical change.[6] These changes will affect the markets for the inputs and outputs, which in turn will trigger further changes in input and output prices.

POLICIES AFFECTING TECHNOLOGICAL CHANGE AND PRODUCTIVITY

This section is intended to contribute to an understanding of how government policies whose goals are unrelated to technical change in the direct sense may affect the rate and direction of such a change. This type of analysis is not unique to the agricultural sector, although the effects may be more easily ascertained given the nature of many of the agricultural programs. Wolff (1985) concludes that the increased government regulations during the 1965–1978 period may have played a significant role in the decline in productivity growth for the nonfarm sectors in the United States. He cites Crandall's (1980) evidence that government regulations restrict competition and that health and environmental regulations divert large quantities of resources to control various hazards, thereby reducing output-to-input ratios.[7]

We can now examine the impacts of government policies on the rate of change of productivity measures and on observed biases of technological innovation. Either directly or indirectly, government programs affect the farmer's expectations about the product price. Direct intervention is manifest in government commodity programs. Intervention is also evident through acreage restriction programs or soil conservation reserves (set-asides), which influence a farmer's production decisions, and in programs designed to enhance export demand. Finally, environmental regulations regarding pesticide usage and ozone levels, for example, also affect the observed productivity measures.

Analyzing the impact of the commodity programs leads to a discussion of effects on price uncertainty. A general result of the theory of decision making under uncertainty is that a decrease in output price uncertainty leads to an increase in quantity produced and increases in scale of operation. To the extent that price supports and associated programs have decreased farmers' uncertainty with respect to postharvest prices, they may have contributed to output expansion. However, the verdict on whether government programs have actually stabilized or destabilized prices and revenues is unclear.

The federal government has spent nearly $20 billion for soil conservation since the programs were begun in the 1930s. Determining the effect of these programs on productivity requires viewing land as another input—stored capital—that is used in conjunction with labor, water, and other resources in the agricultural production process. These inputs are complements in the short run but, to a large degree, substitutes in the long run.

As noted from economic theory, the optimal combination of inputs depends on relative prices. The technology that determines feasible input combinations will evolve through time in such a way as to conserve the most costly inputs.[8] As Gardner (1985) indicates, soil protection can be viewed as an act of investment that produces a rate of return that can be compared with rates of return to other investments. Only if those rates are equal at the margin will economic productivity be maximized. The farm sector continues to have too many resources, and Gardner cites the subsidization of the temporary removal of land from crop protection as one of the government's most-used policies for inducing farmers to remain on the farm. The theory was that these programs would reduce the employment of land and permit labor to remain.

Acreage restriction programs affect the observed measures of land productivity. Farmers will take marginal land out of production, that is, land that has lower-than-average yields per acre for a given level of the other inputs. The impact is to increase the productivity ratio of the land remaining in production. Thus, land productivity appears to have increased although there has been no shift in the production technology.

Environmental regulations that impose additional constraints on the firm's production choices tend to decrease (or at least not to increase) the rate of growth of productivity measured as a one-period change in the observed or marketable outputs-to-inputs from what the rate of growth would be in the unregulated case. This is because resources must be spent on meeting the regulations rather than on producing marketable output. From a theoretical point of view, a constrained profit maximization is never superior to an unconstrained profit maximization because the unconstrained producer is always free to move to the constrained maximization point.

From a dynamic perspective, impact in productivity due to environmental regulations may be the reverse of the observed short-run impacts. The longer run effects of pesticide restrictions—taking into account production externalities such as pesticide resistance—may be to enhance productivity growth because the effects of current production activities on future production are incorporated. Excluding production externalities can overstate productivity gains in the short run because some (social) costs are unaccounted.[9] As public policies move in the direction of requiring producers to bear more of the total (private and social) costs of production and to "internalize" externalities, use of static conventional productivity measures will be less informative as an indicator of "how well we are doing."

In addition to pesticide restrictions, another example of an environmental regulation that can affect the productivity of the agricultural production sector is ambient ozone standards. To analyze the impacts on productivity, recall that technical change is manifested by either an upward shift in the production function or a downward shift in the total cost function. Under competitive conditions the supply curve is also the marginal cost curve and total cost is simply the area under the supply curve. The impacts of more stringent allowable ambient ozone concentrations will theoretically shift the aggregate supply curve for agricultural production to the right. This new supply curve (S^1) is displayed in Figure 2.

In the absence of government price supports, the market-clearing price and quantity before the change in ozone regulations are (P_0,Q_0) and (P_1,Q_1) after the change in the regulations. The productivity gains due to the ozone-induced yield increases measured with respect to production level Q_0 are equivalent to the area ABC, which is simply the difference in the area under the initial and the new supply curves evaluated at the initial equilibrium output level. The productivity gains measured with respect to the new equilibrium output level are depicted by the area ADE.

Two points can be made about this example. First, the supply curve shifted downward because of an ozone-induced increase in yields, which is basically a windfall gain to the farm sector. No costs associated with farm-sector R&D activities are incurred nor does the regulation implicitly place any additional constraints on the farm sector. Agricultural productivity increases, but at the expense of some of the nonfarm sectors.

Second, to reflect the effects of agricultural policy more accurately, the previous analysis would have to be modified to reflect target prices. The existence of a policy that pays farmers the difference between the prevailing market price and a target price (P^*) induces farmers to produce at Q_1 rather than Q_0 under the old ozone regulations. The loss in social welfare is the triangle BDE—that is, the total cost of producing Q_1 minus its market valuation.

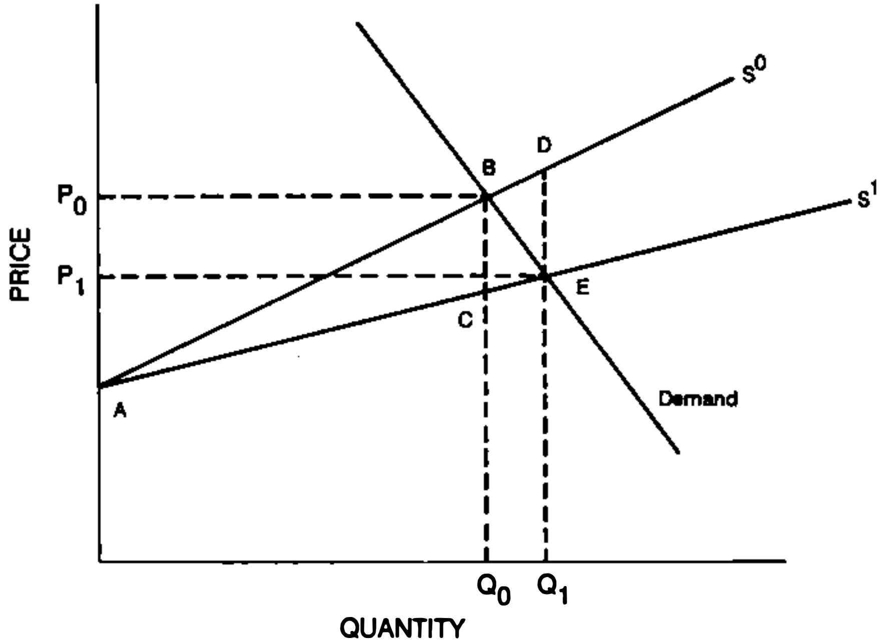

FIGURE 2 **Measuring productivity gains using supply shifts.**

After the more stringent ozone standards are imposed, production is at Q_1, and the welfare loss due to the agricultural policy is now equal to area EHI. There is also a welfare gain, which is equal to the productivity gain ABC, a net gain to consumer and producer surplus BDE, minus the old welfare loss BDE. Thus, the *net* welfare effect, taking into account more stringent ozone regulations and a target price policy, is equivalent to: ABC + BCE + BDE − EHI. Whether this is a net gain or loss depends on the extent of the yield-increasing effects, the demand and supply elasticities, and the magnitude of the difference between the market price and the distorted price.[10]

This simple example suggests that the social benefits or even just the productivity gains from a set of evironmental regulations or from a targeted type of R&D program can be diminished by agricultural commodity policies that encourage overproduction. Moreover, given that the productivity measures are constructed using observed and not market equilibrium prices, what we are picking up as productivity indicators are in fact the end result of a series of effects. The difficulties associated with quantifying the effect of government programs on technological change and productivity are related to separating the effects due to particular programs and those generated by market forces. Identifying the biases and interdependencies that exist is the first step toward trying to quantify the separate effects.

CONCLUSIONS

The effects of technical change are not determined solely by the type of innovation or by the amount of R&D expenditures. As noted by many researchers both in agriculture and other sectors, the political and economic settings into which the innovation is introduced are important factors in determining the eventual impact. That is the focus of this paper: how various government programs and policies, including those whose goals are unrelated to enhancing technological progress, could affect technical change and measures of agricultural productivity.

Productivity growth has been defined as the rate of change in aggregate output per unit of aggregate input. The rate of output growth depends on the state of technology or the production process being utilized, the level of the inputs (scale effect), and the efficiency with which the inputs are utilized. Under the assumptions of economic efficiency and constant returns to scale, productivity growth provides a measure of technical change. If these assumptions do not hold, isolating the share of the productivity residual attributable to technical progress is often difficult even in the absence of government intervention. When the additional impacts caused by government policies are considered, sorting out the technical progress component is even more challenging.

Government policies that influence the set of available technologies are primarily the R&D programs. The commodity programs and related regulations are likely to have their greatest impact on measures of technical change by affecting the incentives to adopt new technologies. Moreover, the commodity programs and regulations will also affect the types of technology developed via their impact on relative prices.

These policies also affect measures of productivity growth in the farm sector by altering the mix of inputs and outputs. Programs that take marginal land out of production will increase the observed rate of productivity growth but only because the least efficient units have been eliminated, not because of adoption of a new technology per se.

Environmental regulations also influence the rate of productivity growth. As agricultural technologies change and the public grows increasingly concerned about the possible effects of chemical exposures, more vigorous regulatory interventions in agricultural practices are likely. Furthermore, recent research suggests that the long run effects of more stringent environmental regulations on agricultural productivity are positive, but they can be diminished by agricultural commodity programs that encourage overproduction. Thus, the impacts of environmental regulations on technical change and productivity growth in agriculture depend on the regulatory climate created by the host of other government policies.

It is tempting at this point to try to sort through reasons for the productivity growth rates based on the general discussion of policy impacts. As shown in Table 1, there has been a dramatic difference in the patterns of growth of total factor productivity in the farm and nonfarm sectors. The productivity slowdown in the agricultural sector started in the late 1950s and continued through the mid-1960s. The 1970s were a decade of substantial productivity growth. How much of this discrepancy, if any, can be attributed to the conditions and policies that are unique to agriculture?

Bailey (1986) indicates that the productivity slowdown in the nonfarm sector after 1973 was caused by a combination of forces, including a slowing in the speed with which the technology frontier was pushed out in many "old-line" industries, as evidenced by a sharp reduction in the growth of R&D spending and in flow of patents and a series of interrelated disruptions to the economy (i.e., recessions in 1975 and 1982, energy price increases in 1973 and 1979, and rapid escalation of government regulations).

What happened within the agricultural sector during the 1970s, which offset the effects of the recession and energy price increases and resulted in an increase in the rate of productivity growth? Was there a slowdown in the speed with which the technology frontier was expanded? To answer this we can examine the expenditures on R&D, keeping in mind the 6- to 10-year lag between the time the R&D investment is made and the time the technology is developed or the effects are observed. Evenson (1982) reports a more than doubling of private R&D expenditures for biological- and chemical-oriented research between 1960 and 1970; public expenditures also showed dramatic increases. Thus, there does not appear to have been a slowdown in the pace at which technologies were being developed. What about the rate of adoption? Evenson (1982) also reports an increase in government expenditures on public extension service. However, what may be a significant influence on the rate of adoption are the economic signals, that is, the substantial increase in product prices in the 1970s due to expanded demand.

Higher revenues placed farmers in a better financial position to consider adoption of the new technologies that were "waiting in the wings." They could afford to undertake innovations that may have been more risky but that also had the potential for higher yields;[11] higher market price implies that the returns for risk taking are also higher. As farmers expanded the scale of operations, productivity gains due to scale changes also came into play.

Thus, the observed productivity gains were likely due to a combination of a true productivity effect and scale effects. Moreover, relative to the manufacturing sectors which were required to invest in pollution abatement capital, the agricultural sector was less negatively affected by the environmental regulations of the 1970s and was positively affected by the yield-increasing effects of cleaner air. In addition, many of the agricultural commodity programs and related policies either were not in place or were not binding. The agricultural sector was probably enjoying its least regulated era, which may help explain the high rates of productivity growth.

In conclusion, the market system's effectiveness in stimulating productivity will be substantially enhanced by the elimination of unnecessary government measures that now impede productivity and by the modification of public policies in ways that encourage investment and complement each other. In the short run, technical change may respond to public policy—an example is the Environmental Protection Agency's halt to further testing by Monsanto of genetically engineered microbes to kill cutworms (see *New York Times Magazine*, November 16, 1986). Past and current farm programs and regulations have affected productivity by slowing or speeding the rate of adoption of technical change, but it is doubtful that they have significantly altered the long-run trends.

NOTES

1. The impacts of tax programs, macroeconomic policies, and marketing policies are not discussed because of space limitations.

2. For a discussion of the distributional aspects associated with productivity growth and farm policies, see Sumner (1985) and the references cited therein.

3. This is the thrust of arguments to adjust the measures of inputs to reflect "constant quality units," as Griliches first proposed in the late 1950s.

4. Examples include Bredahl and Peterson (1976), Brown (1978), Cline (1975), Evenson (1967), and Knutson and Tweeten (1979).

5. This internal rate of return reflects an averaging of negative returns up through the mid-1930s and positive returns thereafter.

6. The evidence in the United States suggests that technical change has been nonneutral. In general, it has been labor- and landsaving and fertilizer- and machinery-using (see Capalbo and Vo, 1988, for a review of the empirical evidence on factor biases).

7. Wolff (1985) notes that this may be somewhat misleading—if the benefits generated by those regulations were reflected in the measures of output utilized, the reported productivity slowdown probably would be somewhat smaller. A similar sentiment is expressed regarding agricultural productivity in Farrell and Capalbo (1985).

8. This is commonly referred to as the induced innovation theory, which is attributed to Hicks (1963). The basic idea is that changes in the level of factor prices influence the direction of innovative activity and observed technical change. Producers will seek out new methods of production that make greater use of the relatively cheap factors of production.

9. For example, Archibald (1988) addresses the impact of pesticide regulations in the California cotton-producing sector.

10. Some preliminary estimates of the net welfare losses associated with different assumptions regarding ozone-induced yield changes and agricultural programs

for various field crops are being calculated at Resources for the Future (Kopp, Resources for the Future, personal communication, 1986).

11. Yields per acre showed dramatic increases during this period.

REFERENCES

Archibald, S. O. 1988. Incorporating externalities into agricultural productivity analysis. In Agricultural Productivity: Measurement and Explanation, S. Capalbo and J. Antle, eds. Washington, D.C.: Resources for the Future Press.

Bailey, M. N. 1986. What has happened to productivity growth? Science (October 24):443–451.

Batie, S. S. 1988. Agriculture as the problem: New agendas and new opportunities. Southern J. Agri. Econ. 20:1–12.

Baumol, W. J., and K. McLennon, eds. 1985. Productivity Growth and U.S. Competitiveness: A Supplementary Paper of the Committee for Economic Development. New York: Oxford University Press.

Bredahl, M., and W. Peterson. 1976. The productivity and allocation of research: U.S. agricultural experiment stations. Am. J. Agri. Econ. 68(4);(Part I, November):684–692.

Brown, R. S. 1978. Productivity, Returns, and the Structure of Productivity in U.S. Agriculture, 1947–1974. Ph.D. dissertation, University of Wisconsin, Madison.

Capalbo, S. M., and J. M. Antle. 1989. Incorporating social costs in the returns to agricultural research. Am. J. Agri. Econ. 71(2):458–463.

Capalbo, S. M., and T. T. Vo. 1988. A review of the evidence on agricultural productivity and aggregate technology. In Agricultural Productivity: Measurement and Explanation. S. M. Capalbo and J. M. Antle, eds. Washington, D.C.: Resources for the Future Press.

Cline, P. L. 1975. Sources of productivity changes in United States agriculture. Ph.D. dissertation. Oklahoma State University, Stillwater.

Cooperative State Research Service. 1984. Research 1984: The State Agricultural Experiment Stations. Experiment Station Committee on Organization and Policy.

Crandall, R. W. 1980. Regulation and productivity growth. In The Decline in Productivity Growth. Boston: Federal Reserve Bank of Boston.

Evenson, R. E. 1967. The contribution of agricultural research to production. J. Farm Econ. 49(December):1415–1425.

Evenson, R. E. 1968. The contribution of agricultural research and extension to agricultural production. Ph.D. dissertation, University of Chicago, Chicago, Illinois.

Evenson, R. E. 1982. Agriculture. Pp. 233–283 in Government and Technical Progress: A Cross-Industry Analysis, R. Nelson, ed. New York: Pergamon.

Evenson, R. E., P. E. Waggoner, and V. W. Ruttan. 1979. Economic benefits from research: An example from agriculture. Science 205(Sept. 14):1101–1107.

Farrell, K., and S. Capalbo. 1985. Natural resource and the environmental dimensions of agricultural development: Coping with the trade-offs. Pp. 273–283 in Proceedings of the 1985 International Association of Agricultural Economists Conference. Institute of Agricultural Economics, University of Oxford.

Gardner, B. D. 1985. Government and conservation: A case of good intentions but misplaced incentives in government and conservation: What should be the role of government? Proceedings from a public policy education program at Purdue University, Lafayette, Indiana, February.

Griliches, Z. 1958. Research costs and social returns: Hybrid corn and related innovations. J. Political Econ. 66(October): 419–431.

Griliches, Z. 1964. Research expenditures, education, and the aggregate agricultural production function. Am. Econ. Rev. 54(December):961–974.

Griliches, Z. 1979. Issues in assessing the contribution of research and development to productivity growth. Bell J. Econ. 10(1):92–116.

Hicks, J. R. 1963. The Theory of Wages. New York: St. Martins Press.

Knutson, M., and L. Tweeten. 1979. Toward an optimal rate of growth in agricultural research and extension. Am. J. Agri. Econ. 61 (February): 70–76.

Nelson, R. 1982. Government stimulus of technological progress: Lessons from American history. Pp. 451–482 in Government and Technical Progress: A Cross-Industry Analysis, R. Nelson, ed. New York: Pergamon.

Norton, G. W. 1981. The productivity of research: U.S. agricultural experiment stations, revisited. N. Cen. J. Agri. Econ. 3(1):1–12.

Norton, G. W., and J. Davis. 1979. Evaluating returns to agricultural research: A review. Am. J. Agri. Econ. 63(November):685–699.

Peterson, W. L. 1967. Return to poultry research in the United States. J. Farm Econ. 49(3):656–669.

Peterson, W. L. 1971. The returns to investment in agricultural research in the United States. Pp. 139–162 in Resource Allocation in Agricultural Research, W. L. Fishel, ed. Minneapolis: University of Minnesota Press.

Peterson, W. L., and J. C. Fitzharris. 1977. The organization and productivity of the federal-state research system in the United States. In Resource Allocation and Productivity in National and International Agricultural Research, T. M. Arnett, D. G. Dalrymple, and V. W. Ruttan, eds. Minneapolis: University of Minnesota Press.

Peterson, W. L., and Y. Hayami. 1977. Technical change in agriculture. Pp. 497–540 in A Survey of Agricultural Economics Literature, Vol. 1, Lee Martin, ed. Minneapolis: University of Minnesota Press.

Ruttan, V. W. 1986. Technical change and innovation in agriculture. Pp. 333–356 in The Positive Sum Strategy, R. Landau and N. Rosenberg, eds. Washington, D.C.: National Academy Press.

Schmitz, A., and G. Seckler. 1970. Mechanical agriculture and social welfare: The case of the tomato harvester. Am. J. Agri. Econ. 52(4)[November]:569–578.

Schultz, T. W. 1953. The Economic Operation of Agriculture. New York: McGraw-Hill.

Sumner, D. 1985. Farm programs and structural issues. In U.S. Agricultural Policy: The 1985 Farm Legislation, B. Gardner, ed. Washington, D.C.: American Enterprise Institute.

Weaver, R. D. 1986. Productivity change: The role of market incentives, land resources, and government intervention in U.S. agriculture. Paper presented at USSR/U.S. Symposium on Agricultural Economics, Fletcher School of Diplomacy, Tufts University, Medford, Mass., June 9–13.

Wolff, E. 1985. The magnitude and causes of the recent productivity slowdown in the U.S.: A survey of recent studies. In Productivity Growth and U.S. Competitiveness: A Supplementary Paper of the Committee for Economic Development, W. J. Baumol and K. McLennon, eds. New York: Oxford University Press.

Pesticide Regulatory Policy: Creating a Positive Climate for Innovation

Charles M. Benbrook

Pesticide regulation in the United States is governed primarily by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This complex statute is unique among environmental laws in two major ways. First, its basic goal is to balance the risks and benefits associated with use of a pesticide. Most environmental statutes do not provide for such an explicit consideration of benefits; rather, they operate by establishing a variety of standards and requirements that, when complied with by industry, are designed to keep pollution and the risks stemming from it at or below some acceptable level—sometimes even zero.

A second critical feature of FIFRA that distinguishes it from other environmental laws is the role it plays in determining technological and economic performance within the pesticide industry. The Environmental Protection Agency's (EPA) Office of Pesticide Programs (OPP) staff must comply with the environmental and scientific criteria of FIFRA, while also dealing with the technological and political consequences that invariably follow any action, or inaction.

The FIFRA statute itself introduces many procedural delays into the regulatory process. FIFRA provides interested parties, generally pesticide registrants and public interest groups, with a variety of administrative remedies and opportunities to influence, alter, or challenge EPA actions. As a result, regulatory decision making typically moves at a slow pace. Registrants are

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always pushing for faster action on new pesticides, yet urging greater care and thoroughness when restrictive actions are contemplated on older compounds.

It has become a mammoth, costly, and time-consuming task, for example, to develop a set of data that shows convincingly that a new pesticide will not pose "unreasonable adverse effects on man or the environment." The only tougher task is one EPA must periodically face—proving that a pesticide on the market, and perhaps used for years without clearly dire consequences, poses risks that are "unreasonable" while weighing the benefits associated with use of the pesticide. Each year a few new pesticides are approved for market, and a few older ones are restricted. As gatekeeper and master of both processes, EPA ultimately plays a critical role in defining the nature and pace of change in pest control technology.

New technologies must appear promising, in terms of commercial prospects, to command the large investments needed before products go into wide use. Hence, evolving perceptions within the industry regarding the EPA's level of scrutiny for new chemicals, in contrast to old chemicals, plays an important role in shaping corporate behavior. In recent years, actions by the EPA have delivered almost universally negative messages—new chemicals are being assessed with increasing skepticism, old chemicals are rarely regulated aggressively, and new products involving genetic engineering have become mired in poorly defined regulatory procedures and uncertain science.

The pesticide regulatory program is largely reactive. Opportunities for regulation to reinforce positive technological change are neither sought nor considered important. Political attention and controversy surrounding the pesticide program for over a decade have concentrated on EPA's inability to deal with old pesticides, dozens of which have not been tested against contemporary standards nor reviewed for safety by the agency. EPA's "old chemical" problem is bound to persist for at least another decade. Regrettably, the agency is not likely to have much chance for several years to focus on a forward-looking regulatory and scientific agenda. Critical steps to establish the science base for resolving emerging pesticide controversies will not be taken until additional resources are earmarked for long-overdue research initiatives.

This practical reality is unfortunate because the scientific capacity clearly exists within the agrichemical industry to move quickly toward commercialization of a new generation of improved pest control technologies. Yet, at this moment of great opportunity, EPA is not sure how to handle new technologies, nor is it sure of its role in providing a receptive climate and clear rewards for positive technological change.

This observation leads to a critical conclusion. A considerable portion of the risks to public health and the environment that are associated with contemporary pesticide use could be eliminated by technological advance, but may not be. The remainder of this paper explores how the pesticide regulatory program may stifle the development of new technologies and suggests options for hastening widespread adoption of safer, improved chemical and nonchemical pest control methods.

FEATURES OF POSITIVE CHANGE IN PEST CONTROL TECHNOLOGY

What is a "positive technological change," in the context of this paper? A positive change would make progress possible toward one or more of three goals:

1. Pest control technologies or chemical pesticides that are safer to humans and the environment because of reduced toxicity; desirable environmental fate characteristics, including low rates of application; and minimal contamination of the food supply and hydrological cycles.
2. Pesticides and control strategies that are less costly for producers and society, taking into account all the direct and possible indirect costs associated with pesticide use.
3. A higher degree of reliability and sustainability in controlling pests, taking into account the skills and equipment available to pesticide users.

This paper focuses primarily on features of regulatory policy that can be expected to bring about safer and more effective pest control technologies. Recent scientific developments and the new class of pesticides being developed suggest that major progress can be made within a decade to reduce levels of risk. In many regions, for many crops, risks in 1996 could be half—perhaps even one-tenth—of current risk levels. As scientific progress and political debate muddle toward a consensus on how "safe is safe," the scientific and technological base exists to reduce pesticide-related risks markedly.

There is less chance that new pest control technologies will significantly lower the cost of pest control any time soon. The new science is expensive, there will be heavy start-up costs to manufacture and market new technologies, and legal and regulatory hurdles will have to be overcome. The most attractive opportunity for near-term reduction in pest control costs is to eliminate, when possible, the need for as much, or any, pesticide. For example, U.S. agriculture continues to grow millions of acres of surplus commodities in some areas that are plagued with uniquely bothersome insect, plant disease, and weed problems. If acreage reduction programs focused on those areas, the overall cost of pest control could fall appreciably. Changes in cropping patterns and cultural practices can also be effective in controlling pests without pesticides, but they come at a cost.

There is a chance for progress toward more reliable and sustainable pest control technologies, particularly as producers who are solely reliant on chemical pesticides move toward adoption of proven integrated pest management strategies. Scouting, preservation of beneficial insects, crop rotations, use of highly selective new chemicals, some use of mechanical cultivation, the timing of planting and harvesting, and selection of rootstock and plant varieties resistant to common diseases and insect pests should all become more efficient and profitable for growers as biotechnology opens new ways to work with natural cycles and to exploit genetic capability.

Given the primitive state of current methods, the most dramatic advances toward more reliable, sustainable control technologies could be made in developing countries that are just beginning to pursue more intensive, higher yielding agricultural production methods. Those countries have the opportunity to learn from pest control mistakes made in developed countries over the past three decades. If such lessons are not heeded, tragic consequences from pesticide misuse and pest control failures can be expected in the developing world. People applying pesticides in developing nations often do not have access to informative pesticide product labels, let alone the knowledge needed to appreciate the possible long-run implications of pesticide misuse. Environmental consequences, particularly surface water and groundwater contamination, are often not considered nor understood. Yet, as always, when used properly and safely, pesticides can make a striking difference in increasing harvested yields per acre.

The United States—the FIFRA statute in particular—can do little directly to foster safe use of pesticides in developing countries. Still, there are critical indirect opportunities that should be more systematically pursued.

The most significant opportunity is to provide stronger incentives for developing inherently safer chemical, biological, and genetic pest control technologies for use in this country. All major global agrichemical firms have to be players in the U.S. market. Because such companies are active (and competitive) worldwide, an effective, profitable—and safer—product developed for a pest problem in the United States can find worldwide applications.

Widespread use of many new pesticides in much of the world often precedes use in the United States. Most improved pesticide products are developed in the United States, Japan, or Western Europe. Then, the new chemicals move through small-scale tests in the research facilities of major agrichemical companies in the United States and Europe. For products that prove effective, the next step typically is field-scale trials in South America, Asia, and the Pacific. If results are promising the trials rapidly expand to strategies to capture the market-share in those countries. Only after a lag of one to three years do most new pesticides complete the EPA regulatory review process, which in recent years has become very strict and deliberate.

CONDITIONS FOR POSITIVE TECHNOLOGICAL CHANGE

For progress to occur toward improved pest control technologies, at least three conditions must be met.

1. The scientific and technical capacity must exist to identify, manufacture, and market improved technologies. It is evident that science is making progress, opening many new avenues from which improved pest control technologies will be generated.
2. New technologies and products must be profitable, or at least promise to be profitable, if private companies are to bring new technologies into commercial use.
3. Farmers, ranchers, and other pesticide users must have the opportunity to use the new technologies profitably, and incentives must exist if they are to make the necessary investments in application skills and equipment. New technologies must work well, special problems must be corrected quickly, and early adopters and should not suffer economic penalties.

Innovation will be encouraged, or discouraged, primarily by market opportunities, and it will be guided by the direction and pace of scientific progress. The FIFRA statute has almost no direct impact on the user-level demand for pest control technologies. Pest control needs—and the demand for pesticides—arise predominantly out of decisions regarding agricultural production systems and cropping patterns. The FIFRA statute works its magic on the supply of pest control technologies, particularly those control strategies that involve pesticides.

Suppose a new group of beneficial pesticides enter the regulatory process. The new sulfonylurea and imidazolinone herbicides are good examples. Their commercial success will be determined, in large part, by how fast the EPA acts to get the new products onto the market and by how quickly and aggressively EPA acts to remove any competing, established products from the market that are no longer justified in terms of their balance of risks and benefits.

Herein lies one of the most fundamental failings of the EPA in its administration of FIFRA. The statute authorizes the EPA to carry out a regulatory program that strikes a continuously improved bargain in terms of the risks that must be accepted by society to attain a given measure of benefits from use of pesticides. In an era of rapid technological advance, opportunities to strike progressively better deals should proliferate, yet now most seem to languish.

There is no mechanism or process that compels EPA to upgrade steadily the balance of risks and benefits that all pesticides must strike. Hence, companies that invest in innovative, improved technologies are rewarded with a regulatory mechanism and process that are, at best, indifferent. Innovative companies committed to safer products should be able to get into the market with minimal delay, yet even this condition is not always met. Regrettably, the more innovative the technology, the more reluctant the EPA may become in reaching scientific judgments regarding new risks. As sophisticated and innovative biological and genetic control technologies move closer to commercial application, the stakes will be high if the EPA remains unable on the risk side of the equation to catch up with the technological state of the art.

Two basic strategies are suggested to encourage development of positive new pest control technologies. First, the EPA could establish new "rewards" as products move through the regulatory system. Second, the EPA could open up commercial windows of opportunity when improved products become available, or appear feasible, by accelerating movement toward regulatory restrictions on established pesticides that no longer offer an acceptable bargain in terms of risks and benefits. EPA has made modest progress on the first front, and none on the second. Decisive steps will be required if this program weakness is to be corrected.

A TECHNOLOGY-DRIVEN AGENDA FOR REFORM

Attention now turns to several ongoing issues faced by the EPA in administrating FIFRA. Each issue is described and its relevance to technological innovation is summarized. Then, possible solutions are outlined. Much progress could and should be made by the EPA through administrative initiatives. Some of the more fundamental problems, however, will require legislative change.

The Old Chemical Problem

About 275 active ingredients are used in pesticides in U.S. agriculture. Only about 150 are used widely and are of regulatory significance. Of these, available data suggest that between one-third and one-half may pose significant risks—and almost all of these chemicals are products first registered 10 or more years ago.

The completion of the chronic toxicology data call-in program in 1985 compelled initiation of hundreds of required studies. As a result, an enormous volume of new data will flow into the EPA over the next four years. Several pesticides remain on the market largely because these data gaps have been allowed to persist. Under FIFRA, the EPA cannot take action until it can document risks. It is inevitable that several older pesticides will soon catch the agency's attention.

To the credit of the agrichemical industry and the EPA, newer pesticides registered since 1978 tend to be much safer, as a group, than older products.

Older pesticides pose by far the greatest risks. Accordingly, the greatest potential for risk reduction rests in regulatory actions involving the most hazardous of the older products. Despite the fact that many safer products are gaining registration, the EPA has cancelled or restricted the use of few older pesticides. Reasons for this reluctance to reassess older chemicals are discussed later in this paper after a second fundamental issue is introduced.

Sources of Bias Against New Chemicals and New Sources of Risk

New pesticides and control technologies are, in effect, guilty until proven innocent. Older pesticides, on the other hand, are innocent until proved guilty. This situation is quite ironic, considering the preponderance of risk derived from older pesticides. Differing burdens of proof, lack of data on older chemicals, and skewed procedural hurdles work together to create a bias against new chemicals that would pose some degree of new risk.

The magnitude of this bias appears to be growing as more toxicology data flow into the EPA with a barely perceptible regulatory response. To the extent this bias persists, interest in sustaining private investments in new, safer pest control technology could wane, which would have negative consequences for exploiting our scientific potential.

A second source of old-new chemical bias is of growing concern. Most older pesticides raise concerns involving the risk of acute or chronic toxicity to humans. With increasing regularity, new pesticides are virtually nontoxic in a traditional sense, yet may appear to pose novel ecological risks. New genetically engineered products, in particular, face delays in the regulatory process as hypothetical ecological hazards are assessed. Indeed, many companies are delaying submission of new product applications for fear of becoming involved in precedent-setting cases that bog down in progressive layers of administrative and legal review.

Several strategies could be pursued to address the problem of older chemicals and the bias against new risks that helps perpetuate the problem. Three new regulatory options appear promising, particularly if adopted as a package.

Phased Cancellation Authority

The EPA could be granted authority to impose phased cancellation actions for selected, or all, uses of a pesticide. Such actions could involve phasing in stricter risk reduction measures over a three to five year period. Once the EPA made a determination that a use of a pesticide posed sufficient risk to justify a phased cancellation, the only way use of such a product could be sustained would be if the registrant comes forward with new data demonstrating that the risk determination was unfounded.

Such a regulatory option could provide the EPA an important new tool to eliminate progressively the risks associated with older products. It would also provide a new way to send a signal to industry about where commercial opportunities will emerge. Public sector research and development (R&D) administrators would also benefit from such an unequivocal indication of where new pest control problems may emerge.

Reluctantly Retained Uses

In cases in which the risk-benefit balance does not warrant immediate or phased cancellations, yet is still troubling, the EPA could benefit from the authority to label certain pesticide applications as "reluctantly retained uses." Such uses would be subjected to a higher degree of ongoing monitoring to quantify more closely all possible sources of exposure and would be studied more carefully for possible sources of hazard. The EPA might also find it useful to have a simplified administrative process to cancel or phase out a reluctantly retained use, if new data heightened the risk or if new products emerged that promised to reduce the benefits associated with a reluctantly retained use.

Designation as a reluctantly retained use would also help define areas of need to public and private sector researchers. The EPA is seriously considering adoption of this concept. Indeed, the concept originated with the agency, and the agency should follow through on this excellent idea.

Crop-Level Regulation

In the past, EPA regulatory actions have been structured on a single active ingredient across all its registered crop uses. This approach to regulation creates a situation in which a regulatory action on one pesticide might actually lead to expanded use of an even more hazardous alternative pesticide. Risk would rise, not fall. As more older chemicals are retested, the EPA will face this potential dilemma with increasing regularity.

The EPA could be given authority to review simultaneously the risks and benefits associated with all chemicals registered for control of a given category of pest on a given crop. For example, for tomatoes, all registered fungicides would be assessed as a class. Those fungicides registered for use on tomatoes that offer the most favorable balance of risks and benefits would be returned. Such a regulatory tool would complement, not replace, existing procedures.

Establishing Incentives for Technological Change

For pesticide uses subject to a phased cancellation action or identified as reluctantly retained, the EPA could offer to expedite regulatory review of new registration applications. A chance of reducing the time needed to reach the market by one or two years would constitute a major new incentive for industry.

Another positive incentive could be established by offering patent term restoration exclusively, or for an extended period, for pesticides that gain registration and compete with pesticides subject to phased cancellation or identified as reluctantly retained. Other options could be studied to provide favorable proprietary protection of new technologies that offer alternatives to existing pesticides that raise questions of risk. Such protection could be crucial when a new pesticide or control technology is developed or uses an innovative method or delivery mechanism that is itself of great value to the company.

A third option would involve use in the pesticide program of a best available technology (BAT) concept for formulation and application technology. Formulation and application methods are essential in determining the extent to which a particular pesticide could contaminate surface water or groundwater or expose applicators or farm workers to heavy doses of a chemical.

When a company develops an improved way to mix or apply a pesticide, the EPA could study the applicability of the technology to other chemicals and crop uses. If the technology is determined to constitute a new BAT, other companies could be required over a period of time to use comparable formulations and application techniques. Companies that propose new registration applications already incorporating BATs, or that voluntarily amend existing uses to employ BATs, would then receive expedited reviews and favorable consideration in the regulatory process.

Excessive regulatory delay in registering novel pesticides and control technologies using genetic engineering also must be addressed by the EPA. Two problems persist: (1) lack of a process for reaching scientific and regulatory judgments on biotechnological product applications and (2) data requirements and test protocols that make it difficult, if not impossible, to satisfy all the possible questions the agency might raise. Totally lost in the EPA's initial struggles with biotechnological applications is the fact these technologies have the capacity to solve pest control needs in safer ways.

New Options for Solving Minor Crop Pest Control Needs

Most fruit and vegetable crops are considered minor crop uses of pesticides. They are minor in potential pesticide markets in terms of the acreage involved. Pesticide residues on these crops, however, are often major sources of dietary exposure. Many uses of pesticides on these minor fruit and vegetable crops are far from minor in terms of risks to applicators, farm workers, and people living nearby. Similarly, in terms of benefits, minor crop uses of pesticides often entail high benefits per acre because of the high value per acre of such crops.

The need for new incentives to encourage innovation is particularly great for minor crop uses of pesticides, yet the interest in attaining minor crop registrations may diminish as regulatory requirements become stricter and as industry consolidation progresses.

In 1986, the EPA took steps toward establishing special incentives for companies and grower organizations to defend and apply for minor crop use registrations. One important initiative is the concept of regional registration, which has been advanced in a variety of EPA policy statements and actions.

A constraint faced by companies in gaining minor crop registrations is the need to conduct required residue chemistry and environmental fate studies in all areas in which a pesticide might be applied on a minor crop. As an alternative, the EPA has begun granting registrations that allow a chemical to be used on a minor crop in one, or a few specific regions, but not in all parts of the country. Such regional registrations exempt applicants from trying to develop data sets sufficient to respond to any and all special problems that might develop in a particular location or in regions where a certain pesticide would never be needed because the target pest is not a problem.

Another interesting idea is establishment of a network of 6 to 12 independent, quasi-public institutes, or centers of excellence, to pursue improved pest control technologies for minor crop use. Such research institutes would conduct research on pest control needs in minor crops, explore chemical and biological control options, and when appropriate, apply for pesticide registrations. The charter of the institutes and their funding base would be broader (and the funding, hopefully, more reliable) than that of the existing InterRegional Project 4 (IR-4) program, which helps generate residue chemistry data for minor crop pesticide uses. IR-4, administered by the U.S. Department of Agriculture's Cooperative State Research Service, provides a mechanism for state agricultural research and extension workers to identify specific pesticides that will meet particular needs on crops and generate data needed to establish how the pesticides should be applied and what residue levels are expected to remain on crops upon harvest. The IR-4 concept and its track record provide a solid base from which to begin in developing the mission and structure of the institutes.

Liability concerns often constitute the critical impediment to minor crop registrations. Pesticide manufacturers have to take into account their liability exposure if high-value crops are lost to pests or pesticide-induced problems. If established by Congress, these research institutes could be exempted from liability claims.

These research institutes could provide an important new vehicle for public-private sector cooperation and collaboration in solving pest control needs. They could help on the scientific front by focusing on safer, more profitable ways to avoid pest losses. Research on pesticides would be an integral part, but not the exclusive purpose, of the centers. They could also be charged with helping to develop the scientific base for improved environmental monitoring of pesticides, a key step if the EPA is to recognize more accurately and insightfully the pesticide risks that warrant regulatory attention.

Populations at Risk and New Routes of Exposure

Goals for improved pest control technologies must include major progress in reducing the level of hazards faced by population subgroups that are occupationally exposed to pesticides. Concern in the United States focuses on farmers and farm workers who mix, load, apply, live near, drink water contaminated by, and work in fields treated with pesticides. The problem is worse in developing countries. Regrettably, little effort—public or private—has been directed at even gaining an understanding of the scope and magnitude of this problem.

The courts charged the EPA with the responsibility of protecting the health of approximately 2 million U.S. agricultural workers in 1974. Since then, barely perceptible efforts have been made to gain a greater scientific or empirical understanding of the problem. Lacking such data on farm workers' exposure, it remains impossible to quantify risks, and as long as risks are unknown, regulatory actions are difficult to justify.

Many organizations and institutions have examined the political forces and institutional limitations that perpetuate this situation. Conclusions are:

- Farm workers are the largest group in the United States who are not protected by a risk-averse set of occupational safety and health standards, like those imposed by the Occupational Safety and Health Administration (OSHA) for most other industries.
- The health risks and health effects of pesticides on agricultural workers have never been studied in a systematic, scientific manner. Without study, regulatory efforts to protect these workers can go nowhere.

It seems clear, then, that any regulatory agenda seeking improved pest control technologies should include practical plans to overcome these problems. Following are some possible strategies:

• Decisions regarding registration and tolerance levels for pesticides used on labor-intensive crops should be based on a more scientific assessment of health risks encountered by farmers and farm workers.

• The EPA should develop an ongoing process within the Office of Pesticide Programs to reach more definitive findings concerning the magnitude and scope of pesticide-related health hazards encountered by farm workers. When appropriate, OPP should seek the help of other divisions of the EPA, the Centers for Disease Control, OSHA, and the National Institutes of Health to conduct research.

• More effective steps should be taken to ensure that people who work with and around pesticides understand the risks involved and what they are *required by law* to do to minimize risks to themselves and others.

On the international level, problems with pesticides track the constantly changing structure of international trade in technology and commodities. Although pesticide manufacturers in the United States are exporting significantly smaller amounts of pesticides that have been cancelled in this country, the use of many of these compounds continues to grow on a global scale. The misuse of highly toxic organophosphate and carbamate compounds persists, as do problems stemming from the near futility of maintaining quality control of pesticide products in developing countries. And, as other nations develop the capacity to export to the United States a broader mix of agricultural and specialty crops, questions of equity in international regulatory standards become an important economic and public health issue.

One of the greatest problems with pesticide use, when considered on a global scale, remains expanding reliance on organochlorine and other persistent compounds. Although some of these compounds, notably DDT, still have certain valuable applications, particularly in the control of insect vectors of infectious diseases, these compounds still present hazards that will have to be addressed.

Developing nations face special problems in reducing their reliance on these older pesticides, many of which are both cheap and available. The largest producers of compounds such as DDT include India, Mexico, China, and Indonesia. In some countries, growth in productive capacity has been directly funded by multilateral development banks; in other countries governments have imported outmoded production facilities piece by piece, often in a joint venture with the previous owners of the facilities. Once these countries sink scarce capital into a manufacturing infrastructure, it becomes difficult for them to finance changes in pest control technologies, even when the need is great. The need for efforts to overcome these international problems is emphasized by the fact that the level of DDT in human breast milk in China, India, and Mexico is about sevenfold higher than in Western developed nations.

Without major institutional and economic reform, problems of quality control and misuse of pesticide products will continue in developing nations. One solution often tried by governments of developing countries is to copy regulatory decisions made by the U.S. Environmental Protection Agency. Such a strategy is rarely optimal and can lead to the adoption of irrelevant, and in some cases counterproductive, regulatory restrictions.

The best way to deal with these problems in developing countries is to support in-country establishment of greater capacity to interpret pesticide data and to make informed decisions regarding control strategies. The emergence of safer alternative technologies should be an objective. Increased cooperation and exchange between the EPA and regulatory officials in developing countries would be another positive step. Freer exchange of technical data on health and environmental effects and a formal program involving the exchange of scientists between the United States and developing countries would also help.

Better patent protection and recognition for new chemicals in developing countries is also a legitimate goal and should be encouraged through diplomatic channels. Other incentives for the transfer of improved technology to developing countries could be devised and implemented by the EPA, multilateral development banks, and international organizations.

Other Issues and Initiatives

The FIFRA statute and EPA's regulatory program are complex. Almost all sections of the statute could have some impact on the development and use of improved pest control technologies. A complete review is beyond this paper, but several items warrant being highlighted for further study.

Economic Issues

In terms of how different components of the pesticide industry interact, the most divisive issue arising from FIFRA concerns the data-compensation provisions. Very simply, once a patent for a pesticide expires, FIFRA allows other companies to cite the data developed by the company that originally discovered, tested, and gained registrations on the pesticide. Citing the existing data provides a follow-on registrant with cheaper, quicker access to pesticide markets.

A major problem routinely arises, however, because the statute calls for compensation to be paid the original registrant, yet provides no clear guidance on how the amount of compensation is to be calculated. The EPA inherited the unfortunate position of administering this complex set of data-compensation provisions and is caught in the middle of multimillion-dollar internal struggles to either gain market entry or protect market share. Data compensation is not an issue for the faint of heart.

The problem poses a serious strain on the entire regulatory process and must be resolved so that the EPA can focus on its primary mission—protecting the public health and environment while ensuring availability of an effective set of pest control methods. Legislation will undoubtedly be required to clarify the criteria and method that should be applied in calculating "fair compensation." Short of Congress legislating the formula for every compensation agreement, this provision of the statute will probably never work. Alternatively, Congress could eliminate data compensation completely and replace it with a fair and workable mix of proprietary protections and generic pesticide law. Such a new approach could be modeled after the bill passed for human medicines in the 99th Congress, and the one likely to be passed in the 100th Congress for animal drugs.

Inert Ingredients

About 50 inert ingredients in hundreds of widely used pesticide products are toxic and could actually be posing greater risks than active ingredients. Virtually no scientific or regulatory attention has been devoted to evaluating these risks. Fortunately, the EPA and the industry are beginning to address this shortcoming. An attractive policy option is the establishment and use of a list of generally recognized as safe (GRAS) inert ingredients. The EPA inclination toward such an approach should be supported with an investment of additional resources and, perhaps, some political attention.

Exemption from Regulation

A recurrent weakness in pesticide regulation is the failure to distinguish real sources of significant risks from trivial sources of implausible risks. The EPA should modify its policies under Section 25 of FIFRA and exempt more products from regulation under FIFRA. Such products could be designated as GRAS and be subject to less rigorous and less resource-intensive regulatory treatment.

Congress should also direct the EPA and other science-based agencies to study the new and anticipated pest control products of biotechnology to determine which deserve GRAS status or other types of expedited review.

Reform Indemnity Provisions

The FIFRA statute now requires OPP/EPA to pay, out of its operating budget, indemnities for unused stocks of pesticides subject to emergency suspension or cancellation. This provision penalizes the EPA for taking such decisive actions. The penalty, moreover, can be serious. A recent EPA emergency suspension could cost the agency more than its annual operating budget. Such a consequence is intolerable. Indemnification funds should be granted by special appropriation or come out of a judgment fund established for this purpose.

Flagging Adverse Effects

A key step toward safer pesticides is recognizing as early as possible when an existing chemical poses worrisome risks. The mechanism for doing so is contained in Section 6(a)2 of FIFRA, and it is one of the critical tools and authorities of the EPA that is poorly used. Much stronger and more direct enforcement and regulatory responses should be built into the requirement to report adverse effects that was established in this section of FIFRA.

Improved Access to Data on Pesticides

The task of monitoring pesticide use, estimating exposure, and calculating risks is growing increasingly difficult. The EPA lacks the resources to carry out this role to anyone's satisfaction. Even with the help of all state regulatory programs, the EPA cannot be expected to identify quickly all problematic situations. To help public agency efforts, the FIFRA statute establishes a role for citizens, pesticide users and applicators, and public interest groups in overseeing and participating in the regulatory process. Restrictions on making data on pesticides available, however, have thwarted public efforts to participate in the regulatory process.

Amendments to FIFRA would be required and are needed to authorize the EPA to release information on pesticide use patterns. It is critical that individuals or groups know which pesticides are being used, and in what quantities, in each region of the country if they are to monitor or conduct research on health or ecological effects.

This statutory restriction is a handicap in the conduct of intelligent research and monitoring efforts. Economic planning and forecasting efforts to identify technological needs are also penalized by a lack of reliable, current data.

A major initiative, mandated and funded in legislation, is needed to overcome this fundamental problem. It will be difficult to monitor pesticide-related problems and economic needs effectively even when patterns of pesticide use are known. Without such an initiative, research on pesticide effects and forecasting pest control technology will progress blindly across the country, imposing higher costs on society and ensuring that some problems—and opportunities—will remain undetected longer than need be.

Cosmetic Standards

Experts believe that a significant portion of the pesticides applied to some fruit and vegetable crops are used only for the sake of appearances or in the hope of ensuring uniformity, extending shelf life, or both. The public should be given a greater opportunity to express its preferences in the marketplace. It is not know whether the public demands blemish-free orange peels, when the pulp of the orange contains toxic pesticides, in contrast to pesticide-free fruit with scabs on the peel.

The EPA has a clear role in identifying uses of pesticides that are solely, or primarily, for cosmetic purposes. A more analytical process should be initiated in calculating benefits associated with cosmetic pesticide use. Such benefits are indirect. When appropriate, consumer surveys and educational initiatives should be undertaken to determine if consumer preferences—and hence pesticide benefits—might shift with the increased consumer education.

THE PROSPECTS FOR CHANGE

A variety of regulatory reforms are discussed in this paper that could be helpful in establishing new private sector incentives for beneficial technological change. To understand the probable likelihood and consequences of pesticide regulatory policy reform, one must consider how such reforms are likely to fit into the broader political context governing FIFRA and the structure and performance of the pesticide industry.

Toward this end, four observations are offered for consideration:

First, although the FIFRA statute is flawed in terms of providing incentives for beneficial technological change, modest statutory and administrative changes may be all that are required to alter the performance of current pesticide programs.

The FIFRA statute is complex, yet most of its concepts, criteria, and procedures are generally well conceived. It would not be difficult to develop a package of FIFRA reforms to induce beneficial technological change, but these would be implemented only if a political consensus supported such change. The impetus for such a change would need to come from politically prominent individuals or groups with a broad vision.

Second, we are in the midst of current economic stress and uncertainty throughout the agricultural sector. Agrichemical companies and farmers have to contend with shrinking markets and unpredictable government policies. Global overproduction, brought on by pricing structures for basic agricultural commodities that are well above market-clearing levels, creates the need for other government policies to hold back production. In 1983, when the United States idled almost one-third of its cultivated cropland, agribusiness companies were caught with excessive inventories. Many suffered major losses that year, and the experience convinced many corporate leaders to pay closer attention to a wider array of agricultural policies.

In the United States and Europe, dissatisfaction is growing with the high cost of programs to support agricultural commodity prices and incomes. Pressure for new approaches is building and could alter the size and nature of markets for agrichemicals around the world. If the United States moves toward a heavy-handed, even mandatory supply control policy, one predictable result is that over 80 million acres will go unplanted for perhaps several years to come. Agrichemical sales will fall in the United States and increase in those countries that rush to capture the share of the export market forfeited by the United States. If other policy strategies and goals are adopted, such as reducing the cost of the programs and establishing new rules governing the distribution of direct payments to farmers, the impact on agrichemical sales will be more complex to predict.

Some leaders, including Senator Sam Nunn (D-Ga.), are exploring other policy options driven by a combination of resource conservation goals and fiscal restraint. An important consequence of a conservation-driven policy is that it could facilitate adjustments in regional production patterns. Such adjustments, in turn, could prove beneficial to U.S. competitiveness, because many of the areas facing serious problems with soil erosion and groundwater depletion and contamination also face high cash costs of production. By targeting these areas for special treatment under an expanded conservation program, nationwide average costs of production could be reduced for basic commodities. Agrichemical sales under such a policy would surely shift in a variety of ways, and important new incentives could be established for safer pest control technologies.

The third observation is that complex economic issue are involved in exploiting the capacity of agrichemical industries to develop improved technologies. Currently, a company can face substantial domestic and international penalties when it chooses to cease use of an older, hazardous product and move a newly registered, safer proprietary product into the same commercial crop uses. The domestic penalty can arise from the actions of a follow-on, generic registrant who could be free to keep the older product on the market in a position to compete with any newer products. A possible solution to this problem is available under FIFRA—seeking voluntary cancellation—but such a strategy may be resisted by the follow-on registrant and may also have adverse international consequences.

The international penalty arises if and when the EPA takes action to cancel a product. Many countries around the world copy U.S. regulatory actions. Hence, loss of a U.S. registration soon undermines a large share of global sales. While this may open other markets, developing countries may not be viable markets for new technology. Companies caught in this paradox often respond by fighting U.S. cancellation actions, even when they privately agree that such actions are warranted under U.S. law.

A fourth basic observation deserves note. Changes in pesticide regulatory policy should take into account the implications of the ongoing consolidation within the global pesticide industry. There are now about 20 major corporations involved in pesticide R&D, manufacturing, and marketing. Most industry analysts and experts expect that there will be only 6 to 10 major corporations within three to five years. Concentration of the industry heightens the importance of resolving intra-industry economic issues, including patent term restoration, compensation for health and safety data, protection of trade secrets, and the nature of public sector oversight and influence on private R&D priorities.

Other issues arise from the interactions of small, research-intensive biotechnology firms and large global chemical companies. A disproportionate share of innovation, measured by either product or process patents, continues to emerge from small companies that have, as a group, virtually no market presence or manufacturing and marketing capability. For innovative pest control technologies to work their way from small-company laboratories to widespread commercial use, the major companies have to be brought into the process. Only they have the capital and expertise to move the new science through scale-up, the regulatory process, and ultimately onto the farm.

The critical unresolved question is whether they will, and under what terms. One thing is easy to predict, they will do so only if there is a plausible prospect of earning a profit. This observation leads directly to the crux of this paper—pesticide regulation must come to grips with rapidly evolving technological opportunities to control pests in safer, more sustainable ways. We have to make it profitable to control pests with safer products.

SUMMARY

Science can deliver improved pest control technologies that will result in much less widespread public risk from dietary exposure and progress in limiting occupational exposures here and abroad. The rate and direction of progress are likely to be determined as much by public policy as by the nature of scientific advances. For this reason, reforms are needed regarding the effects of pesticide regulatory policy on technological change.

New regulatory tools and options would help the EPA to provide greater incentives for development and adoption of innovative products. One of two critical needs in this regard is taking more decisive action toward restricting use of older pesticides found to pose greater risk than once thought. Such actions will open up market opportunities for new, improved technologies. The second need is to overcome within the regulatory process an inherent fear of new sorts of technologies that might conceivably pose some sort of unknown risk. Fear of the unknown is an appropriate public and private response, but when taken to the extreme in the context of pesticide regulation, such fear is likely to prolong the public's exposure to older products that clearly pose toxicological concerns.

To conclude, the distribution of effort to improve pest control technologies should be refocused, both in the public and private sectors. More attention should be directed to analyzing the prospects for innovation in control technologies for minor crops and meeting pest control needs in developing countries. The special hazards faced by occupationally exposed individuals also deserve more prominence on scientific and regulatory agendas. The extent and severity of hazards faced in developing countries from pesticide misuse and the nutritional consequences of failed pest control efforts are troubling and warrant a concerted and enlightened response from the developed world.

Can or Will the New Technologies Pay?

Darryl D. Fry

Can the new agricultural technologies pay? There is no question. The answering is a resounding yes. Society can benefit from the new agricultural technologies. It always has; and many times, the long-term benefit has been orders of magnitude greater than the first applications.

The second part—will these technologies pay—is more difficult. For any technology to pay, three separate conditions must exist. In the scientific realm, the technology must be safe and effective. In the economic realm, it must be cost-effective and there must be market demand. In the policy realm, it must survive the risk-benefit process and not be unduly handicapped by governmentally imposed external costs or unfair treatment of competitors. So the answer to this question depends on what technologies we are talking about and on who we are talking about—the consumer, farmers, or manufacturers. Third, it depends on which public policies we are implementing.

The types of technologies that are the subject of discussion can be summarized as follows. Through genetic engineering, there is hope we can develop plants that can produce their own nitrogen and give larger yields and ore nutrients. We are looking for plants with built-in resistance to insects, fungi, disease, drought, and temperature extremes. On the animal side of agriculture, the new biotechnology holds promise for new immune systems, new vaccines, and proteins that will stimulate lower cost milk production and animal growth. And these will only be the first generation of products.

In reality, many of these so-called new biotechnologies involve concepts based on centuries-old applications. Genetic engineering by classical selection was employed to transform wild plants into most of the crop varieties and ornamental plants we find today. These same genetic technologies have bred ever more efficient swine, cattle, dairy cows, and poultry. In the past, the process of breeding both plants and animals took a long time, but the results have been astounding.

Bovine somatropin (BST) is an interesting example of the new biotechnology versus genetic selection. In the past 30 years, milk yield of dairy cows has increased dramatically from an average U.S. dairy herd yield of under 6,000 lbs of milk per cow per year to over 13,000 lbs, and the record top producing cow is about 50,000 lbs. All of these improvements have been achieved by classical breeding selection coupled with good dairy management. It is a fact that high-producing cows naturally have correspondingly higher levels of BST, and apparently this was the genetic trait actually being selected over the past 30 years by classical breeding.

While scientists have been aware of BST's role in diary production for years, collecting enough naturally occurring BST was very expensive. American Cyanamid is one of the pioneers in accelerating BST production from genetically altered bacteria, thereby ensuring wide availability at economical prices. Cyanamid is now engaged in intense and lengthy government approval processes as a prerequisite to BST commercialization. When these approvals are received the product will be available to U.S. farmers, and this genetically engineered BST will supplement the classical breeding selection that has already been a standard for improving milk productivity and reducing cost.

This is just one example of a new technology that mimics older technology—making it seem less forbidding and futuristic.

IMPACT OF CONSUMER

Let us look at the impact of the early biotechnologies and if they will pay for consumers, farmers, and manufacturers like Cyanamid. Generally, new agricultural technology almost always benefits consumers. Innovation leads to improvements on the farm, and the intense competition among farmers and among manufacturers creates a pass-through to consumers.

At the start of this century 50 percent of the U.S. population lived on farms. Food costs represented 40 percent of consumer spending. Through the adoption of technology our on-farm population is now only about 2 percent, and food costs represent only about 15 percent of consumer spending. Many of the things we take for granted today as necessities never could have been developed were we not able to free up sufficient people from the production of food.

Some might argue that we have gone far enough because there are no unfilled needs today; we have enough agricultural technology; the reduction in the number of farms from a 6.8 million high in 1935 to 2.1 million today is enough; having over half of the world's food supply in the hands of just

1 million farmers is enough; and there is no need to concentrate our food production even further through more new technology. Why risk oversupply of food to decrease food costs below just 15 percent of disposable income? This perspective has several flaws.

First, to the affluent or even the average person, decreasing food costs below 15 percent of income is a small matter. But not all of our citizens are affluent or average, and decreasing their cost of food would substantially improve the quality of their lives, or at least the quality of their diets.

Second, some say we should control world food supply by cutting back production at home, since it only affects a few farmers who will be leaving their farms eventually. But we cannot ensure that other countries will not adopt the new agricultural biotechnology, thereby decreasing their costs or increasing their output, both of which would place the United States at a competitive disadvantage. One need only look at what other countries have done to our agricultural product sales and our steel and automotive industries. And, the U.S. agricultural industry is far more than just 2 million farms. It includes equipment, fertilizer, and chemical manufacturers, seed suppliers, distributors, dealers, transportation groups, and many other support systems. In total over 20 percent of the U.S. work force derives its primary income from farming or the food supply system. Placing so large a group at a competitive disadvantage would have significant long-term implications for the United States.

Third, the new biotechnology appears to promise a decreased chemical load on our environment as well as reduced demand for energy. As an example, early herbicides generally were used at rates of pounds per acre, while the more recent herbicides are used at rates as low as grams per acre. Biotechnology promises to continue this trend to further reduce concerns over food safety and groundwater contamination.

Finally, when we think of the new biotechnology, we seem to focus too much on producing greater volumes and not enough on lowering costs. That is not unusual. Contemporaries often view new technology simply as a substitution to wit, cars replaced horses; electricity replaced the oil lamp. But applications for the power engine and electricity have expanded far beyond those first uses. Clearly when the engine and electricity were first introduced, their inventors and their customers did not conceive future potential uses in television, computers, airplanes, and space travel. When biotechnology passes the first wave, we will have the ability to create unfilled needs never before contemplated. For example, the second phase of biotechnology in agriculture could result in the development of designed food stuffs that are free of naturally occurring carcinogens and cholesterol ("Guess Who's Coming to Dinner? Mother Nature and Her Spectrum of Chemicals," American Council on Science and Health). Nature has provided hydrazines, nitrates, toxins, carcinogens, and mutagens. These naturally occurring chemicals may be engineered out or replaced with beneficial compounds in future crops.

In short, the consumer will definitely benefit from agricultural biotechnology if it is adopted.

BENEFITS FOR FARMERS

Farmers, on the other hand, may not benefit quite as broadly. Not all technologies are alike. Some, such as mechanization, require large investment and are best suited to large farming operations. Others, like agricultural chemicals, seeds, and bovine somatropins generally do not have threshold farm size requirements. These technologies seem equally suited for small, medium, and large farms. Overall, however, most of the biotechnology will probably be helpful on progressive farms of any size.

An important question is: Will U.S. farmers benefit overall from the new biotechnology? If we adopt new concepts faster than other countries, our costs will be lower and our quality can be better. The U.S. farmer used to prosper through his rapid adoption of new technology. Until the recent past, the United States led the world in technology. But agricultural technology worldwide is now increasingly uniform, and the U.S. farmer's prosperity has suffered. National policies that do not encourage use of new technology will prove to be shortsighted. In addition, other industrialized nations are aggressively promoting new technologies, and U.S. policies that discourage technological innovation will diminish the competitiveness of U.S. farmers in world markets. In the world market, it will not be difficult to raise prices for agricultural products. So for our farmers to survive, they will need to be the most cost-effective producers. If they are not on the leading edge of the new technologies, they simply will not be able to compete without heavy government subsidies.

MANUFACTURERS' CONSIDERATIONS

But let us not focus solely on the impact of biotechnology on the consumer and farmer. In reality it is not "au fait accompli" that they will be impacted at all. Manufacturers will not develop products if their risk-benefit assessment does not make sense. Therefore, let us look at the manufacturer.

Even with a public policy climate that is conducive to technological innovation, manufacturers face significant risks. First, the cost of research and development (R&D) can be astronomical. The top 20 agricultural chemical companies spend about $1.5 billion a year on R&D, about one-half of which is spent in the United States. Then, the technology must be safe, ease to use, cost-effective, and timely. When all is said and done, not all companies are likely to profit from their technology investment. It is clear that many companies will not get a return on their investments from the past 5 to 10 years. But that is the reality of competition.

A strong corporate commitment to technology is needed for companies to spend so heavily on agricultural R&D. At the same time there is pressure on manufacturers to maintain their financial health. The current poor agricultural economy is stressful to manufacturers as well as farmers. Clearly, one of the most pronounced symptoms is the consolidation taking place among the basic agricultural supply companies. For example, in the past year, we have seen the divestment of the agricultural businesses of Shell USA, Diamond Shamrock, Northwest Industries, Union Carbide, and Uniroyal. And that is just in the agricultural chemical industry. The same thing is happening in the animal products industries.

In point of fact, many manufacturers are saying the new technologies will not pay, or at least that the economic risk in developing and commercializing them in today's environment is too great. At my company, American Cyanamid, which can be classified as a middle- to high-level investor in agricultural technology, the results of R&D have been as good as any company's. The company has been increasing its investment in R&D for many years and will increase it again next year, but it has become more cautious.

One major concern regarding the consolidation of agricultural companies is that in many cases agricultural research has been or will be shut down. This is a loss to the United States, and it is all the more troubling because agricultural technology is an area where we have traditionally shown leadership. Agricultural technology today, hopefully, is not analagous to the U.S. auto industry which years ago had many competing firms. The auto manufacturers consolidated into four and slowed their technology improvement. Now there are dozens of auto firms again, although most of them do no research nor manufacture autos in the United States.

Perhaps some of this consolidation should occur; perhaps there were too many agricultural companies. Perhaps these companies were spending too much on agricultural research. But focusing on unwise research investment tends to miss the point—investments are fragile—some succeed and some fail. The important thing is for society to provide the proper environment for innovators to take the economic risk.

PUBLIC POLICIES

A perfect environment for innovative companies does not exist, and it might never exist. However, some fundamental issues must be considered, one of which is whether the current regulatory framework is adequate for biotechnology. Some argue that the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) are inadequate for the task. It is said that a separate, new agency is needed to consolidate review of new technologies. However, each of those agencies is doing a good job in its scientific protocols for reviewing new technologies. These U.S. regulatory agencies are probably the best in the world, because they generally conduct sound scientific analyses.

One concern in the current regulatory framework, however, is the potential for fragmentation. The new technologies have national, indeed global, application and public policy can be established at the federal level. We can ill afford to have diverse state agencies conducting their own reviews and enacting their own individual policies when there is no clear local need.

Public safety and environmental protection should not be short-changed, however. As a large chemical manufacturer, these concerns are particularly recognized. First, there is a strong social responsibility for the public safety, and second, there is practical motivation: unsafe products and practices expose manufacturers to insurance liability and may threaten corporate survival. Another obstacle to technology investment is deficiencies in worldwide protection of industrial property rights, especially in Third World countries. Government should encourage the development of an international system to prevent the piracy of technologies.

Overall, however, the U.S. patent system has been responsive to the new biotechnology. The Supreme Court's decision that lifeforms can be patented was a major and appropriate step. However, there are 6,000 biotechnology patent applications yet to be decided by the U.S. Patent Office. Until these patents are issued or denied, it will not be known whether these inventions are protected or blocked. Also, until more biotechnology patent cases are litigated, case law will be difficult to project. But these problems are due mainly to the newness of the technology. The patent policy framework is fundamentally sound and does not require major change.

There has been significant discussion about Patent Term Restoration. Obviously, legislation is needed to make research investments realistic.

Recently during a session on Capitol Hill, a legislative aide said, "Your basic manufacturers are a bunch of cry babies, never satisfied, and always looking for something—Third World protection, patent term restora-tion, no additional state regulations, and speeding up the agencies. The next thing you'll ask for are target prices and deficiency payments."

Manufacturers are not asking for deficiency payments, but improvements are necessary to maintain investment risks at reasonable levels because the time span required to discover and then take a product to market continues to increase. Also, profitable product life cycles are shorter, investments are higher and more front-loaded, and more money is spent in discovery per marketable product and less is spent in manufacturing facilities.

Barriers to entry by pirates or generic producers are lower because facility investment is lower. For example, older agricultural chemicals required $1.00 of capital per $1.00 of annual sales capacity. With the newer products, this amounts to pennies of capital investment.

Other initiatives that might be useful include encouraging the development of uniform regulations on a worldwide basis to evaluate and approve new technologies; instituting procedures that ensure timely reviews by regulatory agencies; seeking reforms in domestic product liability laws to better balance society's need to encourage progress with the needs of individuals to receive appropriate compensation for injuries; and developing uniform regulations on a worldwide basis, from regulatory reviews to liability laws.

POLICY FORMULATION

Now let me comment on formulating public policy. Current policy formulation on highly complex scientific issues raises questions about the basic processes employed. Public policy formulation in a democracy relies on a well-informed public. But a 1979 study found that only 7 percent of adults in the United States met a minimal definition of scientific literacy. Lack of public knowledge of scientific approaches severely jeopardizes the ability to develop sound public policies with respect to new technologies. It makes the public susceptible to the allegations of those who know how to exploit fears and to conduct unfounded campaigns against technology. Therefore, credible agencies are essential. The FDA, EPA, and the U.S. Department of Agriculture are extremely critical to the well being of our country. Most people believe they are credible agencies, particularly when it comes to science. If those agencies make decisions on the basis of pressures from outside the scientific and safety communities, however, their charters will be violated and their credibility lost.

This is not to discount the need for public debate; interest groups can serve a valuable role in helping to crystallize the issues and bring matters to satisfactory resolution. Discussions that have an unfounded bias against biotechnology and other innovations are another matter, however. Unable to refute these technologies with arguments based on scientific merit, interest groups resort to minor technicalities in the process, or raise such a specter of fear with their rhetoric that progress might be delayed indefinitely. We cannot allow policy formulation to be dominated by public relations campaigns. Shortsighted political decisions based on unreasonable fears threaten to slow the pace of technological innovation in this country. We must seek out ways to reemphasize sound scientific analysis as a basis for decisions on science policy and the introduction of new technologies.

At the very least, scientific leaders need to mobilize a responsible public information campaign to educate the media and the public about the real risks and benefits of new technologies so that rational choices can be made. Knowledge is the antidote to extremists who prey on widespread and irrational fear of the unknown. The universities, particularly the land-grant universities and extension services, must focus more heavily on communicating that knowledge. Biotechnologies are an area of growth for the universities as well as for industry. The manufacturers and the trade associations stand ready to assist the universities in informing the public.

CONCLUSION

The new technologies can pay—for our country as a whole—and for forward thinking farmers, manufacturers, and others in agricultural fields. Whether they will pay or not depends to a large degree on the formulation of public policy.

And this is largely a question of where we set our focus—on technical merits, on market forces, or on political choices. Regarding technical merits, society rightly demands verifiable proof. Regarding market forces the consumer and farmer insist on safety and cost-effectiveness. Regarding political choices, they are best made when the electorate—and decision makers—are well educated as to both the risks and benefit involved.

These technologies will come to pass, they will be safe, and they will pay because this country is still blessed with responsible pioneers in government, science, and business who have the courage to forge ahead.

Issues Affecting Technical Change and Its Impact on the International Agribusiness Environment

Thomas W. Parton

This paper provides an overview of seven issues that impinge on technical change and its impact on international agribusiness. As used here, "technical change" refers to the further development of existing technologies that are made available to agriculture as well as the new technologies that can be foreseen, particularly in the area of biotechnology.

There can be no doubt that the international agribusiness environment has been changing rapidly. In many developed countries, agricultural production is in surplus, some sections of the general public perceive the risks from using modern technology as being unacceptable, and some legislators and regulators are responding accordingly. There can also be no doubt that clear links exist among these environmental factors. The high rate of technological change, the "who needs it" syndrome arising from the surpluses, and the high level of individual material satisfaction make an antitechnology attitude a very easy one to adopt. On the other hand, many developing countries face a nutritional deficit and lack the resources to respond to their needs either by increasing their own production or by importing food.

FINANCIAL SUBSIDIES FOR AGRICULTURE

The extent of government-provided financial subsidies for agriculture will certainly have an impact on both technical change and agribusiness. Such support will likely continue in many countries, but on a gradually decreasing scale. The extent of the subsidies will depend on whether the head or the heart rules governmental policies. Rationally, a reduction in subsidies will increase efficiency, but emotionally, so much tradition, ways of life, social upheaval, and votes are at stake that subsidies for agriculture will continue to play a larger role than in many other industries. In fact, it seems clear that within certain limits the general public supports such subsidies.

The policies of the European Community (EC) are of particular concern to U.S. agriculture, and there is great interest in what those policies will be over the medium term. The EC's policies will also probably have a mixture of the head and the heart in them. It seems clear that the maintenance of financial subsidies for agriculture in their current form will slow the full acceptance of new technology, reduce the efficiency or productivity of agriculture, and ensure a continuation of surpluses and a reduction of competitiveness.

What is needed are financial support policies that respond to social needs but that require farmers to make decisions at the microeconomic level that are linked to world market conditions. We must uncouple social needs from the need to face economic reality. It may appear, at first glance, that lower crop prices for the farmer, which would follow from such policies, would hurt the input side of agribusiness. It may well do so in the short run, but in the long run, it will produce an industry that is responsive to technological change, that is competitive, and that has the capability to secure and to create new markets.

DEVELOPED AND DEVELOPING COUNTRIES

The developed countries will be in a position to accept new technologies and improvements in existing technologies more readily than developing countries. The infrastructure is there. Indeed, in the United States, if agriculture is to remain competitive, it will have to continue to improve its productivity, and the acceptance of new technologies is a clear need in that respect. The overwhelming part of the agrichemical industry's contributions to new technology, for example, will be initially aimed at developed countries.

Developing countries already have tremendous opportunities for increasing productivity through existing technology. They should, and by and large will, progress gradually through the stages of technological development as they build their infrastructure. Some countries will undoubtedly try to move more quickly than others to the more advanced technologies, but in most cases it will be a wasteful use of very scarce resources. Agribusinesses, for their part, have a clear responsibility to adapt existing technologies more fully to the needs of the developing countries. It is for the world's political leaders to create the right economic and political climate to enable the developing world to help itself. But it would be a major disservice to the *developing* world if the *developed* world failed to accept new technologies.

INTERNATIONAL TRADE

Governmental intervention, and thus the distortion in the international trading of agricultural commodities, will continue, to the chagrin of those countries that claim to have unsubsidized agricultural exports. Better or more appropriate agricultural support policies would reduce the need for governmental interference, and perhaps some clear, statesmanlike views will be expressed and carry weight at GATT (General Agreement on Tariffs and Trade) conferences. We could make better use of the world's resources, for example, if we had less interference in the trading of agricultural commodities. Moreover, if more markets could be opened to products from developing countries, a significant contribution could be made to narrowing the North-South gap, to the ultimate benefit of everyone.

It is of great importance to agriculture that the international debt crisis be solved. As long as it exists, it will cause distortions in the way national agricultural policies are directed in many developing countries, to the detriment of economic development in those countries. The debt crisis will also distort international competition in agricultural products. It is not as simple as it is made to sound here, but one may well wonder why normal economic business laws should not apply to loans—if you make a bad loan you should suffer for it.

IMPLICATIONS FOR CROPS

Only those crops that offer large enough markets to facilitate recovery of research and development (R&D) investment will be the major focus for the new technologies. It is also apparent that in biotechnology, as with all private research, protection of proprietary rights is a critical consideration. Researchers will be attracted to the crops and countries that offer the best opportunities for them to protect their inventions.

Before the turn of the century, there will be an increasing focus on crops that will provide an energy-chemical resource as an alternative to fossil fuels. This area of technological development is receiving less attention now than it did in the late 1970s, but the focus will return.

REGULATION OF TECHNICAL CHANGE

Perhaps the most important area of concern for the future of agribusiness is the regulation of technical change. Legislators and regulators must interpret their public responsibility in a way that strikes the right balance, that is, takes advantage of the opportunities for society while minimizing the risks inherent in any new technology. Neither legislators nor regulators will be able to discharge their public responsibility optimally, however, unless the public they represent has a clear understanding of the benefits and risks associated with new technology and is satisfied that the risks can be managed.

The agribusiness industry itself has a clear responsibility to explain the benefits and risks of the new technologies, but it is seen as being biased. Legislators and regulators can greatly assist the process if they see themselves not only as policemen but also as facilitators of an understanding of technology. It is a proper function for regulators to explain to the general public the true nature of the risks and benefits of new technologies in language that the layman can understand. There is no doubt that the environmentalist (for the want of a better word) has done a better job of explaining the risks of modern technology than those—including agribusiness—who should have been explaining the benefits.

Some aspects of regulatory policy on biotechnological developments will increasingly influence the course of agribusiness. The most immediate and controversial issue in biotechnology is the release of genetically modified organisms into the environment. There is growing public concern that such organisms released in field tests could proliferate far beyond the test site and pose potential danger to public health and the environment. In response to this concern, regulators in many countries are in the process of establishing laws and guidelines to govern modern industrial biotechnology. In some areas of biotechnology, the existing regulations are adequate, but in others, rules have yet to be established. Many regulatory and other agencies (e.g., the U.S. Department of Agriculture, the Environmental Protection Agency, the National Institutes of Health, and the Food and Drug Administration in the United States) are involved in this process. It is still too early to make any judgment on the kind of impact this regulatory trend will have. What is required for appropriate regulation of this key sphere, however, is an open, frank, balanced, and public discussion of the issues involved, followed by a reasoned evaluation of the risks and benefits. At the same time, we must never forget to deal with the emotional element of the public's concern. Legislators' ears, in general, are much more finely tuned to emotional reactions than to scientific ones.

The *need* to regulate technology is not at issue here. Society has a right to be protected from unreasonable risks, but society, or its representatives, also has obligations. It must say what standards it wants and why it wants them, and then technology will find a way to meet those standards. Standards must also be upgraded from time to time, but in upgrading them society must not apply today's standards to yesterday's actions and make moral judgments about those actions.

EFFECT ON AGRIBUSINESS

One effect of the new technology will be to change the structure of agribusiness. There is no alternative to a reduction in the number of companies producing agricultural chemicals, for example. Indeed, the reduction is already taking place. The research investments required for individual projects are going to get bigger and the elapsed time between initiation and realization is going to get longer. In many parts of the industry only the largest companies can make the necessary investments and take the long view. History has shown, however, that new technology and the existence of a healthy climate for its adoption will spawn many new entrants and keep the old guard on its toes by providing the necessary competitive stimulus.

There is still considerable scope for improving the chemical approach to solving plant protection problems, and most major companies in this field will retain an interest in both the chemical and biological approaches. What is needed are improvements that aid productivity (not necessarily volume of production), safety, and convenience.

The wave of antitechnology feeling mentioned in the introduction will affect corporate decisions as well as regulatory ones. Most corporate decision makers have options on how to spend their research dollars. If the emerging climate of public opinion that opposes industrial farming and high-technology inputs, such as chemicals and biotechnological products, is allowed to continue unchallenged, it will inevitably lead to a lowering of corporate investments in those fields. That would be disastrous for the United States, which has always enjoyed a lead in efficient agricultural production and in chemical research. The jury is still out on biotechnology, but here, too, the United States has tremendous potential. In the United States, some realism can be detected in public attitudes toward the benefits of new technology, but in Europe the problem is a very real one.

ROLE OF ACADEMIA

As the debate on the risks and benefits of new technologies gathers momentum, it is timely for all those with a vested interest in the issue to make themselves heard. Industry has to improve its own defensive strategies, but it needs help; academia can provide some of that help. Members of the academic world must defend their sciences. They have both a civic duty and a vested interest in this regard. If our colleges and universities are to have science students in the future, if they are to have research possibilities, whether government or privately sponsored, and if they are to enjoy public esteem in the pursuit of science, then they must explain the benefits and risks of science in language that citizens can understand and accept. Progress has been made to this end in the United States, but there is still room for improvement.

CONCLUSION

Tremendous opportunities for benefits to society from technical change seem possible over the medium term. If those benefits are to be realized, however, there must be constructive cooperation among legislators, regulators, academia, and industry. In particular, all must do a better job of explaining the benefits and managing the risks than they have done up to now. One final caution: If society rejects new technology, it will always be the marginal member of society who will suffer, even in developed countries.

Technical Change and Common Agricultural Policy

Günther Schmitt

Technological innovations have been and still are a major source of rising food supply in western Europe. This is even more the case than in most other parts of the world, where agriculture relied on placing additional land into agricultural production, changes in crop rotation toward high-yield crops, and the substitution of mechanical power for draft animals—the more traditional sources of increasing farm production (Food and Agriculture Organization, 1981; Grigg, 1980). Rising demand for food as a result of population and income growth within the context of industrialization had exhausted those traditional means early in the eighteenth and nineteenth centuries and stimulated the search for land-substituting production technologies as well as for synthetics to replace agricultural raw materials used by industry. Those technologies had been developed by applying scientific methods systematically to cultivating, growing, and nourishing plants as well as to breeding and feeding animals.[1] Biological innovations in agriculture dominated the progress made in production techniques and led to continuous growth of farm output, income, and productivity until almost the middle of this century.

HISTORICAL OVERVIEW

Productivity growth due to technical advances in agriculture has contributed to economic growth mainly by releasing farm labor to nonfarm and more efficient sectors, although to a declining degree (Denison, 1967). Economic growth, on the other hand, has stimulated labor costs in agriculture and led to the application of mechanical innovations by substituting capital for labor. Those innovations, however, have mainly been imported from Great Britain and the United States, countries in which land and capital have been and still are less costly relative to labor.[2] Due to both biological and mechanical innovations, total input in European agriculture increased, but slowly, whereas long-term farm output grew by less than 2 percent a year. This growth rate lagged the growth rate in demand for food at least until the Great Depression. Food imports, especially of food and feed grain to West Europe, rose dramatically; declining real world market prices due to the expansion of production in the New World and declining freight rates stimulated the growth in imports.[3] The international division of labor turned toward specialization in agricultural production in the New World and to industrial production in Europe.

Since the Great Depression (or even since the turn of the century), conditions started to change in almost the opposite direction. Productivity growth in agriculture lagged behind growth outside agriculture, so that farm income declined relative to nonfarm income. This process was accelerated by deteriorating sectorial terms of trade after World War I. For European farmers, the agricultural treadmill started to work (Cochrane, 1958), and farmers organized in effective interest groups forced the political decision-making bodies toward a farm policy that supported farm income by protective measures. Such rent-seeking activities of interest groups have always been supported by policymakers who fear declining degrees of self-sufficiency in domestic food supplies, worsening trade balances, and social unrest in farm regions.[4] Protectionistic measures, which were introduced in the 1880s, were reintroduced in the 1920s, and reinforced in the 1930s and again after World War II.[5]

When the European Community (EC) was founded in 1957, the most important member states, such as France, Italy, and the Federal Republic of Germany, had already established an extensive farm policy that protected domestic agriculture by restricting foreign farm imports.[6] As a consequence of this situation, the Treaty of Rome (1957) asked the EC Commission, in Article 43, to "convene a conference of Member States, with a view to comparing their agricultural policies by drawing up, in particular, a statement of their resources and needs." Such a conference was held in Stresa, Italy, in 1958. Based on the results of that conference, the EC Commission had to "submit proposals concerning the working out and putting into effect of the common agricultural policy" based on three types of such a common policy that had already been suggested in Article 40 of the Rome treaty: "common agricultural policy," mainly restricted to price and market policy measures, should be organized either by "common rules concerning competition, compulsory coordination of the various national market organizations or a European market organization." The EC Commission, as well as the Council of Ministers of the European Parliament, favored the latter, which led to a stepwise establishment of both common agricultural market organizations that were subject to price and policy decisions of the Council of Ministers and a centralized agricultural budget to manage the financial repercussions of price and market policies within the EC.

The establishment and consolidation of the Common Agricultural Policy (CAP) during the early 1960s had far-reaching consequences for agriculture in and outside the European Community. The most striking consequence has been and still is the EC's inflexibility in responding to the fundamental changes in the overall conditions of supply and demand for agricultural products within and outside Europe. Agricultural productivity growth, stimulated by an extensive price policy on the one hand and a successive enlargement of the EC to include originally low-price countries (such as the United Kingdom, Denmark, and Ireland) on the other hand, stepped up to about 2 percent a year. Agricultural research and the application of technical innovations generated by such research have been the favored farm policy measures of the EC and member states as well. Rates of growth in the demand for food, however, declined steadily to about 0.5 percent a year due to declining population growth and income elasticity of demand.

In the 1960s, the continued rise in farm output and the decline in demand turned the EC from a net importer to a net exporter of those farm products produced mainly by European farmers. Rising degrees of self-sufficiency and surpluses have been the consequence. And such surpluses could only be exported with the help of export subsidies that compensated for the difference between domestic and world market prices. The fact that export subsidies were absorbing more and more of the financial resources available had a depressing and destabilizing effect on world market prices and negatively affected agriculture in countries already or potentially exporting farm products.[7]

Especially in the 1980s the prevailing imbalance in the growth of supply and demand within the EC grew even worse, due in part to admitting Greece, Spain, and Portugal to membership but mainly to the economic recession within the context of the energy crises. This recession not only depressed the demand for food buy also adversely affected the process of structural adjustment in agriculture. Rising unemployment resulted in a decline in the opportunity costs of agricultural labor input, which resulted in a further increase in land prices despite declining real farm income and, consequently, in a further stimulation of land-saving and output-increasing production technologies.

The inability of the CAP to react adequately to the fundamental changes in supply and demand cannot be explained solely by the pressure of rent-seeking farm interest groups, well known though they be in Western parliamentary democracies. Those rent-seeking groups have been extremely successful due to fundamental institutional imbalances in the EC.[8] The EC was originally intended as a common market for goods (including farm products), services, and factors of production; economic and monetary policies were to be left to each member state. But with respect to farm policy, the CAP had to be established, because all the founding EC states had established national policies that had to be harmonized if farm products were to be included in the common market.

As a consequence of the establishment of a common market without centralized or harmonized fiscal and monetary policies, however, economic development within member states diverged more and more, as the large differences in inflation and growth rates, unemployment, and balance of payments demonstrate. Agriculture in those member states subject to unified producer prices has been and still is affected by those discrepancies in overall economic conditions and changes over time. Diverging levels and changes in farm income in member states are the most obvious consequences and have resulted in growing distortions of factor allocation within the EC. Farmers in member states that are subject to relatively unfavorable economic conditions are pressing the national government to "improve" price policies at the EC level as well as to extend national support of agriculture through social and structural policy measures that are not or are only partly subject to decisions of the Council of Ministers.

Moreover, decisions on the CAP are made by the ministers of agriculture; neither the ministers of finance and economy nor the European Parliament has any constitutional competence of control or co-determination. Thus, ministers of agriculture in member states marked by more stable economic conditions mostly do not resist the demand for increases in farm prices because they not only like to favor their "own" farmers, but they also likely expect a correction in exchange rates, which will sooner or later result in a decline of "national" producer prices.[9]

Finally, it must be added that the demand for higher farm prices is indirectly supported by the common budget that finances the farm exports of every member state: Higher producer prices are stimulating production and exports of farm products, which result in increasing export restitution payments and, in turn, contribute to the balance of payments of exporting member states.[10] Thus, farm interests are coinciding with the general economic interests of those countries.

In more recent times, budget expenditures for agriculture have exhausted the EC's available financial resources, although the direct transfer payments of member states have been lifted. Thus, the EC has been forced to reform its CAP. As a first step, price increases have been reduced, which resulted in a marked decline of real farm prices. Among other more minor measures, the EC has restricted milk production by a quota system. Those measures, however, are insufficient, given budget expenditures that are still rising and that exceed budget receipts. Further reform measures seem to be unavoidable. The prevailing discussion of such reform has resulted in a number of proposals that are being advanced mainly by the EC Commission's so-called "Green Paper" (Commission of the European Community, 1985d). Those proposals will certainly exert a strong influence on the type and direction of technical innovation in agriculture. More specifically, some of those proposals, as well as others put forward by member states and still other institutions, deal explicitly with innovations in production techniques for alternative products, the use of conventional outputs, and the support to be provided by corresponding research policies.

The financial and political support for agricultural research to generate such innovations is stimulated by the expectation that technical advances in traditional food production, either those available but not yet fully used by farmers or those expected soon given advances in basic and applied research, will expand farm output at similar rates as in the past despite a more restrictive EC farm policy. For its part, the research policy of the EC, most probably stimulated by extensive budget support as well as corresponding adjustments in farm policies, will have a far-reaching impact on technical change in European agriculture. Member states are supporting several research activities and will probably increase such support in the near future in order to gain the advantage over other member states. Agricultural interest groups are pressing national governments for additional support for research projects. National governments, for their part, have started a race among member states for such research subsidies. It seems quite obvious, however, that given that research activities will result in innovative farm products and production methods, those outcomes will themselves exert a strong influence on the future farm policy decisions of the EC.

The mutual interdependencies among the current CAP, the technical changes being stimulated by the agricultural research policy of the EC and individual member states, and the future adjustment of the CAP are discussed in the following section. First, the discussion turns to the current state of affairs concerning technical change in European agriculture and its economic and political repercussions. Following that, the impact of CAP on technical change in agriculture and future prospects for technical change are examined. The paper concludes with some speculations concerning the future of agriculture in Europe as well as of the European agricultural policy.

TECHNICAL CHANGE IN EUROPEAN AGRICULTURE: ITS SOURCES AND DIMENSIONS

Historically, as noted previously, technical change in Western Europe's agriculture has been dominated by land-substituting biotechnological innovations that stimulate the physical output per unit of land input. The "agricultural revolution," which started in the early eighteenth century in England with the application and intensification of "modern" production methods already in use in the Netherlands (Bairoch, 1976), was characterized by a systematic selection of high-yielding seed and breeding cattle, changes in crop rotations toward more intensive crops and less fallow land, and improvements in the productiveness of land, as well as in production tools. Almost half a century later, the continental countries of Western Europe, particularly France, started to overtake England and prepared the way for the Industrial Revolution, as well as further population growth.

The agricultural revolution of the eighteenth century, however, was dramatically stimulated by the Physiocratic movement, which declared agriculture to be the real source of economic wealth and spurred the foundation of numerous agricultural societies all over Europe that promoted technical innovations in agriculture. It is in this context that the establishment of various research stations, agricultural experiment stations, and schools and colleges of agriculture has to be placed. Those research stations turned the agricultural revolution into a scientific revolution by applying research methods systematically to the needs of agriculture. The resulting innovations have been generally biased toward biotechnical processes for raising yields per unit of land input. This "bias" was the consequence of the prevailing factor-price relations, as Hayami and Ruttan (1985) have demonstrated so convincingly: Land prices, already relatively high, increased relative to labor and capital due to population growth, which favored the generation and application of technologies that increased land productivity much more than labor productivity.

Not until the 1930s and, more pronounced, after World War II, did mechanical innovations, developed and applied in less densely populated countries of the New World, start to dominate technical innovations in agriculture in Western Europe.[11] The basic reason for the long-delayed application of mechanical innovations has to be seen in the fact that only at that time did overall economic growth force structural adjustment in agriculture toward substitution of capital for labor, the outmovement of farm labor, and consequently, improved farm sizes.

Biological technologies, nonetheless, are still playing an important role in technical changes in agriculture in Western Europe. Although changing factor-price relations in the United States have stimulated the "substitution" of biological for mechanical innovations to a large degree, growth of farm output in the EC still exceeds output growth in the United States, as shown in Table 1. Differences in output growth are even more striking with respect to growth rates of crop productivity, which results in higher growth rates for land productivity in the EC. The diverging U.S.-EC growth rates, however, have to be related to the fact that the level of yields already achieved in Western Europe is much higher than in the United States, as seen from Table 2. Table 2 also reveals that yields per hectare are still growing faster in the EC than in the United States. Moreover, most experts

TABLE 1 Growth Rates, 1973–1983: Output, Labor, and Land Inputs and Productivity of the European Community and the United States

	Farm Output[a]						Land Productivity[d]	
Country	Total	Crops	Livestock and Products	Farm Labor[b]	Land in Farms	Labor Productivity[c]	Total	Crops
Germany, Federal Republic of	1.7	1.9	1.6	3.3	–1.0	5.2	2.8	3.0
France	1.1	1.3	1.7	–3.2	–0.3	4.5	1.4	1.7
Italy	1.8	1.1	2.5	–3.3	–0.1	5.3	1.9	1.3
Netherlands	3.8	3.6	3.6	–0.7	–0.5	4.9	4.3	4.1
Belgium	0.5	0.6	0.8	–3.0	–0.8	3.6	1.4	1.5
Luxembourg	0.5	–2.2	1.3	–4.9	–0.4	5.6	0.9	–1.7
United Kingdom	1.6	4.0	0.6	–1.4	–0.2	3.1	1.9	4.3
Ireland	3.0	3.8	3.2	–3.0	1.7	6.2	1.3	2.0
Denmark	2.7	6.2	1.8	–0.9	–0.4	3.7	3.1	5.7
Greece	2.0	3.0	0.0	–0.9	0.0	3.6	2.0	3.0
European Community[e]	1.8	2.0	1.8	–2.8	–0.2	4.7	2.0	2.3
United States	1.7	1.8	0.8	–3.5	–0.3	5.4	2.0	2.1

NOTE: Annual growth rates, 1973–1983 = 1972–1974 and 1982–1984.

[a]EC: Value of production (at constant prices).
[b]Total employment in agriculture, fisheries, and forestry.
[c]Farm output per unit of farm labor.
[d]Farm output per unit of land.
[e]Ten countries.

SOURCES: Derived from data from the Commission of the European Community and the U.S. Department of Agriculture.

TABLE 2 Crop Yields and Milk Production, 1972–1983, European Community and the United States

Country	1971–1973	1982–1984	Annual Growth Rates
	Wheat (yield/hectare in metric tons)		
Germany, Federal Republic of	4.38	5.72	2.47
France	4.32	5.61	2.41
Italy	2.51	2.79	0.79
Netherlands	4.84	7.44	3.99
Belgium-Luxembourg	4.59	6.04	2.50
United Kingdom	4.33	6.74	4.14
Ireland	4.25	7.12	4.81
Denmark	4.55	6.78	3.69
Greece	—	2.60	—
European Community[a]	3.41	4.91	3.36
United States	2.04	2.59	2.42
	Corn (yield/hectare in metric tons)		
European Community[a]	5.14	6.59	2.51
United States	5.43	6.29	1.49
	Milk Production per Cow (metric tons)		
European Community[a]	3.61	4.33	1.66
United States	4.61	5.51	1.64

[a]Ten countries.

SOURCES: Based on data from the European Community, U.S. Department of Agriculture, and Food and Agriculture Organization.

are convinced that growth rates in yields in Europe will not decline in the near future, even without the application of such modern breeding methods as genetic modifications.[12] Experts also disregard as a factor the fact that in agriculturally less developed regions of the EC, yields are currently low (they are expected to rise considerably in the near future).

As seen in Tables 1 and 3, growth in labor productivity in agriculture exceeded growth in land productivity. Labor productivity grew more in the United States than in the EC, however, whereas total productivity growth in

TABLE 3 Growth Rates, 1963–1976: Output, Factor Inputs, and Total Factor Productivity of the European Community and the United States

Country	Farm Production[a]	Total Input	Total Productivity[a]	Factor Input Components[a]						
				Labor	Land	Machinery	Buildings	Fertilizer	Feedings	Livestock
Germany, Federal Republic of	1.46	–0.56	2.02	–6.8	–0.5	1.9	2.5	2.3	3.9	–0.2
France	1.90	0.29	1.61	–3.6	–0.4	5.3	2.6	5.0	7.0	0.5
Italy	1.67	0.44	1.17	–1.2	–1.1	5.5	2.0	2.8	6.1	–1.7
Netherlands	3.77	1.28	2.45	–3.2	–0.8	6.6	2.1	1.0	6.4	2.7
Belgium-Luxembourg	2.80	0.93	1.85	–5.5	–0.8	3.1	2.6	0.5	1.4	1.4
United Kingdom	1.26	–0.14	1.41	–3.8	–0.5	1.7	4.2	2.9	0.4	0.9
Ireland	2.95	0.95	1.98	–3.1	0.3	4.1	3.9	5.7	4.5	2.7
Denmark	0.31	–1.15	1.47	–4.9	–0.3	4.0	0.4	2.9	1.5	–0.3
European Community[b]	1.96	0.18	1.76	–3.4	–0.6	3.7	2.4	3.3	4.6	–0.6
United States	1.49	0.23	1.38	–4.6	–0.7	1.7	—	6.4	1.5	

[a] EC: Average annual growth rates of trend values.
[b] Nine countries.

SOURCES: Behrens and de Haen (1980:133) and statistical publications of the U.S. Department of Agriculture.

the EC exceeded that in the United States—smaller growth rates for output coincided with higher growth rates for inputs (Table 1 and 3). In some member states (West Germany, the United Kingdom, and Denmark), even total input decreased, which resulted in a growth in output below the EC average. Tables 1 and 3 reveal that in the EC output and productivity grew during 1973 to 1983 even more than between 1963 and 1976, although total input increased by similar rates of growth.

Recall that farm output has been increasing by about 2 percent annually, and demand for food and agricultural products has been increasing in the EC by only 0.5 percent annually. The modest increases in food demand are due to low and still-declining rates of population growth, further declining income elasticities of demand for food, and relatively low rates of real income growth (which became negative in the early 1980s). The total population of the EC (10 member countries) has grown by only 0.2 percent a year since 1975, whereas population growth rates in the United States have been 1.02 percent since 1975. Gross domestic product (at 1980 market prices and exchange rates) grew by 1.8 percent annually in the EC and by 3.1 percent in the United States. Income elasticity of demand for food in the EC is estimated at about 0.2, so that total demand for food has been rising by about 0.5 percent annually (Statistical Office of the European Community, 1986).

The prevailing discrepancies between growth rates of supply and demand have resulted in rapidly growing degrees of self-sufficiency in those farm products that are traditionally produced in Western Europe, especially cereals (soft wheat), sugar, wine, and milk. Whereas in the mid-1970s self-sufficiency had not been achieved for those products, 10 years later agricultural supply exceeded domestic demand by about 17 percent, and self-sufficiency had been reached with respect to most other products as well (Table 4).[13]

Those discrepancies between supply and demand, as would be expected, have had far-reaching implications for the EC's foreign trade in farm products. Whereas imports of agricultural products grew by 140 percent between 1973 and 1984 (by 120 percent from the United States), exports grew by 330 percent (to the United States by 300 percent) (Table 5). The EC's share of world food imports declined from 31 to 20 percent in the same period. With respect to cereals (excluding rice) the EC imported in 1975 about 26 million metric tons and exported 17 million metric tons. In 1983–1984 the EC imported 10 million metric tons and exported 24 million metric tons—the EC had changed from a net importer of about 10 million metric tons to a net exporter of 14 million metric tons. Similar changes in exports over imports can be observed with respect to other farm products, namely sugar, beef, and milk products. Only with respect to feedstuffs, such as soybean meal and corn gluten feed used in milk and meat produc-

TABLE 4 Degree of Self-Sufficiency (in percent) in Selected Farm Products, European Community, 1974, 1980, and 1984

Commodity	Year 1974	1980	1984
Cereals, total	94	106	128
Sugar	87	127	132
Vegetables	95	99	98
Fruits	83	87	83
Wine	—	100	114
Meat	96	99	103
Butter	—	120	130
Skimmed milk powder	—	132	103
Cheese	—	107	104

NOTE: EC (10 countries); domestic production relative to domestic consumption.

SOURCE: European Community data.

tion, have EC imports increased significantly. Imports of soybean meal, for example, increased from 4.6 million metric tons to 12 million metric tons between 1973 and 1984; to a certain extent these feedstuff imports substitute for cereals within the EC and therefore stimulate EC cereal exports (Bureau of Agricultural Economics, 1985) These changes in imports of feedstuffs and their substitution effect on cereal consumption by animals within the EC, however, are a direct consequence of the specific design of EC agricultural policy. This point is discussed in the following section within the context of the CAP as a whole and its relation to technical change in European agriculture.

TECHNICAL CHANGE AND ITS REPERCUSSION ON THE CAP

Technical change in agriculture due to biological, mechanical, and organizational innovations had a far-reaching impact on the shape and adjustment of the Common Agricultural Policy and will have an even greater impact on the future CAP adjustments. The reverse is true as well, however. The CAP and the national farm and research policy measures of the member states have had and still have far-reaching implications for the development and application of technical advancements and corresponding technical changes in agriculture. Moreover, unavoidable adjustments of the CAP in the near future will influence innovations and changes in European agriculture either directly, by promoting those technical innovations that

TABLE 5 Exports and Imports of Agricultural Products, European Community, 1973–1984[a]

Trade Status	1973 Amount[b]	1973 Percent[c]	1980 Amount	1980 Percent	1981 Amount	1981 Percent	1982 Amount	1982 Percent	1984 Amount	1984 Percent	Growth[d]
Exports[e]											
Total	7,381	21.1	14,521	5.0	26,055	15.0	25,576	14.6	31,211	14.5	331.0
To U.S.	1,222	16.5	1,965	10.1	2,657	10.2	3,220	12.6	4,907	15.7	301.6
Imports[e]											
Total	24,520	30.9	42,496	24.3	44,721	20.2	47,595	20.8	58,264	19.7	137.6
From U.S.	4,236	17.3	8,135	19.1	9,264	20.7	9,684	20.3	9,407	16.1	122.1
Trade balance											
Total	–17,139		–22,975		–18,666		–22,019		–27,053		
Comparing U.S.	–3,014		– 6,170		–11,921		– 6,464		– 4,500		

[a] Ten countries.
[b] In millions of European currency units.
[c] Percentage of world exports or imports.
[d] From 1973 to 1984.
[e] CTCI: 0, 1, 21, 22, 232, 24, 261–265, 268, 29, 4, 592, 11, 12.

SOURCE: Data from European Community.

offer a way out of the prevailing farm policy dilemma, or indirectly, through policy changes that affect the development and application of technical innovations.

This discussion begins with a short analysis of the implications of technical change in European agriculture for the EC's agricultural policy. As stated previously, the most striking effect of technical change in agriculture has been that output growth has outmatched the growth of domestic demand for food. Increasing self-sufficiency of food would not be a policy problem if EC farmers were able to compete on world markets. That does not seem to be the case, however, mainly because of constraints on sufficient adjustment in farm structure, although the international competitiveness of European farmers has been improved by advancements in production techniques.[14] Since the end of the 1800s, agriculture in most European countries has been protected by import-restricting and output-supporting policy measures (Strecker, 1958; Tracy, 1982), both of which seek to increase self-sufficiency in domestic food production and to support farmers' incomes relative to incomes outside agriculture.

After World War I and the Great Depression, protection of agriculture was systematically extended, so that with the founding of the Common Market, the measures to protect farm income already established by member states had only to be harmonized among founding member states. Later, new entrants, such as the United Kingdom, Denmark, and Ireland, were forced to accept the prevailing protections; protection of agriculture in those countries has been modest, as seen from Table 6.

Table 6 also shows that the nominal protection rates of the EC[15] increased somewhat between 1955 and 1980, although in 1965 and 1970 they were higher than in 1980 due to relatively low world market prices. In 1975, high world market prices kept the rates low. Compared with the United States, however, EC protection rates have been high since 1955. Because changes in protection rates reflect both changes in import prices as well as changes in domestic producer prices, however, those protection rates demonstrate only the extent of protection of domestic producers vis-à-vis foreign competitors, given that those competitors are not protected by domestic farm policy measures. Thus, in Table 7 data are presented on the changes in prices received by farmers, prices paid by farmers for production items (excluding labor, interest rates, and taxes), and the sectorial terms of trade (ratio of prices received to prices paid) for both EC and U.S. agricultural products.

The data in Table 7 can be interpreted as follows:

1. Producer prices in the EC and in the United States have increased steadily since 1975, but more so in the EC.[16] Consequently, the ratio of EC

TABLE 6 Nominal Rates of Agricultural Protection, 1955–1980, European Community and the United States

Country	1955	1960	1965	1970	1975	1980
Germany, Federal Republic of	28.0	40.6	46.8	44.3	35.8	42.0
France	31.2	23.4	28.2	44.1	28.0	29.6
Italy	43.3	46.5	60.2	64.2	35.6	53.8
Netherlands	11.9	19.2	30.7	34.4	28.6	24.9
United Kingdom	34.9	33.7	18.9	24.9	5.6	32.1
Denmark	4.5	3.2	4.6	16.3	18.3	24.4
European Community[a]	30.7	32.8	40.3	47.1	27.1	35.7
United States	2.4	0.9	8.2	10.9	4.0	–0.1

NOTE: Rates are the weighted average of 13 products.

[a]Weighted average of France, Germany, Italy, and the Netherlands (1955–1970) plus the United Kingdom and Denmark (1975–1980).

SOURCE: Honma and Hayami (1986).

to U.S. farm prices increased to 164 in 1984. Relative crop prices in the EC increased even more than livestock prices.

2. In both the United States and the EC, prices paid by farmers increased due to inflationary pressures. Again, however, input prices grew much faster in the EC than in the United States. Because EC farmers became more subject to those pressures, the ratio of EC to U.S. prices paid increased to 133 in 1985.

3. Due to the fact that the index of EC producer prices increased almost as much as the index of input prices, the terms of trade have been unchanged over the long run. In the United States, producer prices declined relative to input prices, so that the terms of trade for agriculture worsened by about 20 percent. Consequently, the EC's agricultural terms of trade improved by 23 percent relative to U.S. agricultural terms of trade.

To summarize, EC agriculture not only has been and is still much more protected than its international competitors, it also has improved its economic situation relative to U.S. agriculture since 1975. Whereas the terms of trade for European farmers have remained almost unchanged, those terms have deteriorated continuously for U.S. agriculture. With respect to EC agriculture, however, the terms of trade improved until the end of the 1970s, and then began to decline because producer prices increased less than the prices paid by farmers for production items.

TABLE 7 Prices Received and Paid by Farmers, 1975–1985, European Economic Community and United States

	European Community[a]					United States					Changes of EEC Prices Relative to U.S. Prices				
	Prices Received[b]					Prices Received					Prices Received				
Year	Farm Products	All Crops	Livestock[c]	Prices Paid[d]	Ratio[e]	Farm Products	All Crops	Livestock	Prices Paid	Ratio	Farm Products	All Crops	Livestock	Prices Paid	Ratio
1975	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1976	117.1	124.3	112.1	112.7	103.9	102.3	98.0	102.3	106.6	96.0	114.5	125.8	109.6	105.7	108.2
1977	126.4	134.2	121.2	122.8	102.9	103.1	95.8	101.5	109.9	93.8	122.5	140.1	119.4	111.7	109.7
1978	131.0	137.9	126.3	125.6	104.3	113.8	100.9	125.5	118.7	96.0	115.1	136.7	100.6	105.7	108.6
1979	139.9	150.3	132.6	137.1	102.0	129.3	110.8	149.4	137.4	94.1	108.2	135.6	88.6	99.7	108.4
1980	151.1	165.0	141.4	154.2	98.1	133.6	119.2	145.8	151.6	88.1	113.1	138.4	97.0	101.7	111.4
1981	169.2	185.5	158.1	174.7	96.8	136.5	128.3	145.1	162.6	83.9	124.0	144.6	109.0	107.4	115.4
1982	188.4	242.1	175.9	190.7	98.8	129.8	115.9	146.8	164.8	78.8	145.1	208.9	119.8	115.7	125.4
1983	200.9	207.7	181.7	205.1	98.0	132.9	121.9	143.2	168.1	79.1	151.2	170.3	127.0	122.0	123.8
1984	210.2	229.4	188.2	218.0	96.4	137.0	132.3	147.8	170.3	80.5	153.4	173.4	127.3	128.0	120.0
1985	216.1	—	—	221.0	97.8	132.0	115.0	138.0	165.9	79.6	163.7	—	—	133.2	122.9

NOTE: 1975 = 100.

[a]Ten countries.
[b]Without value-added taxes.
[c]And livestock products.
[d]Production items and services consumed.
[e]Prices received for all farm products divided by prices paid.

SOURCE: Data from the European Community and the U.S. Department of Agriculture.

This remarkable change in the terms of trade for EC agriculture is the consequence of rising surpluses, as mentioned earlier. Those rising surpluses forced the EC to react, one way or the other. The impetus toward a change in farm policy, however, was not stimulated by the negative effects of surpluses disposed through export subsidies or by the level and stability of world market prices.[17] Rather, it was forced by the growing exhaustion of financial resources available to support the EC's agricultural policy. As seen in Table 8, total EC budget expenditures (measured in terms of European currency units—ECUs) increased from 11.4 billion ECUs in 1978 to 28.4 billion ECUs, or by about 150 percent.[18] Budget receipts increased during that time from 12.2 billion to 28.1 billion ECUs, or by 130 percent, so that in 1978 about 95 percent of budget receipts had been spent, whereas in 1985 expenditures exceeded receipts by 1.3 percent. The EC budget deficit is expected to increase dramatically in the future due to the rising financial burdens of the CAP (Petersen, 1983). In 1978, 77 percent of total EC expenditures went to financing agriculture, but in 1986 that figure declined to 73 percent due to rising budget expenditures for nonfarm policy measures. However, CAP expenditures did increase by 134 percent, mainly due to the rising financial costs of surplus disposal by export subsidies, storage costs, and additional costs for subsidizing domestic use of agricultural surpluses. In 1978, 8.7 billion of the 8.8 billion ECUs expended for CAP had gone to farm price supports. In 1985, 20 percent had to be spent for export subsidies alone.

Although budget expenditures have increased dramatically, by about 20 percent per year, since CAP was established, real farm income per labor unit, measured in ECUs, declined in most of the member countries (Table 9). Declining real farm income has been the result of a modest decline in real producer prices, the slowdown in the transfer of farm labor to nonagricultural employment, and changes in exchange rates of national currencies vis-à-vis the ECUs.[19] With respect to those changes in exchange rates, however, it must be stressed that real farm income, measured in corresponding national currency units, increased in most member countries at least until the early 1980s due to the fact that gains in labor productivity were greater than the decline in real producer prices.

Rising farm surpluses and the growth of budget expenditures compelled the EC finally to undertake some steps to reform the CAP and to consider more far-reaching reform measures. The reform measures already launched and further reform measures being discussed by the EC Commission and the Council of Ministers are discussed in the next section in terms of how they will affect technical change in European agriculture. First, however, the discussion turns to the impact of the agricultural policies executed until recently by the EC and member states on technical change in European agriculture. Up to this point, the farm policy decisions of the EC have been

TABLE 8 European Community Budget Expenditures for Agriculture, 1978–1985 (in million European currency units)

	Budget Expenditures		Expenditures of Section Guarantee		
Year	Total	Agriculture	Total	Export Restitutions	Others[a]
1978[b]	11,434	8,839 (77)	8,673	3,538 (41)	5,134
1979[b]	13,985	10,681 (76)	10,441	4,982 (48)	5,459
1980[b]	15,826	11,630 (73)	11,315	5,695 (50)	5,620
1981[c]	17,389	11,643 (67)	11,141	5,209 (47)	5,933
1982[c]	20,423	13,060 (63)	12,407	5,054 (41)	7,318
1983[c]	25,313	16,538 (65)	15,812	5,560 (35)	10,360
1984[c]	27,398	18,746 (69)	18,347	6,619 (36)	11,753
1985[d]	28,433	20,755 (73)	19,979	6,834 (34)	13,176
(1978 = 100)	240.7	234.8	230.1	193.2	256.6

NOTE: Numbers in parentheses are percentages.

[a]Storage costs, special subsidies, and so on.
[b]EC—9 countries.
[c]EC—10 countries.
[d]Preliminary data.

SOURCE: Data from European Community.

described as a reaction, in part, to technical changes in agriculture. In the near future, those policy reactions will be intensified due to budget restrictions, still growing surpluses, and the financial consequences of the additions of Greece, Spain, and Portugal to the Common Market. The most important point, however, is that the farm policies of the EC and individual member states have exerted far-reaching effects on the development and application of technical innovations and changes in European agriculture. The reactions of agricultural researchers and farmers in response to farm and corresponding research policies are illustrated by the following observations:

1. The relatively high producer prices, supported by import-restricting policy measures, have, of course, stimulated the development and application of yield-increasing biological innovations.[20] Price policy, therefore, has biased technical change toward productivity growth through output-increasing technologies rather than through input-reducing and land- and labor-substituting technologies. As a consequence, land prices and rents have been relatively high and are still rising, the outflow of farm labor has

TABLE 9 Real Net Farm Income per Labor Unit,[a] European Community, 1975–1976 to 1983–1984

Country	1975–1976 ECU	1975–1976 EC = 100	1980–1981 ECU	1980–1981 EC = 100	1983–1984 ECU	1983–1984 EC = 100	1983–1984 1975–1976 = 100
Germany, Federal Republic of	6,400	87	5,529	105	6,612	120	103.3
France	5,999	82	5,448	104	4,734	86	78.9
Italy	4,291	59	3,167	60	2,775	50	64.7
Netherlands	13,099	179	12,033	229	15,504	281	118.4
Belgium	10,999	150	9,881	188	11,648	211	105.9
United Kingdom	11,237	154	5,157	98	6,611	120	58.8
Ireland	7,820	107	3,731	71	4,316	78	55.2
Denmark	12,300	168	7,997	152	9,057	164	73.6
Greece	—	—	—	—	1,616	29	—
European Community[b]	7,314	100	5,261	100			
European Community[c]					5,513	100	

[a]Labor unit = farm labor in terms of full–time labor input on annual base. Net farm income in prices of 1975–1976.
[b]Nine countries.
[c]Ten countries.

SOURCE: Data from European Community.

been delayed, and structural adjustment has been hampered (Schmitt and Tangermann, 1983).

2. On the other hand, the farm policy of the EC and individual member states has attempted to stimulate and accelerate structural adjustment in agriculture by numerous and intensified adjustment aids in order to improve the competitiveness of (national) agriculture within the Common Market. Government expenditures for such social and structural policy measures have increased in almost all member countries.[21] The effect of these measures, however, has been at least partly neutralized by the price policies discussed previously. The measures have favored the introduction of biological innovations mainly linked to modern technologies, which have been introduced within the context of structural adjustments stimulated by investment aids; improvements in education, training, and extension services for farmers; and retirement programs for elder farmers and training programs in nonfarm occupations for small farmers.

3. Provisions of the General Agreement on Tariffs and Trade (GATT) and specific technical aspects of various farm products, the structure of the protections for EC agriculture vis-à-vis international competition is far from being consistent. Some products, such as feedstuffs, vegetables, fruits, and certain specific crops (e.g., string beans), are less protected or free of import-restricting levies than more traditional (northern) farm products.[22] Those inconsistencies have resulted not only in corresponding adjustments in factor allocation and output structure, but also in a concentration of research activities and the application of biological innovations on the more protected farm products. Less-protected agricultural commodities, therefore, have been neglected with respect to research activities and resulting technical advance.[23]

To conclude this section, EC and national farm policy measures, on the one hand, have stimulated technical changes in agriculture to a large degree and in specific directions, both of which would have been different had technical changes been generated and applied under free-market conditions. On the other hand, those policy-induced technical changes that resulted in high-growth rates of production and land productivity have, in turn, forced changes in farm policy measures. Those changes had to be adopted, at a minimum, because expenditures for surplus disposal approached and then exceeded the financial resources available. Further growth of output, and especially of surpluses, due to declining growth of domestic demand is intensifying the need for a more basic reform of the CAP, which has already been launched to a certain extent. In addition, rising public awareness of the negative external effects of intensive agriculture on the quality of groundwater, land, and environment have resulted in further pressure for a reform of European farm policy.

Those policy changes have already started and those to be expected in the near future will have consequences for future technical changes in agriculture. Moreover, with respect to future reforms of CAP, technical innovations stimulated by public research policy will play an important role within the context of such a reform. These topics are addressed in the following section.

FUTURE PROSPECTS FOR TECHNICAL CHANGE IN EUROPEAN AGRICULTURE

Looking ahead to future technical changes in agriculture, based on prevailing information, three separate but interrelated trends can be distinguished:

1. Due to scientific progress, mainly in the basic sciences, applied research in agriculture will achieve or has already achieved further advances in biotechnologies, which will be applied in European agriculture. The process of applying those advanced technologies will be influenced by policy measures, but only to a limited degree. Hence, those innovations are referred to here as "autonomous" innovations and corresponding technical changes. Those changes will further increase the productive capacity of European agriculture and will consequently maintain pressure on the CAP.
2. Because the growth of demand will decline still further, the productive capacity of EC agriculture has to be reduced by adequate policy measures. Unless this happens, European agriculture will not become competitive on international markets. (Technical changes in some regions of [northern] Europe might improve international competitiveness;[24] in other [southern] regions, however, this will not be the case.) Restriction of productive capacity will neither be achieved by an accelerated outmovement of labor, nor by idling land or transferring it to other uses, such as forestry. Changes in those directions might occur, but only to a limited extent. Instead, the productive capacity of agriculture mainly will be used to produce nontraditional agricultural goods. Public research activities, therefore, will be concentrated on the development and improvement of production technologies for nontraditional agricultural outputs.
3. Public policy in the area of nontraditional agricultural products as well as nontraditional use of traditional farm products will be dominated by public support of agricultural research in those nontraditional areas. Even more important will be the fact that nontraditional production and use have to be supported to some degree by either government subsidies or import-restricting protectionistic measures, because production and use of goods will not be competitive vis-à-vis traditional goods or imports. Protection of European agriculture will be reduced to a certain extent for traditional farm

products but extended for nontraditional products. Such a change in farm policy will have different, but far-reaching consequences on the structure of European agriculture as well as on the structure of international trade in farm products. It should be noted that these trends are already apparent in recent developments in agricultural research and public research policy, as far as the first and second trends are concerned, and in changes in European farm policies.

As already mentioned, recent farm policy decisions are aiming toward the restriction of productive capacity of EC agriculture. Further and more effective restrictions are to be expected in the near future, mainly by means of one or more of the following:

1. More restrictive price policy decisions. As stated earlier, real producer prices started to decline in more recent times (Table 7) due to more modest increases in nominal producer prices by the Council of Ministers, the introduction of coresponsibility levies for various farm products, and various administrative measures resulting in decreases of producer prices.[25] The EC Commission has repeatedly warned that further reductions in real prices have to be expected.[26]

2. Quantitative restriction on production of various farm products. Besides the quota system for sugar-beet production established since the beginning of the CAP, such a system was introduced in 1984 for milk production, which fixed milk production at about 100 million tons. Because only 90 million tons are expected to be consumed or exported, a further reduction of milk quotas will have to be imposed. The only problem to be solved is how this reduction will be achieved. Moreover, stimulated by the "Green Paper" of the Commission of the European Community (1985d), there has been discussion whether, by what means, and with respect to what products further quantitative restrictions on output should be introduced. It is to be expected, therefore, that further output-restricting measures will be taken, given that administration of the measures seems to be technically feasible.

3. Surplus reduction. To reduce surplus production still further, the West German government proposed in 1985 a program of idling land of (elder) farmers through compensation payments within the prevailing system of social security for farmers (Schmitt and Thoroe, 1986). The EC Commission has been asked by the West German government to introduce such a program for European agriculture as a whole. Meanwhile, the EC Commission had suggested such a program—called Option A of the Green Paper—as one of the various means to reduce overcapacity in land use. Option B of the Green Paper refers to income transfers to more efficient farmers within a policy of "a strict price policy," and Option C refers to a minimum income guarantee as "a last resort."

4. Buy-outs. Option D of the commission's proposals, called a buying-out approach, involves setting aside agricultural land either by idling it, by using it for "the production of alternative (less supported) products," or by "renting . . . for nonagricultural uses, e.g., the creation of ecological refuges and reserves, leisure parks, afforestation." Meanwhile, some member states, such as the United Kingdom and West Germany, have already introduced some subventions to stimulate such a transfer of farmland to conservation and ecological purposes on a voluntary basis.[27] Other member states will undoubtedly introduce similar programs as well as expand existing ones. They will probably also be supported financially by the EC, but they will have only a minor effect on output.

Since 1985, the structural policy measures of member states have been fundamentally changed in reaction to EC guideline No. 797/85 concerning the "efficiency" of structural policy. In accordance with this guideline, structural policies have replaced prevailing policies aiming at the acceleration of structural adjustment in agriculture. The objective of the more modern policy measure is basically the preservation of the current farm structure. Thus, structural as well as technical changes in European agriculture will be retarded, an objective that is contrary to economic necessity and to policy measures to reduce surplus capacity and encourage more efficient use of production factors.

It is quite obvious that the policy measures outlined here are insufficient to reduce the productive capacity of European agriculture to a degree that is consistent with current and future demand for farm products. Because it has to be expected that the EC is neither able nor willing to restrict its current volume of subsidized exports of farm products to a greater extent,[28] future growth of farm production will mainly be restricted by future growth of internal demand. This means that the 2 percent annual growth in output (Tables 1 and 3) has to be reduced to 0.5 to 1.0 percent a year. The policy measures outlined earlier in this paper are insufficient to achieve such a dramatic decline in output growth. Thus, it is understandable that farmers, agricultural ministers, politicians, and the EC Commission are pressing for technological innovations that offer the chance of using existing and still rising overcapacity to produce nontraditional farm products as well as to use traditional farm products for nontraditional purposes. The EC Commission has stressed that "it is necessary to strengthen research and counselling services so that the farmer is provided with as complete a technical-economic inventory as possible of all the possibilities of conversion" toward alternative production and alternative use of farm products.

The trend toward alternative production and alternative use of conventional products is supported by member states and by expanding government expenditures for research in those areas.[29] The main objective, however, of those efforts is to reduce overall CAP budget expenditures. Thus, the real benefits of the stimulation of technical advances in the area of alternative products and use are seen by policymakers not mainly in terms of achieving international competitiveness but in terms of reducing the financial support required relative to the financial burden of maintaining traditional output (per unit).

With respect to those alternative methods of production and use, the following approaches are discussed and practiced to a certain degree within the EC at the present time:

1. The use of traditional farm products as a renewable "source of energy," mainly as bio-ethanol from direct fermentation of sugar beets, molasses, and the like and by indirect fermentation of raw materials containing starch (e.g., wheat, maize, potatoes), has become the center of interest as a result of the high energy prices of the 1970s. Research efforts have been intensified by increased budget expenditures at the EC and the member state levels and have resulted in various pilot projects.[30] It is obvious, however, that at the present time the subsidies required for approaching competitiveness with bio-ethanol would be even higher than the subsidies needed for exports of the raw materials used in bio-ethanol production.[31] Thus, research is expected to increase productivity of ethanol production at least so far as the subsidies required per unit of raw material input are less than the export subsidies. The further decline in energy prices, however, has intensified skepticism that such a situation can be achieved without a drastic reduction in farm product prices.
2. Similar considerations and conclusions have been made regarding the use of sugar and starch in nonfood industries, such as paper and cardboard, chemical, and pharmaceutical industries, through fermentation and some traditional or enzymatic synthetic processes. Under the current EC rules, the EC pays a production refund for EC sugar and starch supplied to processors. Those refunds, however, are still too small to offset the differences between EC and world market prices for the basic substrates. Thus, the EC Commission has proposed to increase those refunds to open European agriculture world market outlets for nonfood use of starch, which is expected to expand due to recent advances in biotechnology. Again, research in this and other related fields is and will be supported by public expenditures in the hope that technological innovation may contribute to the improvement of the international competitiveness of domestic raw materials. Almost similar arguments are put forward with respect to the improvement of industrial uses of oil seeds and animal and plant fats, which are also to be stimulated by public support of relevant research.
3. As far as alternative types of production are concerned, the expectations are that either the traditional, "intensive" products that contribute to

prevailing surpluses will be replaced by "extensive types of farming" or the production of less-protected farm products will increase. Oil seeds and protein crops, such as bitter lupins and cuphea, are seen as the ideal replacements for surplus production. Further replacement is expected by wood crops for the production of bulk wood fiber for pulping and for the production of energy (e.g., eucalyptus). Finally, in fruit growing, replacement of traditional fruits by almonds, pistachio nuts, and other types of fruit production should, according to the EC Commission, be supported. As with alternative uses of traditional crops previously mentioned, however, the prevailing CAP has to be adjusted to achieve profitability of alternative types of farm products. The Commission of the European Community (1985d:32) has therefore pointed out that (1) for those products the market organization should be adapted, (2) "aids to encourage farmers to switch to other products" should be granted, (3) incentives for the creation of the processing and marketing facilities are needed, (4) a legal framework "for the harmonization of the quality standards" has to be created, and (5) "incentives to applied research and to technical and economic counselling on ways and means of switching products" have to be provided. It is quite obvious that such measures would not only have far-reaching consequences for factor allocation within EC agriculture and for the international division of labor but also implications for the EC budget. Whether those measures would reduce budget expenditures as compared with a continuation of the current CAP is an open question.

With respect to future budget expenditures, however, the fact that further biotechnical advances in agricultural production techniques are to be expected or are already on the way must be taken into account. In general, the "emerging technologies" in agriculture, mainly biotechnological advances and new information technologies to be applied to animal and plant production, are seen or expected in Europe as well. These technologies have been described and analyzed in detail by the Office of Technology Assessment (OTA, 1986). A report on *Biotechnology and Agriculture* released by the West German Ministry of Agriculture in 1985 (Bundesministerium für Ernährung, Landwirtschaft und Forsten, 1985) concluded that "there is no doubt that those biotechnical advances will have far reaching repercussions on agribusiness, consumers etc. They will open many changes. However, there are many risks and uncertainties involved."

It is not possible to enumerate here all of the potential fields of new technologies to be applied successfully and the specific techniques to be used, or the economic implications of a large-scale application of those modern technologies. That has been done by the OTA and, to a lesser degree, by the West German report mentioned here.

The West German report comes to several conclusions. First, productivity gains from new production technologies will improve the competitive position of European agriculture vis-à-vis foreign competitors. Such a view, however, neglects the fact that foreign competitors will also apply those or other technological advances. Some foreign countries are already ahead as far as the generation and application of such technologies are concerned due either to more advanced research or to legal and other restrictions on the application of new technologies to EC agriculture. Productivity gains are expected through reducing inputs per unit of output, improving the quality and stability of output, and reducing losses and wastes. Second, increases in yields per unit of input will aggravate the prevailing surplus situation, depress producer prices, and stimulate further policy interventions. Third, policy interventions are also to be expected with respect to the far-reaching structural adjustments in agriculture and agribusiness as a whole. Such interventions will restrict further concentration in farming. Fourth, advances in production technologies for nonconventional farm products and for alternative use of conventional products, therefore, are expected to bring some relief, especially with respect to the prevailing and increasing overcapacity of European agriculture. This is in line with the trends described earlier. However, in one way or the other, those trends will have far-reaching implications for the future Common Agricultural Policy, as discussed in the following section.

FARM POLICY IMPLICATIONS OF FUTURE TECHNICAL CHANGES

This review of recent and prospective adjustments in the CAP and of technical changes in European agriculture either already being developed or soon to be expected leads to three conclusions:

1. Pressures for more restrictive EC domestic farm policies are still rising due to internal budget constraints and the restrictions placed on expansion of agricultural exports by competing exporting countries. Basically, those pressures will result in further quantitative restrictions on production and factor use in agriculture. Those restrictions, however, will not lead to a reduction in the volume of agricultural exports. The EC will continue to claim its current share of world markets, partly because of the balance-of-payment concerns of member states and partly because output restrictions to the extent required to reduce exports will not be feasible politically.
2. The consequences of output-restricting measures on factor use in agriculture will stimulate the search for, and political support of, alternative uses of current and rising overcapacities in factor supply. Although unemployed factors of production will be used for environment-preserving purposes through expanded subsidies, such programs will be limited as far as

their impact on supply is concerned. Thus, alternative uses of traditional farm output and alternative types of production will be supported by public research subventions as well as by farm policy measures, such as restrictions on competing imports, financial support of domestic production and use, and to a certain extent, export subsidies. With respect to nonconventional products, the EC will change its current position as a net importer to one of increasing degrees of self-sufficiency, as happened during the 1960s and 1970s with respect to conventional farm products, provided the major exporting countries do not resist such activities on the part of the EC.

3. Administrative restrictions on production, further reduction in real producer prices, and a conservative policy concerning structural adjustments in agriculture will depress farm income as well as restrict productivity growth in European agriculture. As a result, farmers as well as politicians will ask for direct income transfer payments to a growing degree. Because of the prevailing EC budget constraints, member states are increasingly supporting income of domestic agriculture mainly under the heading of social policy measures and tax exemptions. This, however, means a renationalization of EC farm policy, which has already happened to a certain extent. Expanding renationalization means, moreover, an uncontrolled expansion of farm production in various member countries, especially the economically more advanced ones. The less-advanced member countries, which are financially unable to support domestic agriculture to the same extent, will resist those tendencies toward renationalization. Thus, conflicts within the EC, which are already far-reaching due to the diverging economic conditions of agriculture among member countries, different views concerning future changes in farm policy, and a disproportionate distribution of costs and benefits of the CAP among member states, will intensify dramatically. Whether the EC will resolve the conflicts between member states, as well as vis-à-vis third countries exporting competing farm products, is a major question. What is urgently needed is far-reaching reform of the institutional arrangements of the policymaking bodies of the EC to enable those bodies to resist national as well as producers' pressures on policymaking. Time is much too short, however, to achieve those institutional reforms and corresponding farm policy decisions.

NOTES

1. For a detailed analysis of the history of technical changes in European agriculture, see among others, Abel (1978), Bairoch (1976), and Grigg (1980).
2. See Bairoch (1976), Bitterman (1956), and Haushofer (1963).
3. See *Finck* v. *Finckenstein* (1960), Hanau and Pentz (1964), Jasny (1940), Krohn (1957), Malenbaum (1953), and Timoshenko (1933).
4. See Schmitt (1986b) and Schmitt and Hagedorn (1985), and literature cited.
5. See Strecker (1958), Tangermann (1982), Teichmann (1955), and Tracy (1982).

6. See Fennel (1979), Honma and Hayami (1986), Plate and Woermann (1962), and United Nations Conference on Trade and Development (1983).

7. See among others, Bureau of Agricultural Economics (1985) and literature cited.

8. See literature cited in note 4.

9. For a detailed analysis of the agri-monetary systems of the CAP, see Bureau of Agricultural Economics (1985:37–46).

10. Restitution payments for exports are discussed by Malmgren (in this volume).

11. See literature cited in note 3 and Hayami and Ruttan (1985).

12. See literature quoted in note 4.

13. Official data on the degree of self-sufficiency in food are systematically underestimated because domestic use of surplus products being subsidized are neglected in those estimates.

14. This at least has been found to be the case by Stanton (1986).

15. Within the so-called import levy system of the EC, domestic producer prices are fixed at a certain level, independent of the prevailing import price level. The difference between those prices (nominal protection rate) is subject to variable import levies, which are used to finance the EC budget. For more details, see Bureau of Agricultural Economics (1985:31–33).

16. It has to be admitted, however, that U.S. as well as world market prices have been relatively high due to a strong import demand by many socialist countries.

17. See especially Bureau of Agricultural Economics (1985) and literature cited.

18. At this writing (1987) a European currency unit (ECU) is equal to about 1.15 U.S. dollar.

19. Between 1970 and 1983 the West German mark has been evaluated vis-à-vis ECU by 64 percent, the Dutch guilder by 46 percent, and the Belgian franc by 12 percent, whereas the currencies of all other member states have been devaluated (France by 16 percent).

20. Based on various though diverging estimates, the Bureau of Agricultural Economics (1985:119) has estimated "the long-term supply elasticity with respect to changes in real prices to be 0.7." However, those estimates do neglect the indirect effect of changes in real prices on the creation of new biological technologies by induced scientific research (Schmitt, 1986a).

21. According to estimates of the EC Commission, national government expenditures for agriculture (excluding social security payments) were about 12.6 billion ECUs in 1972 and in 1980 11.6 billion ECUs (EC, nine countries), whereas EC expenditures rose from 4.0 billion to 11.4 billion ECUs. However, national supports seem to be greatly underestimated, not only due to the omission of support for social policy measures, but especially by omission of tax relief for agriculture, expenditures of regional authorities, and the like (Schmidt, 1976; Seebohm, 1981).

22. This is reflected in the fact that nominal rates of protection differ between various EC farm products (Bureau of Agricultural Economics, 1985:52). Differences in rates of protection are even greater if measured by effective rates of production. According to Sampson and Yeats (1977), the average rate of protection of EC agriculture was 158.1 percent in 1977. However, the rates varied between 1,322.7 percent (butter) and –9 percent (sheep).

23. Those implications of farm policy measures on the generation of corresponding technologies, of course, are in line with Hayami's and Ruttan's theory of induced technological innovations.

24. See note 14.

25. For example, quality constraints and restrictions on repayment of subsidies.

26. See the Green Paper, Commission of the European Community (1985d).

27. For a list of those programs in German, see Agrarsoziale Gesellschaft (1986).

28. In particular, the French government insists on at least the status quo of exports, explaining that its economy depends on exports of the "green oil."

29. In 1980 the EC Commission estimated that the member states had spent about 748 million ECUs for agricultural research and development. Again, those estimates seem to be conservative because nonagricultural departments, such as departments for technology, do support agricultural research as well. The EC is spending about 35 million ECUs for such research but intends to increase those expenditures dramatically.

30. As far as West Germany is concerned, the pilot projects are listed in Deutscher Bundestag (1986).

31. Several studies support this conclusion, although they are based on different research methods and technical information. See Deutscher Bundestag (1986), Bundesministerium für Ernährung, Landwirtschaft und Forsten (1983), and references quoted. Also see Meinhold et al. (1986).

REFERENCES AND BIBLIOGRAPHY

Abel, W. 1978. Agrarkrisen und Agrarkonjunktur. Hamburg.

Agrarsoziale Gesellschaft. 1986. Ländlicher Raum 37:10–11.

Bairoch, P. 1976. Die Landwirtschaft und die Industrielle Revolution 1700–1914. In Europäische Wirtschaftsgeschichte (The Fontana economic history of Europe), Vol. 2. Stuttgart and New York: Gustav Fischer.

Behrens, R., and H. de Haen. 1980. Aggregate factor input and productivity in agriculture: A comparison for the EC member countries, 1963–1976. Europ. Rev. Agri. Econ. 7:109–146.

Bitterman, E. 1956. Die Landwirtschaftliche Produktion in Deutschland 1800–1950. Khün-Archiv 10. Berlin.

Bundesministerium für Ernährung, Landwirtschaft und Forsten. 1983. Gesamtkonzeption Nachwachsende Rohstoffe. Angewandte Wissenschaft. Sonderheft. Münster-Hiltrup: Landwirtschaftsverlag.

Bundesministerium für Ernährung, Landwirtschaft und Forsten. 1985. Biotechnologie und Agrarwirtschaft. Angewandte Wissenschaft. Sonderheft. Münster-Hiltrup: Landwirtschaftsverlag.

Bureau of Agricultural Economics. 1985. Agricultural Policies in the European Community. Their Origins, Nature, and Effects on Production and Trade. Policy Monograph No. 2. Canberra: Australian Government Publishing Service.

Cochrane, W. W. 1958. Farm Prices—Myth and Reality. Minneapolis: University of Minnesota Press.

Commission of the European Community. 1985a. Agrareinkommen 1985. Entwicklung seit 1983. Bruxelles.

Commission of the European Community. 1985b. Die Lage der Landwirtschaft in der Gemeinschaft. Bericht. Bruxelles.

Commission of the European Community. 1985c. Eine Zukunft für die Europäische Landwirtschaft. Orientierungen der Kommission. Bruxelles.

Commission of the European Community. 1985d. Perspectives for the Common Agricultural Policy. The Green Paper of the Commission. Brussels: Commission of the European Community.

Denison, E. F. 1967. Why Growth Rates Differ. Postwar Experience in Nine Western Countries. Washington, D.C.: Brookings Institution.

Deutscher Bundestag. 1986. Drucksache 10/5558. Nachwachsende Rohstoffe. Bonn.

Fennel, R. 1979. The Common Agricultural Policy of the European Community. London: Granada Publishing.

Food and Agriculture Organization. 1981. Toward 2000. Rome.

Finck v. *Finckenstein,* H. W. 1960. Die Entwicklung der Landwirtschaft in Preußen und Deutschland 1800–1930. Würzburg: Holzner-Verlag.

Grigg, D. B. 1980. Population Growth and Agrarian Change. A Historical Perspective. Geographical Studies 13. New York: Cambridge University Press.

Hanau, A., and W. Pentz. 1964. Getreidewirtschaft. In Handwörterbuch der Sozialwissenschaften, Vol. 4. Stuttgart, Tübingen and Göttingen: J.C.B. Mohr.

Haushofer, H. 1963. Die deutsche Landwirtschaft im technischen Zeitalter. Deutsche Agrargeschichte, Vol. V. Stuttgart: Ulmer.

Hayami, Y., and V. Ruttan. 1985. Agricultural Development: An International Perspective. Baltimore, Md.: Johns Hopkins University Press.

Honma, M., and Y. Hayami. 1986. Structure of Agricultural Protection in Industrial Countries. J. Int. Econ. 20:115–129.

Jasny, N. 1940. Competition Among Grains. Stanford, Calif.: Stanford University Press.

Krohn, H. B. 1957. Die Futtergetreidewirtschaft der Welt 1900–1954. Berichte über Landwirtschaft, Sonderheft 35. Hamburg and Berlin: Paul Parey Verlag.

Malenbaum, W. 1953. The World Wheat Economy 1885–1939. Harvard Econ. Stud. 92. Cambridge, Mass.: Harvard University Press.

Meinhold, K., et al. 1986. Möglichkeiten und Grenzen beim Anbau regenerativer Rohstoffe für Energieerzeugung und chemische Industrie. Enquete-Kommission Technologiefolgenabschätzung des Deutschen Bundestages. Braunschweig.

Office of Technology Assessment. 1986. Technology, Public Policy, and the Changing Structure of American Agriculture. Washington, D.C.: U.S. Government Printing Office.

Petersen. V. 1983. Agrarpolitik und EG-Haushalt. Angewandte Wissenschaft 278. Münster-Hiltrup: Landwirtschaftsverlag.

Plate, R., and E. Woermann. 1962. Landwirtschaft im Strukturwandel der Volkswirtschaft. Agrarwirtschaft, Sonderheft 14. Hannover: Strothe-Verlag.

Rat von Sachverständigen für Umweltfragen, ed. 1985. Landwirtschaft und Umwelt. Stuttgart: Kohlhammer-Verlag.

Sampson, G. P., and A. J. Yeats. 1977. An evaluation of the Common Agricultural Policy as a barrier facing agricultural exports to the European Community. Am. J. Agri. Econ. 59:99–106.

Schmidt, P. 1976. Eine Theorie der Struktur und Dynamik der staatlichen Landwirtschaftsförderung. Ph.D. dissertation. Göttingen.

Schmitt, G. 1986a. Agrarforschung, technischer Fortschritt und Agrarpolitik: Eine andere Sichtweise. Göttinger Schriften zur Agrarökonomie 58. Göttingen.

Schmitt, G. 1986b. Agricultural policy decisions in the EC: Consequences of institutional imbalance. Food Policy 11:334–345.

Schmitt, G., and K. Hagedorn. 1985. Die politischen Gründe für eine wirtschaftspolitische Vorzugsbehandlung der Landwirtschaft. Jahrbuch für Neue Politische Ökonomie, Vol. 4. Tübingen: J.C.B. Mohr-Verlag.

Schmitt, G., and S. Tangermann. 1983. Die zuknüftige Rolle der Agrarpreispolitik der EG. Göttinger Schriften zur Agrarökonomie, Vol. 56. Göttingen.

Schmitt, G., und Thoroe, C. 1986. Flachenstillegungen: Losung für die Agrarprobleme? Agra-Europe, 27/9:1–15.

Seebohm, E. 1981. Nationalstaatliche Landwirtschaftsförderung und Europäische Agrarpolitik. Agrarwirtschaft, Sonderheft 89. Hannover: Strothe-Verlag.

Statistical Office of the European Community (Eurostat). 1986. Various statistical publications. Luxembourg.

Stanton, B. F. 1986. Production Costs for Cereals in the European Community: Comparisons with the United States, 1977–1984. A.E. Res. 86–2. Agricultural Experiment Station. Ithaca, N.Y.: Cornell University.

Strecker, O. 1958. Der Kampf um die Agrarzölle in Großbitannien und in Deutschland (1871–1902). Berichte über Landwirtschaft 36:869–904.

Tangermann, S. 1982. Agricultural protectionism. The European perspective. Paper presented at the Global International Interdependence Center Conference on International Food, Finance, and Agricultural Trade: Critical Issues in the 1980s. Minneapolis, Minnesota.

Teichmann, U. 1955. Die Politik der Agrarpreisstützung. Köln: Bund-Verlag.

Timoshenko, V. P. 1933. World Agriculture and the Depression. Michigan Business Studies 5. Ann Arbor. Reprinted 1983, Garland Publishing, N.Y.

Tracy, M. 1982. Agriculture in Western Europe: Challenge and Response, 1880–1980. London: Granada Publishing.

United Nations Conference on Trade and Development. 1983. Protectionism and Structural Adjustment in Agriculture. Report prepared for the twenty-sixth session of the Trade and Development Board. Geneva.

U.S. Department of Agriculture. Various statistical publications. Washington, D.C.: U.S. Government Printing Office.

Weinschenck, G., ed. 1973. Die künftige Entwicklung der europäischen Landwirtschaft-Prognosen und Denkmodelle. Schriften d. Gesell- für Wirtschafts- und Sozialwiss. des Landbaues, Vol. 10. Nünchen, Bern and Wien: Bayr. Landwirtschaftsverlag.

Technical Change: Sources of Income and Agricultural Production in Developing Countries

G. Edward Schuh

We are in the midst of one of those crucial times in history when contemporary events are poorly understood and the potential for making serious mistakes in policy is great. Popular writers discover experimental results that promise important technological breakthroughs and conclude that the world's food production problem has been solved. Low commodity prices are attributed to rapidly growing production in the developing countries, and the demand side of the market is neglected. And U.S. agricultural interests rediscover the World Bank and U.S. aid programs, try to use them as scapegoats for their misguided programs, and take steps to choke off funding for agricultural development programs by those institutions.

It is the thesis of this paper that (1) the problem of low commodity prices that characterized the mid-1980s was as much a consequence of continued disinflation of the global economy, U.S. and European Community (EC) agricultural policies, and weak aggregate demand as it was a function of supply that was expanding at too fast a pace; (2) the global capacity for agricultural research is far short of what it should be, and consequently we are far from having the capacity to generate self-sustaining agricultural development worldwide; and (3) new production technology is as important as a source of new income streams as it is of increased production, but this point is often neglected in discussions of technology and agricultural research. Each of these points is discussed in the sections that follow. A concluding comment is made about the tendency of the international community to underinvest in social science research and thus to offer an inadequate supply of policy and institutional technology.

The views expressed herein are the views of the author alone and in no way reflect official views or policies of the World Bank.

THE EXCESS SUPPLY PROBLEM IN AGRICULTURAL COMMODITY MARKETS OF THE MID-1980s

Low commodity prices, for many people, imply a problem of excess supply, and excess supply for some reason implies that it is supply that is out of adjustment, not demand. This naive interpretation of a basic economic concept is misleading and has created a great deal of mischief. Excess supply can be created as much by weak demand as by strong supply. In the situation that prevailed in the mid-1980s, even the supply side of the market did not seem to be understood very well.

Consider the principal forces at work in those commodity markets. Probably the most overriding factor was the continued disinflation from the inflationary surge of the 1970s. This disinflation started in 1980 and continued into early 1987. Monetary policies, in particular, were unusually restrictive, in part in response to highly stimulative fiscal policies in the United States. Real interest rates in international financial markets remained at relatively high levels in historical terms as 1987 began. It is well known that commodity prices rise faster and further than other prices in periods of inflation, and that they fall faster and further than other prices in periods of disinflation. The low commodity prices of the mid-1980's were due to factors that went beyond industry-specific forces and can be illustrated by the fact that with the exception of gold, silver, and platinum, almost all commodity prices were at quite low levels.

The sluggish economic growth, the result of restrictive monetary policies and high real interest rates, was exacerbated by a serious international debt crisis and a broad-based transition to more rational economic policies in the developing countries. The debt crisis was the major causal variable in this situation. The problem had been especially severe because it came hard on the heels of a period of strong markets in the 1970s, which were financed, especially in the middle and late years of the decade, by foreign borrowing on the part of the developing countries. In that earlier period commercial banks in the developed countries worked diligently to recycle the burgeoning supply of petrodollars, and the developing countries absorbed the funds with alacrity. Imports of agricultural commodities grew rapidly and international commodity markets boomed.

The early 1980s witnessed record-high real interest rates and a rise in the value of the dollar, both of which raised the costs of servicing previously accumulated debt and contributed to the world's worst economic recession since the 1930s. The developing countries faced serious balance-of-payment problems and difficulty in servicing their debt. Their initial (short-term) response was the usual one, to reduce their imports significantly by whatever means possible.

The longer term adjustment in countries facing a serious debt crisis is to devalue their currency and to reduce or eliminate other restrictive policies affecting trade. The International Monetary Fund and the World Bank encouraged such changes in policies. These changes, and especially the currency devaluations, reduced the demand for imports and increased the supply of exports. Thus, there was a double effect in international markets. These "price" effects, coupled with sluggish economic growth worldwide (1984 excepted), contributed to weak international commodity markets in a very significant way.

Another factor in the markets is that the United States, the EC, and Japan all have domestic commodity programs that support prices above market-clearing levels, thus causing supply to be significantly above what it would otherwise be. These policies directly contributed to the excess supply problem of the mid-1980s. The EC, for example, in the short space of a decade shifted from being a net importer of cereals in the early 1970s to being an exporter of 24 million tons in 1984–1985—largely as a consequence of highly distorted prices. The EC also shifted from being a net importer of sugar to being the world's largest gross exporter, and from being a major import market for beef to being the world's largest exporter.

The policies of the United States, given the importance of that country in international commodity markets, have contributed to more general supply problems. The 1981 farm legislation mandated annual increases in support levels for major commodities and took away the flexibility of the Secretary of Agriculture to lower those levels to meet market conditions. The dramatic rise in the value of the dollar in the first half of the 1980s translated those prices into ever higher levels compared with the currencies of other countries. The result was to stimulate production in a wide range of countries. As we know, bringing about reductions in agricultural supply is often more difficult than increasing it. Moreover, the United States pulled the props out from under the commodity markets with the 1985 farm bill (Food Security Act of 1985), which led to a drastic lowering of support levels and, in turn, of world prices.

This problem was exacerbated by the growing use of export subsidies by the EC and the United States. Thus, surpluses were dumped into a market that was already out of balance. In addition, program payments to U.S. farmers were being paid in part with grain from government stocks. Farmers converted these payments to cash by selling the grain on the market, driving prices down even further.

Another factor affecting commodity markets is the widespread use of barriers to trade in agricultural commodities. These barriers isolate national economies from international markets, thus limiting the extent to which adjustments can be made to changing market conditions and exaggerating price fluctuations. Unfortunately, these protectionist barriers are no longer limited to the developed countries. South Korea and Taiwan have now joined the protectionist club.

Another significant factor in commodity markets in the mid-1980s was the agricultural reforms in China and that country's subsequent virtual withdrawal as a major importer. In fact, in 1985 China exported maize. But this huge supply response in China has to be viewed in its proper context; it is a one-time gain from moving away from a highly distorted situation. China can be expected to be back on something approaching its longer term trend line before too long.

To conclude this discussion, the low prices in commodity markets during the mid-1980s reflected a combination of both supply and demand factors, with weak demand probably being the predominant factor. Distortionary policies contributed in an important way to the problem, however, especially those in the developed countries. Widespread adoption of new production technology in the developing countries played only a modest role. Even in India, a country that is often cited as a source of technology-based increases in supply, the rapid growth in wheat production and the shift to being a net exporter were as much consequences of domestic prices being set above levels prevailing in international markets as they were consequences of improvements in the underlying technological base.

GLOBAL CAPACITY FOR AGRICULTURAL RESEARCH

Two sets of data can be used to address this topic: (1) production and yields, which in a general sense should indicate the extent to which new production is being adopted at the farm level and raising resource productivity; and (2) research capacity and the commitment to support agricultural research programs.

Trends in Production and Yields

Two issues are important in introducing this topic. First, what growth rate in agricultural output is required if agriculture is not to be a brake on economic development? Second, to what extent are productivity gains needed as the basis for increased output?

Perspective on the first question can be gained from an analysis of the expected increases in demand associated with economic development. Population is growing at a rate of 2 to 3 percent in most developing countries. Increases of between 3 and 5 percent in per capita incomes are not an unreasonable expectation for low-income countries that are catching up. An income elasticity of demand for food on the order of 0.6 seems reasonable for the majority of developing countries. This means that an increase of 10 percent in average per capita income, for example, would increase the quantity of food demanded by 6 percent.

A 2 percent annual growth rate in population and a 3 percent annual increase in per capita income would result in an increase in demand for agricultural output on the order of 4 percent a year. A 3 percent growth rate in population and a 5 percent annual increase in per capita income would increase aggregate demand at a rate of 6 percent a year.

These are useful benchmarks, although it should be recalled that the income elasticity of demand will vary both among commodities and among countries according to their stage of development. Three points need to be emphasized. First, obtaining annual increases of 3 to 5 percent in per capita income on a sustained basis is plausible for countries playing catch-up if they pursue rational economic policies. Many countries, such as the newly industrializing countries (NICs), have done better. Second, few countries have been able to obtain increases in their agricultural output of 4 percent per year on a sustained basis. Those who have are countries such as Brazil, which has been able to bring large quantities of new land into production each year. That option is no longer open for most countries, however. Consequently, increases in output will have to be obtained by means of increases in productivity. Raising productivity at a rate of 4 percent per year on a sustained basis is also not easy.

Third, as per capita incomes rise, the configuration of demand for agricultural products changes significantly. Consumers tend to shift away from cereals, roots, and tubers and toward increased consumption of livestock, livestock products, fruits, and vegetables. The commodities with rising demand potential tend to be more resource intensive in terms of conventional resources and thus demand more land and labor. Moreover, the available research capacity to produce new technology for these commodities is substantially less than that available for the grains and cereals.

The following discussion focuses for the most part on the productivity of land. The reader should keep in mind, however, that labor scarcity (in peak seasons) is a key issue in much of Africa and, increasingly, in the NICs. Mechanized technology tends to be more easily transferable, however, and the private sector is generally willing to supply most of it.

Table 1 provides an overview of trends in production and land productivity for 15 commodities and commodity groups for the period 1961–1985, based on World Bank data. Table 1 demonstrates that increases in yields have already accounted for a significant share of the increase in production in the developing countries, and that this productivity growth tends to be limited to the cereals and soybeans. It has been much less for roots and tubers, food legumes other than soybeans, and cash crops.

More detailed data on these same commodity groups are provided in 15 appended tables. Together, the data in these tables show that:

1. For the primary cereals as a whole, growth in yields for the developing countries as a group increased modestly in each of the three periods (1961–1970, 1971–1980, and 1978–1984).

TABLE 1 Comparative Data on the Growth Rates of Production and Yields for Selected Commodities, 1961–1985

	Growth Rates of Production (P) and Yields (Y) (LSQ%), 1961–1985					
	World		Developing Countries		Industrial Countries	
Commodities	P	Y	P	Y	P	Y
Cereals, total	2.8	2.4	3.1	2.6	2.7	2.0
Rice	2.8	2.0	3.0	2.2	0.2	0.7
Wheat	3.3	2.7	4.8	3.5	3.1	1.9
Maize	3.6	2.4	3.8	2.3	3.7	2.3
Sorghum	3.0	2.1	3.5	2.7	1.9	0.9
Millet	−1.0	0.9	−1.0	1.0	−4.0	−0.9
Roots and tubers, total	0.7	0.9	2.0	1.4	−1.5	1.7
Cassava	2.6	0.8	2.6	0.8	−1.0	1.3
Potatoes	0.2	0.8	4.1	1.9	−1.3	1.7
Food legumes pulses, total	0.4	0.6	0.6	0.4	0.5	2.1
Oil-bearing						
Groundnuts	1.0	1.0	0.9	0.9	2.7	2.8
Soybeans	5.5	2.0	6.0	3.2	5.2	1.0
Cash crops						
Coffee	1.1	0.9	1.1	0.9	−2.4	−0.6
Cocoa	1.4	0.9	1.4	0.9	−3.0	0.2
Sugar cane	3.2	0.8	3.4	0.9	0.7	0.0

SOURCE: World Bank data.

2. The increase in yield is attributable primarily to rice, wheat, and to a lesser extent, maize. Sorghum and millet have performed significantly less well.

3. Rice and wheat yields increased at a rapid pace in the 1978–1984 period, and wheat yields grew at a significantly higher rate than the other cereals.

4. Among the developing countries, yield increases for rice and wheat are limited for the most part to Asia and the Pacific and to Latin America and the Caribbean.

5. Sorghum and millet yields increased at a significantly more rapid rate in the 1961–1970 period than they have since.

6. Performance in Africa has been uniformly poor in both the 1970s and in the early 1980s.

7. Compared with the growth in yields of cereals, increases in yields of roots and tubers in all developing countries have been modest in the 1970s and 1980s. The growth rate for roots and tubers was significantly higher in the 1960s.

8. Potato yields increased significantly in both the 1970s and the early 1980s in Asia and the Pacific, and in Latin America, Asia, and the Pacific in the 1978–1984 period.

9. Yields of total pulses (edible seeds of legumes) have not done well in the developing countries as a whole. The growth rates were fairly high, however, for groundnuts and soybeans in Asia and the Pacific and in Latin America and the Caribbean in the 1978–1984 period. Interestingly, there was rapid growth in yields of soybeans in the Eastern Mediterranean and North African regions during the 1971–1980 period.

10. Yields of the three cash crops (i.e., coffee, cocoa, and sugar cane) have done almost uniformly poorly. The exception is cocoa in Asia and the Pacific during the 1978–1984 period.

As these data suggest, the main breakthroughs at the farm level have been with the high-yielding varieties of rice and wheat that have been developed by national research programs, in part from genetic materials provided by the International Agricultural Research Centers. It is estimated that these improved varieties now cover approximately 115 million hectares, or half the total plantings of wheat and rice in the developing world. (These and the data that follow are taken from Consultative Group for International Agricultural Research [CGIAR, 1985].)

Table 2 provides data on how the proportion of high-yielding rice and wheat plantings differs by region of the developing countries. As the data in Tables A1–A15 (see pages 198–212) suggest, the most extensive adoption of these varieties has been in Asia and Latin America. A different way of evaluating this feature is by regional distribution of the high-yielding varieties themselves. Such data are presented in Table 3, together with the regional distribution of all production of these crops. These data indicate that the adoption of the improved varieties of rice and wheat are concentrated in Asia and Latin America in part because that is where those crops are grown.

It is estimated that the improved varieties of rice and wheat annually yield about 50 million tons more than the old varieties would have produced. That is enough to provide food grain for about 500 million people, which is a significant part of the growth in population in that period.

It is important to note that these high-yielding varieties will probably never completely replace traditional varieties. Hence, the larger production increase associated with geographic diffusion of the improved varieties may well be mostly behind us. Future increases in output will increasingly have

TABLE 2 Estimated Area of High-Yielding Varieties (HYVs) of Rice and Wheat as a Proportion of Total Area Planted With Those Crops in Developing Countries, 1982–1983

Region	HYV Rice (Percent)	HYV Wheat (Percent)	Total (Percent)
Asia	44.9[a]	79.2	54.6
Near East	8.4	30.6	29.6
Africa	4.7	50.6	13.3
Latin America	32.9	77.6	59.0
Total	41.6	60.9	49.8
Communist Asia[b]	81.0	30.6[c]	58.0
Total	53.6	51.9	52.9

[a]Excludes Taiwan.
[b]Excludes North Korea.
[c]China; incomplete estimate of short high-yielding varieties.

SOURCE: Consultative Group on International Agricultural Research (1985).

to come from improvements in the high-yielding varieties themselves. In addition, maintenance research becomes increasingly important as yields increase. Hence, a larger and larger share of research budgets will have to be used just to sustain present yields, rather than to make additional breakthroughs.

Although the aggregate data in Tables 1, 2, and 3 do not show it in a decisive way, the CGIAR impact study found that varieties of maize and field beans derived from genetic material provided by the International Agricultural Research Centers are beginning to have a measurable impact on food production. Developing countries have released over 200 center-related maize varieties and more than 6 million hectares are now planted to them. Nearly 100 center-related bean varieties have been released. About half the field beans planted in Argentina, Costa Rica, Cuba, and Guatemala are center-related varieties. The CGIAR impact study also estimated that over 250 center-related varieties of sorghum, potato, cassava, chickpeas, cowpeas, pasture species, pearl millet, pigeon peas, and durum wheat have been named by national authorities. The area planted with them is still small, however, because many of the varieties were not released until after 1980.

In evaluating the status in terms of producing new technology for agriculture in the developed countries, a number of points must be emphasized.

First, the significant breakthroughs have been in rice and wheat. Both of these crops are widely produced in areas where the bulk of the world's population is concentrated. Moreover, production conditions were such that the improved varieties were widely and rapidly diffused. That process will probably now begin to level off.

Second, significant breakthroughs for other food crops are fairly limited. Moreover, the conditions under which other crops are produced make the potential for rapid and widespread diffusion of improved varieties for other crops far more limited. Ecological, economic, and institutional arrangements are far more important for these crops than for those in which there have already been breaktroughs, and the heterogeneity in the conditions under which these crops are produced make location specificity more important in the research needed to sustain improvements. Contrary to rice and wheat, the other crops tend to be produced in multiple-crop systems, and under conditions of high risk and ecological variations. This is one of the reasons why there has been so little adoption of improved varieties in Africa. (Highly discriminatory economic policies have also played an important role.)

Finally, diversification is becoming increasingly important, especially in Asia. Two factors are at work. First, as per capita income rises and the opportunity cost of time (what labor can earn in employment outside the home) in the household rises, the configuration of demand shifts away from household-time-intensive commodities, such as rice. Second, continued progress in improving yields and broadening adaptability will create the need to shift resources out of rice production. The problem, of course, is

TABLE 3 Distribution of High-Yielding Varieties (HYVs) of Rice and Wheat Among the Developing Regions of the World, 1982–1983 (in percent)

	Rice		Wheat		Total	
Region	HYV	All	HYV	All	HYV	All
Asia	92.9	86.2	60.8	46.5	76.3	69.9
Near East	0.3	1.2	18.2	36.6	9.5	15.7
Africa	0.5	4.4	1.2	1.4	0.9	3.2
Latin America	6.3	8.2	19.9	15.5	13.3	11.2
Total	100.0	100.0	100.1[a]	100.0	100.0	100.0

NOTE: Excludes Communist Asia.

[a]Total does not equal 100 percent due to rounding.

SOURCE: Consultative Group on International Agricultural Research (1985).

that the available technology for this process of diversification is simply not at hand. Neither is the capacity in terms of research staff or research facilities to develop such technology.

The Installed Capacity for Agricultural Research

The issue becomes: What is the installed capacity to carry out agricultural research so as to produce locally adapted new production technology? The answer is that it is fairly limited, especially when it is recognized that priority should be given to location-specific research efforts, even for continued improvements of rice and wheat. In addition, there are large parts of the world not yet touched by new production technology, while diversification is becoming increasingly important in areas where new production technology has become available.

National agricultural research systems in developing countries have grown rapidly during the past 25 years. Between 1959 and 1980, for example, the number of agricultural researchers in developing countries rose from 14,700 to 63,000. Serious efforts have been made to build effective agricultural research systems in countries as disparate as Brazil, India, and Indonesia. But in comparison with the need, the available capacity falls far short. No less an authority than Vernon Ruttan (in this volume) argues that the international capacity will not be complete until there is an effective research station for every ecological zone. It does not require extensive documentation to prove that we are far short of that goal.

Two other factors must be weighed. First, the international debt crisis and retrenchment efforts associated with restoring economic growth have forced budget cuts on national agricultural research systems that were once fairly strong. Brazil is an important example. Mexico is another. Hence, from a global perspective, the fairly modest national agricultural research capacity in developing countries may in fact be declining.

Second, few developing countries have a higher-level educational system that is sufficient to sustain any modern agricultural research systems on a self-reproducing basis. In country after country where there was once considerable strength, such as Brazil and India, the capacity is now declining. In part this is a reflection of the fact that these educational institutions never achieved the level they should have in the first place. But in part it is again a reflection of the lack of resources to retain faculty and sustain programs.

It is imperative that we address this problem. Many of the more well-trained staff in national agricultural research systems were trained abroad at a time when there were ample resources for that purpose. Similarly, many of the viable higher-level educational institutions were built with the assistance of foreign aid in an era in which institution building was a respectable activity. Reduced donor budgets for these purposes have brought training and institution building almost to a halt. And national governments have been unwilling or unable to sustain the capacity they had achieved through further training and retraining. We must keep in mind that sustainable research systems are not possible without sustainable educational institutions.

Finally, there is the issue of sustained research on the cash crops. The colonial empires maintained effective research stations for the cash crops in widely dispersed parts of the world. Those stations produced new production technology for sugar cane, cotton, coffee, tea, rubber, cocoa, and other crops. As the empires collapsed, so did the research efforts. And with a few exceptions, the research efforts have not been sustained or replaced by national governments. Consequently, with the limited exceptions noted in this section, there is very little new production technology for these crops. Yet millions and millions of people depend on them for their livelihood.

To conclude this section, the international effort that led to the new production technology for rice and wheat was an unusual success story. Hundreds of millions of people are better fed, and millions of producers earn a better livelihood. But we should not let that success lead to a false sense of security. The scope of that technological revolution has been fairly narrow. The national capacity to sustain and broaden the process is quite limited and possibly declining. An adequate educational capacity to support those research systems never existed. What did exist is most likely declining.

Some people look at the world and are mesmerized by low commodity prices and the new things that are coming out of the laboratories and research stations in the developed countries. A more sober appraisal of the situation would see the low prices to be a consequence of sluggish economic growth, weak demand, and highly distortional agricultural policies. A more sober appraisal would also recognize we never did have an adequate research capacity to sustain the productivity gains we had realized and that capacity is declining. With all the misplaced rhetoric and the political pressures of interest groups in the developed countries, we may well be laying the ground for the next Malthusian crisis a decade from now.

NEW PRODUCTION TECHNOLOGY AS A SOURCE OF INCOME STREAMS

The international commodity boom of the 1970s, coinciding as it did with the simultaneous publication of a number of popular books that argued that the world was on a collision path with natural resource constraints that would soon halt economic growth, was widely interpreted at the time as a Malthusian crisis. This focused attention on the problem of food production and caused agricultural research and new production technology to be harnessed to that end.

This perspective has created a number of biases in our agricultural research efforts. First, it has caused us to neglect almost totally the cash crops and their potential as earners of foreign exchange and generators of income and employment. What is perhaps more important, it has caused us to view new product technology strictly as a source of increased production and to neglect it as a source of increased income streams. This in turn has caused us to fail to recognize the chief benefit of new technology, that is, lower-priced commodities, and instead to view low prices as a problem rather than the benefit they are.

Professor Schultz's conceptualization of new production technology in *Transforming Traditional Agriculture* viewed it as a source of new income streams (Schultz, 1964). His perspective was that of Fisherian capital theory, and he had an economic growth perspective that viewed new production technology as a cheap source of such income streams, which is to say one whose production had a high rate of social return. In the final analysis, these increased income streams are realized for the most part by consumers, although producers also can reap an important share. On the consumer side, low-income families benefit in a relative sense.

Unfortunately, the international development community seems to have lost sight of this broad perspective and opted instead for a narrower perspective that focuses on increasing production and raising resource productivity. The narrower perspective is all right as far as it goes, but it has caused us to underestimate the potential of developing agricultural research capacity as a source of economic growth, and, thus, to underinvest in it.

Three issues arise from the narrower perspective. First, when this narrower production or productivity perspective is taken, there is a tendency to put production technology at the service of drives for food self-sufficiency. If the more general question were asked, it would at least be possible to calculate trade-offs and show how much was being sacrificed in terms of economic growth to attain the goal of food self-sufficiency.

Second, the broader perspective forces one to consider the full range of income sources from the new production technology. For nontraded commodities, the consumer is the eventual beneficiary, in the form of lower prices. In general, these benefits will tend to be much larger than those reflected only in the value of increased output at projected prices—unfortunately an all-too-frequent form of measurement for the benefits of new production technology. For traded commodities, there is not likely to be a price effect—unless the country is a dominant supplier. But there will be net rents for producers, and either foreign-exchange earnings (for exporter countries) or foreign-exchange savings (for importer countries). The foreign-exchange earnings (or savings) can also produce large benefits in terms of income streams and employment. Clearly, the broader perspective will tend to yield higher social rates of return. New production technology, of course, can be a critical means of retaining or conquering international markets.

Finally, the broader perspective would cause us to give more attention to cash crops and tree crops. As a source of income and employment these crops are important. We have neglected them for far too long.

New production technology for agriculture can be a powerful source of economic growth in the developing countries. To realize that potential we must both strengthen existing capacity and broaden it to include a wider range of crops and livestock. To fail to do this is to sacrifice economic growth worldwide, including growth in the United States and other developed countries.

CONCLUDING COMMENTS

All too frequently when we talk about agricultural research we have in mind primarily the work of the biological and physical sciences. The social sciences are almost totally neglected. Yet when we look at the global agricultural economy, we see a sector that is fraught with massive resource distortions, economic policies that are equally distorted, serious adjustment problems, and institutional arrangements that do not work. Globally, we are grossly underinvesting in social science research. To make the kind of world we would all like to live in, we must invest in the capacity for social science research, for our policy and institutional "technology" is every bit as important as our biological and physical technology.

REFERENCES

Consultative Group for International Agricultural Research (CGIAR). 1985. Summary of International Agricultural Research Centers: A Study of Achievements and Potential. Washington, D.C.: World Bank.

Judd, M. A., J. K. Boyce, and R. E. Evenson. 1986. Investing in agricultural supply. The determinants of agricultural research and extension investment. Econ. Dev. and Cultural Change 35:77–144.

Schultz, Theodore W. 1964. Transforming Traditional Agriculture. New Haven, Conn.: Yale University Press.

TABLE A1 Rice

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent) 1961–1970	1971–1980	1978–1984	1961–1985
Africa	6,622	3.1	1,405	1.2	0.4	0.4	0.5
Asia-Pacific	396,653	3.0	3,149	1.9	2.1	3.9	2.3
Latin America and the Caribbean	16,387	3.2	2,154	–0.2	1.0	3.3	1.1
Eastern Mediterranean and North Africa	5,0261	0.4	3,923	1.6	0.2	0.2	0.7
North America	5,935	3.6	5,330	2.9	–0.3	1.3	1.0
Industrial Pacific	14,226	–0.8	5,947	1.8	0.0	0.4	0.5
Western Europe	1,402	1.2	5,641	–1.2	1.0	0.5	0.4
Eastern Europe and Soviet Union	2,739	8.7	3,796	5.1	0.8	0.3	2.1
World	448,993	2.8	3,117	1.8	1.8	3.5	2.0
Developing countries Total	424,691	3.0	3,043	1.8	1.9	3.7	2.2

TABLE A2 Wheat

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent) 1961–1970	1971–1980	1978–1984	1961–1985
Africa	3,594	3.4	1,193	4.1	0.2	1.3	2.2
Asia-Pacific	135,658	6.5	2,207	4.5	3.8	6.1	4.6
Latin America and the Caribbean	21,163	2.7	1,965	–0.1	0.6	6.1	1.4
Eastern Mediterranean and North Africa	42,730	2.5	1,554	1.6	2.8	0.9	2.2
North America	95,389	3.3	2,331	3.4	0.4	2.3	1.8
Industrial Pacific	17,424	2.6	1,383	–1.2	1.0	–1.0	0.2
Western Europe	71,741	2.9	4,566	2.9	2.6	4.6	3.3
Eastern Europe and Soviet Union	112,456	1.6	1,834	4.9	1.3	–1.0	2.6
World	501,239	3.3	2,146	3.3	1.8	2.8	2.7
Developing countries							
Total	204,229	4.8	1,978	2.9	3.1	4.9	3.5

TABLE A3 Maize

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent) 1961–1970	1971–1980	1978–1984	1961–1985
Africa	20,490	2.7	1,113	0.1	1.3	–4.0	1.1
Asia-Pacific	91,869	4.8	2,669	–0.5	4.0	4.6	2.5
Latin America and the Caribbean	48,625	3.0	1,839	2.0	2.1	2.3	2.1
Eastern Mediterranean and North Africa	19,401	2.9	3,711	4.5	2.9	4.2	3.2
North America	176,539	3.6	6,287	3.0	1.4	–0.7	2.2
Industrial Pacific	354	1.6	4,246	2.0	4.0	–1.2	3.5
Western Europe	22,176	5.3	6,369	6.5	2.1	2.5	3.6
Eastern Europe and Soviet Union	36,791	2.1	4,119	3.8	3.2	1.9	3.1
World	416,254	3.6	3,333	1.5	2.6	0.8	2.4
Developing countries Total	180,393	3.8	2,135	0.9	2.9	2.8	2.3

TABLE A4 Sorghum

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	9,331	1.4	583	–1.1	0.9	–5.6	–0.4
Asia-Pacific	19,763	3.0	1,007	6.5	3.0	1.2	3.3
Latin America and the Caribbean	14,737	9.4	2,810	3.5	3.5	0.5	3.2
Eastern Mediterranean and North Africa	469	–3.6	674	0.6	1.8	–8.0	0.4
North America	18,533	1.5	3,436	2.6	–0.5	–0.5	1.0
Industrial Pacific	1,387	9.5	1,989	0.2	0.0	0.2	1.3
Western Europe	459	9.2	4,483	3.1	1.9	–0.3	2.8
Eastern Europe and Soviet Union	235	5.3	1,222	7.8	0.3	–0.4	1.0
World	64,993	3.0	1,352	3.2	1.1	–0.2	2.1
Developing countries Total	44,379	3.5	1,064	3.9	2.6	–0.2	2.7

TABLE A5 Millet

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent) 1961–1970	1971–1980	1978–1984	1961–1985
Africa	8,259	0.6	535	–0.4	0.8	–3.2	–0.2
Asia-Pacific	18,287	–1.6	818	4.3	0.7	3.5	1.6
Latin America and the Caribbean	156	0.1	1,160	–2.7	1.7	–2.0	0.2
Eastern Mediterranean and North Africa	780	–1.0	2,473	3.3	–1.1	–0.6	0.2
North America	—	—	—	—	—	—	—
Industrial Pacific	38	–4.5	1,047	–3.5	–3.8	5.4	–1.6
Western Europe	9	–1.9	3,480	6.6	1.3	8.3	3.4
Eastern Europe and Soviet Union	2,239	–1.7	804	3.8	–5.1	4.6	–0.2
World	29,780	–1.0	725	3.2	0.1	1.4	0.9
Developing countries Total	27,494	–1.0	719	3.1	0.5	1.1	1.0

TABLE A6 Cassava

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	52,856	2.3	7,237	1.8	1.3	2.2	0.8
Asia-Pacific	47,681	5.2	12,387	1.8	2.7	1.8	2.1
Latin America and the Caribbean	28,562	0.4	10,872	1.2	–1.7	–0.7	–0.8
Eastern Mediterranean and North Africa	—	—	—	—	—	—	—
North America	13	1.0	8,879	3.1	7.4	0.3	3.8
Industrial Pacific	—	—	—	—	—	—	—
Western Europe	23	–1.8	10,486	0.1	0.4	–1.0	0.1
Eastern Europe and Soviet Union	—	—	—	—	—	—	—
World	129,134	2.6	9,367	2.3	0.9	1.2	0.8
Developing countries Total	129,099	2.6	9,367	2.3	0.9	1.2	0.8

TABLE A7 Soybeans

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	232	7.0	705	3.2	5.8	–0.3	3.8
Asia-Pacific	11,734	0.3	1,154	3.0	0.7	3.0	1.8
Latin America and the Caribbean	20,985	23.0	1,753	1.3	1.5	4.7	2.3
Eastern Mediterranean and North Africa	531	21.0	2,239	0.8	5.7	2.6	4.2
North America	52,434	5.0	1,928	1.3	1.0	–1.2	1.0
Industrial Pacific	300	0.7	1,606	0.3	0.8	1.9	1.2
Western Europe	94	36.0	2,419	–1.8	3.8	7.6	0.6
Eastern Europe and Soviet Union	1,015	5.0	843	4.2	4.9	–0.6	2.7
World	87,327	5.5	1,703	3.6	1.4	0.4	2.0
Developing countries Total	86,311	6.0	1,473	3.3	2.8	4.1	3.2

TABLE A8 Potatoes

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	3,469	5.2	6,755	4.4	0.1	–1.0	0.7
Asia-Pacific	64,095	4.8	12,055	–1.1	5.1	3.0	2.0
Latin America and the Caribbean	11,238	2.0	11,109	2.2	1.9	3.3	2.1
Eastern Mediterranean and North Africa	13,224	3.0	12,672	1.3	1.8	1.1	1.4
North America	18,612	1.3	29,599	1.5	2.0	0.5	1.7
Industrial Pacific	4,878	0.1	27,875	3.1	2.6	1.7	2.4
Western Europe	42,277	–3.3	26,675	2.5	6.9	0.7	1.6
Eastern Europe and Soviet Union	137,540	–0.6	13,533	3.3	0.0	–0.3	0.8
World	295,449	0.2	14,444	2.1	0.7	0.7	0.8
Developing countries Total	92,141	4.1	11,660	0.0	3.9	2.5	1.9

TABLE A9 Coffee, Green

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	1,184	0.8	332	1.5	–1.9	0.8	–0.5
Asia-Pacific	631	5.3	629	3.2	1.7	–5.1	1.7
Latin America and the Caribbean	3,393	0.7	618	0.1	–0.5	1.9	1.5
Eastern Mediterranean and North Africa	4	–1.6	506	–6.1	2.6	–1.7	–2.4
North America	14	–1.6	309	–2.6	–0.7	5.7	0.0
Industrial Pacific	—	—	—	—	—	—	—
Western Europe	1	–7.6	235	0.6	–4.1	–10.1	–3.7
Eastern Europe and Soviet Union	—	—	—	—	—	—	—
World	5,228	1.1	516	0.4	–0.8	0.8	0.9
Developing countries Total	5,212	1.1	518	0.4	–0.8	0.8	0.9

TABLE A10 Sugar Cane

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent) 1961–1970	1971–1980	1978–1984	1961–1985
Africa	55,398	4.0	63,568	0.8	–1.6	1.1	0.2
Asia-Pacific	352,588	3.2	53,057	0.8	0.6	1.6	0.9
Latin America and the Caribbean	421,502	3.5	60,409	1.6	1.6	0.8	1.1
Eastern Mediterranean and North Africa	11,355	4.2	76,730	0.7	–1.7	–0.1	–0.7
North America	27,058	–0.4	82,757	0.5	–0.4	1.0	–0.3
Industrial Pacific	27,263	2.9	78,206	1.1	0.2	–0.7	0.5
Western Europe	3,439	–2.1	56,905	–0.6	2.0	–2.0	–0.4
Eastern Europe and Soviet Union	—	—	—	—	—	—	—
World	898,611	3.2	58,427	1.2	0.8	1.1	0.8
Developing countries Total	840,845	3.4	57,418	1.3	0.9	1.2	0.9

TABLE A11 Cocoa Beans

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	928	0.2	341	3.3	−1.5	−1.6	0.1
Asia–Pacific	137	7.9	425	1.6	0.1	5.7	1.3
Latin America and the Caribbean	583	3.2	377	1.9	2.5	−1.7	2.1
Eastern Mediterranean and North Africa	—	—	—	—	—	—	—
North America	0	1.8	441	11.4	−0.5	0.4	3.7
Industrial Pacific	—	—	—	—	—	—	—
Western Europe	0.1	−3.9	286	−3.8	1.8	1.9	−0.3
Eastern Europe and Soviet Union	—	—	—	—	—	—	—
World	1,648	1.4	328	3.0	−0.2	−0.8	0.9
Developing countries Total	1,648	1.4	351	3.0	−0.2	−0.8	0.9

TABLE A12 Total Roots and Tubers

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	91,244	2.3	7.2	1.4	1.2	1.6	0.7
Asia-Pacific	216,968	2.1	13.5	4.2	1.4	2.3	2.2
Latin America and the Caribbean	43,243	–2.6	10.3	1.5	–1.0	0.2	–0.1
Eastern Mediterranean and North Africa	13,493	3.0	12.7	1.3	1.8	1.1	1.4
North America	19,272	1.2	28.3	1.9	2.0	0.6	1.9
Industrial Pacific	6,891	–2.6	24.3	1.2	1.8	1.4	1.5
Western Europe	42,451	–2.3	26.5	2.4	0.9	0.7	1.6
Eastern Europe and Soviet Union	137,542	–0.6	13.5	3.3	0.0	–0.3	0.8
World	571,221	0.7	12.2	2.6	0.5	0.8	0.9
Developing countries Total	365,064	2.0	10.7	3.1	1.0	1.4	1.4

TABLE A13 Total Primary Cereals

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	51,010	2.0	0.8	0.5	1.0	–3.2	0.7
Asia-Pacific	674,137	3.3	2.5	2.9	2.9	4.4	3.1
Latin America and the Caribbean	103,577	3.4	2.0	1.4	2.0	3.0	2.1
Eastern Mediterranean and North Africa	84,127	2.2	1.7	2.2	2.3	1.2	2.0
North America	333,387	2.9	3.7	3.3	1.4	–0.6	2.1
Industrial Pacific	40,218	1.1	2.0	–0.8	–0.7	–1.1	–0.5
Western Europe	164,660	2.7	4.3	2.9	1.8	3.2	2.6
Eastern Europe and Soviet Union	264,683	2.1	1.9	4.5	0.6	–0.2	2.2
World	1,717,128	2.8	2.4	2.8	1.9	2.0	2.4
Developing countries Total	914,174	3.1	2.1	2.4	2.6	3.4	1.6

TABLE A14 Total Primary Pulses

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	4,904	2.2	428	–1.4	1.8	–1.2	0.2
Asia-Pacific	21,171	0.1	653	0.3	0.0	1.4	0.6
Latin America and the Caribbean	5,170	1.3	567	0.2	–1.5	–0.3	–0.4
Eastern Mediterranean and North Africa	2,989	0.8	887	5.9	–0.5	0.2	1.4
North America	1,415	1.2	1,539	0.0	0.6	–0.4	0.5
Industrial Pacific	558	2.1	1,085	1.5	–1.2	–2.4	–0.3
Western Europe	1,922	–0.6	1,832	2.7	3.0	7.2	3.5
Eastern Europe and Soviet Union	8,397	–0.2	1,176	6.5	0.4	–0.2	1.7
World	46,542	0.4	705	1.1	–0.1	1.0	0.6
Developing countries Total	34,250	0.6	608	0.2	–0.0	0.7	0.4

TABLE A15 Groundnuts in Shells

Region	Production: Metric Tons, 1982–1984 (000)	Production: Growth Rate, 1961–1985 (percent)	Metric Tons per Hectare, 1982–1984	Yield Growth Rates (percent): 1961–1970	1971–1980	1978–1984	1961–1985
Africa	3,909	–1.3	663	–0.9	–0.3	–3.1	–0.7
Asia–Pacific	12,472	2.2	1,094	0.5	1.6	3.3	1.6
Latin America and the Caribbean	866	–1.4	1,458	–1.0	1.8	3.8	0.8
Eastern Mediterranean and North Africa	170	3.1	1,889	–0.9	–0.5	0.3	–0.6
North America	1,685	3.3	2,978	5.6	–0.2	2.2	3.2
Industrial Pacific	92	–2.9	1,455	–2.0	–0.8	–2.7	–1.3
Western Europe	6	–4.8	2,365	0.2	3.5	–0.6	1.3
Eastern Europe and Soviet Union	8	9.3	1,531	0.6	–3.5	8.3	1.6
World	19,221	1.0	1,033	0.2	0.9	1.7	1.0
Developing countries Total	17,430	0.9	970	–0.1	1.0	1.7	0.9

Agricultural and Trade Policy Reform

Kenneth R. Farrell, George E. Rossmiller, M. Ann Tutwiler, and Kristen Allen

Dairy, prairie, quite contrary,
How does your surplus grow?
With lobbies strong, so prices wrong,
And subsidies all in a row.

Economist, November 15, 1986

The article from which the quotation was taken is one of several scathing reviews of world agricultural and trade policies that have appeared in the business-oriented press. With some temerity and with the alacrity business editors are wont to exhibit in diagnosing complex economic problems, the *Economist* (1986) intones:

> In the rich and mainly industrial countries farmers are paid too much, so they produce too much. In the poor and mainly agricultural countries farmers are paid too little, so they produce too little. Europeans trample Cognac grapes into industrial alcohol; Americans fill Rocky Mountain caverns with butter; Japanese pay eight to ten times the world price for their bowl of rice. Meanwhile, many million Asians and Africans live in rural poverty and go hungry to bed. Do not despair. The mistakes are so large that these contrary policies will soon collapse. Properly staged and handled, that collapse will leave the whole world better off.
>
> If all the [agricultural] subsidies and protectionism were removed, calculates the World Bank, consumers and taxpayers in the rich OECD [Organization for Economic Cooperation and Development] countries would be $100 billion a year better off, while their farmers would be only $50 billion worse off. Conclusion: win your next election by paying farmers a net $50 billion a year in a wiser way.

Conclusions and recommendations are solely those of the authors and do not constitute a statement of policy on behalf of Resources for the Future.

In a similar vein, Lee Smith (1986) advised in *Fortune:* "The government should quit paying crop subsidies and instead fashion a straightforward welfare program for farmers who can't hack it in the open market."

World agricultural and trade policies are in disarray. So too are world macroeconomic policies, which circumscribe and constrain agricultural and trade policies. Concern is warranted regarding the adequacy of current agricultural and trade policies either for taking the lead in formulating coherent expression of future technical change in world agriculture or for responding to technological changes now under way. As to whether failures are so large that policies will soon self-destruct, we are much less sanguine than the *Economist*.

We have some sympathy with the *Economist*'s prescriptions—that is, resist temptations to tinker with poor policies; instead, widen the cracks, hasten the collapse, and then build a better system. Pragmatically, however, that kind of solution has at least two deficiencies. First, the problem itself is just not that simple—there is, or should be, more to agricultural policy than simply getting prices right, although certainly that should be a prime objective of any policy reform. Second, there is no universal recipe for a "better system"—as powerful and efficient as markets can be in allocating resources, they also may fail to yield socially acceptable outcomes. Moreover, we just do not believe it will happen that way. We believe that political systems will maintain a high capacity and proclivity for "muddling through," for doing things necessary to curry political favor, as seems inevitable in democratic, pluralistic societies even when contrary to perceived economic wisdom.

In making these assertions, we are not suggesting a standpat, continue-to-tinker policy strategy. Clearly, changes are called for in the context of the science-driven, globally interdependent agricultural and trade systems envisaged in the papers in this volume. However, if one is to sort out what is worth keeping from what needs to be changed, one needs a clear understanding of the causes of current policy failures, acceptable public policy goals for agriculture, and, finally, the means of achieving them. Accordingly, the discussion begins with the six areas in which U.S. agriculture has undergone major changes over the past 50 years—areas that are relevant to past policy failures and future policy designs, incorporating aspects of conclusions presented in the papers in this volume. We conclude by setting forth two major objectives for future policies related to technology and agricultural policy, and provide some thoughts on "getting from here to there."

MAJOR CHANGES IN U.S. AGRICULTURE

Since the early 1930s, when the federal government first began to play a major role in agriculture, U.S. agricultural policy has incrementally evolved.

Each major new law has been built on the legislation that preceded it and has been modified to reflect changing circumstances. The basic goals and methods of government intervention in agriculture have changed little over those 50 years.

The patchwork of policies emerging from this process has become increasingly antiquated. Agriculture and rural communities have undergone such major changes in structure and in their relationships to the domestic and world economies that some of the very premises of longstanding policies are at issue. And, as the pace of technological change continues to quicken and as new technologies evolve, the tensions between modern agriculture and dated policies will only increase. Following is a brief discussion of six interrelated and especially significant areas of change, and a summary of the major implications each has for agricultural policy.

The Changing Role of Agriculture in Rural America

The first major change concerns the place of farming in the rural setting and in the total food system. When price and income programs for farm commodities began, much of the nation was rural and the national economy was based on agriculture. In the 1930s, 44 percent of the total U.S. population was rural, and farm people accounted for more than half of the rural population. Today, 24 percent of the nation's total population is rural, and farm people account for only 10 percent of the rural population. Overall in the United States, 25 million fewer people now live on farms than in the 1930s, and the farm population has fallen from 25 percent to 2 percent of the national total (De Are and Kalbacher, 1985).

The importance of farming in the rural economic base also has changed. As recently as 1950, farming accounted for at least 20 percent of the economic activity in two-thirds of the nation's more than 3,000 counties. Today, that is true for only one-fifth of the counties, not necessarily because agricultural economic activity has declined but because nonagricultural economic activities have grown much more rapidly (Starsinic, 1985).

Policy Implications

1. The historical-traditional case for agricultural policies based on the premise of the uniqueness of agriculture and rural areas has been greatly weakened as the make-up of both has changed since the 1930s, when many of the policies were begun.

2. Traditional agricultural policies have less and less bearing on economic activity in rural areas and on the economic welfare of rural people.

3. If the maintenance or improvement of income in rural communities is a policy goal, agricultural policies have become less and less significant in

achieving that goal in a national context. Broad-based development strategies offer more hope in many communities.

Structural Change in the Farm Sector

A second category of changes in U.S. agriculture concerns the structural evolution of the farm sector itself. Today in the United States there are 2.3 million farms; they are highly diverse and very difficult to characterize broadly. One of the most striking features, however, is the concentration of production among them. Some 30 percent of U.S. farms—those selling more than $40,000 in agricultural products annually—account for 90 percent of the nation's entire agricultural output. The largest farms (about 31,000, or 1.3 percent of the total number of U.S. farms) annually sell at least $500,000 each in products and together account for 33 percent of all agricultural product sales. Midsize and large commercial farms, those selling $100,000 or more annually in agricultural products, represent about 14 percent of the farms but account for almost 75 percent of the sales. The 1.6 million farms annually selling less than $40,000 each in agricultural products account for 70 percent of all farms but only 10 percent of the nation's agricultural output (Lee, 1986).

Farms in the United States today, moreover, differ widely as to source of income. Off-farm income now accounts for 56 percent of the total income of farm people. The 70 percent of the farms with less than $40,000 each in annual gross sales now earn much of their total family income from off-farm sources. The average net farm income for this group of farmers has been negative for most of the 1980s. In 1985 they incurred total net farm income losses of $2.7 billion. Thus, industrial and nonagricultural resource policies have become much more important to the economic well-being of rural residents and communities (U.S. Department of Agriculture, 1985a).

Raising farm incomes so that they are closer to incomes in the nonfarm sector has been an overriding policy objective since farm programs began in the 1930s. In large part that objective has been achieved. Average incomes and net worth of farm people now compare favorably with those of the rest of the population. Although pockets of poverty persist, widespread poverty is no longer the chronic, pervasive problem it once was in agriculture, largely because of income earned off the farm by residents of smaller farms.

A central question in commodity price and income policies relates to who needs assistance and who receives it. A strong case can be made that the 1.6 million farms each with sales of less than $40,000 annually receive little from the commodity programs; in 1985 they received only 9.5 percent of all direct agricultural payments. On average, they would be little affected by the abandonment of commodity programs. On the other hand, relatively large farms with sales of at least $250,000 received nearly 33 percent of all direct government payments made in 1985, although they represented only 4 percent of the total number of U.S. farms. Many of these large farms are highly capitalized, science-driven businesses and probably would do well even without the commodity programs.

If there is a case to be made for income transfers through commodity programs, it is probably on behalf of the midsize farms that still largely depend on agriculture for their income. But even here, questions arise as to how much, how long, and whether the income objectives of public policies would not be more efficiently served by targeted, direct income transfers than through the blunt instruments of commodity price programs.

Policy Implications

1. The structure of U.S. agriculture is trifurcated. The benefits of production-based commodity programs flow disproportionately to the largest farms and to landowners—those that need it least by economic standards.
2. To the extent that income maintenance or improvement is a goal of commodity programs, the case is strong for targeting benefits to midsize farms that still largely depend on agriculture.

Expanding Productive Capacity

By conventional measures, the productivity and output of U.S. agriculture have dramatically increased since World War II. Based on recent research by Capalbo and Vo (1985), total factor productivity (the difference in the proportional rates of growth of aggregate output and aggregate input) in the farm sector grew at an average annual rate of 1.4 percent in the 1950s, 1.2 percent in the 1960s, and 2.3 percent from 1970 to 1982.

As the papers in this volume confirm, there are no inherent technical reasons why growth in agricultural output at the rate of recent decades could not be maintained or even increased well into the twenty-first century. The sources of that growth will essentially be the same as those of the past several decades—productivity-enhancing technology, more intensive use of resources, more effective management, interregional shifts in production patterns, and if necessary, a modest net increase in harvested cropland. Moreover, productivity of both crops and livestock can be expanded substantially with off-the-shelf technology. The public is only beginning to glimpse the productivity-enhancing effects of biotechnologies potentially available on a general basis by the turn of the century.

The growth in productive capacity in the United States and in other countries in the next decade or two may well perpetuate the long-term decline in real prices of agricultural commodities—a trend characteristic of much of the past 75 years. The production-expansion path, however, is likely to be irregular and marked by year-to-year and cyclical instability, as it has in the past. A dominant message among agriculturalists in the 1970s was one of impending scarcity of resources and food. In the 1980s agriculturalists appear to be assuming abundance forever. Yet, as agricultural history indicates, the future likely will continue to be characterized by alternating periods of relative abundance and scarcity.

Policy Implications

1. The orderly adjustment of U.S. and global productive capacity to effective demand for farm products in light of relentless technological advance will continue to be a central policy issue of the future. At issue is the role of government versus the role of markets in the adjustment process.

2. Instability will continue to characterize the global agricultural production-expansion path, science and technology notwithstanding. More effective stabilization policies, national and international, will be needed to mitigate the effects of inherent instability.

Dependence on Foreign Trade

A fourth significant change for agriculture, and one especially pertinent to the policy issues discussed in this volume, has been the extent to which the United States has come to depend on trade. In 1970, U.S. agricultural exports amounted to $6.9 billion and imports amounted to $5.6 billion, which resulted in a trade surplus of $1.3 billion. Exports accounted for only 14 percent of farm cash receipts. But export growth was rapid in the 1970s and peaked in 1981 at $43.8 billion. Imports in that year were $17.2 billion. The trade surplus of $26.6 billion was more than 20 times greater than it had been just 12 years earlier. Although exports have dropped precipitously since 1981 to less than $30 billion in 1985–1986, they still account for nearly one-fourth of farm cash receipts (U.S. Department of Agriculture, 1985b).

The economic status of the farm sector—indeed, of the entire food and agricultural system—has become geared to foreign markets and to factors that drive those markets. With increasing productivity, export markets will become even more important to U.S. agriculture. To illustrate, assume a 2.0 percent annual growth rate in U.S. agricultural production between now and the year 2000 and overlay that with the projected growth in domestic demand for farm products estimated as follows.

Structural shifts in demand depend basically on two variables, growth in population and per capita incomes. Current and projected population growth in the United States is about 0.8 percent per year. In a mature developed country like the United States, aggregate food demand at the farm level increases slowly, if at all, as per capita income grows. Assume, however, for the sake of argument, that the demand for food at the farm-gate end of the agricultural product chain increases from 0.2 to 0.4 percent with trend increases in per capita income. The population growth rate plus the food-demand increase associated with rising per capita incomes, then, result in an increase in the demand for agricultural products of about 1.0 to 1.2 percent a year. The high estimate (1.2 percent) is about 60 percent of the projected increase in the production growth rates. Thus, with agricultural production growing at 2.0 percent per year, it would exceed domestic agricultural demand by 0.8 percent per year.

Assuming a cropland base of approximately 300 million acres and production outstripping demand by 0.8 percent per year, 4 percent of the cropland base (about 12 million acres) must be retired within 5 years. To maintain the dynamic supply and demand balance, within 10 years, 8 percent, or 24 million acres, would have to be retired. And that is in addition to the 30 million to 50 million acres being retired under the set-aside and conservation reserve program that is in effect today.

To put it in other terms, domestic utilization of U.S. agricultural production is about 75 percent of total output; export markets absorb about 25 percent. A 0.8 percent annual difference between production and domestic utilization indicates that export demand must grow at about 3 percent per year if the United States is to remain in its present position, that is, with approximately a 32-month export supply on hand.

Productivity and output will grow in other countries as well as in the United States, however. U.S. competitors will also adopt new technologies that will allow them to increase their productivity. Many of them, like the United States, are mature economies unable to absorb much of that added production. Their excesses will also have to be exported. In addition, new technologies will enable some importing countries to expand their own food production. In some cases, this may decrease their demand for food imported from the United States or other current exporters.

Policy Implications

1. To absorb the potential increase in U.S. productive capacity, U.S. agricultural policies must be export-oriented.

2. With the likelihood that productivity and output in other countries also will increase, competition in world markets will be intense.

3. There is obvious need for major reform in global farm policies to reduce the incentives leading to overproduction in the developed countries, stimulate production in the least-developed countries, and correct the serious distortions that now characterize and impede world trade. This means, at a minimum, reducing prices in real terms at a rate at least equal to

productivity increases. That is, if we cannot get the prices right, at least we should not let them become more wrong.

Macroeconomic Linkages

The increased dependence on trade discussed in the previous section leads into and overlaps with the fifth major change affecting U.S. agriculture—the overriding importance of macroeconomic policy to the health of the farm sector, indeed to the entire food system and rural America. The farm sector has become increasingly integrated into the national economy with the heavy use of inputs of industrial origin, large capital requirements, a high degree of specialization, and dependence on foreign markets, where U.S. access and competitiveness are determined largely by macroeconomic policy.

The significance of agriculture's macroeconomic linkages is vividly illustrated by the boom-bust cycle of the past 13 years. The 1970s boom was made possible by devaluation of the dollar, low real interest rates, global economic growth, gradual decreases in price supports in the late 1960s, massive increases in world liquidity generated by recycled OPEC (Organization of Petroleum Exporting Countries) petrodollars, and other factors. The bust of the 1980s was strongly influenced by global recession, the debt crisis, a sharply strengthening dollar, high interest rates, and high, rigid price supports. The farm sector is clearly no longer isolated from fundamental economic trends at home or abroad. It has a large stake, for example, in the pace at which developing countries grow, in the way the Third World manages its debt, in the size of the U.S. budget deficit, and in the value of the dollar.

Policy Implications

1. The pervasive influence of macroeconomic policies greatly alters what farm programs can and cannot achieve and, consequently, how they should be structured.
2. Over the long term, the most important policy adjustments are those to promote sustained, stable economic growth in the United States and in countries abroad, particularly in the developing countries.

The Natural Resource Base and Environmental Quality

Agriculture in the United States has a richly endowed natural resource base, but that, too, is under pressure. Some of the gains in productivity and output have come at considerable cost to the physical environment. Sheet and rill erosion now exceeds the level that permits crop yields to be maintained economically and indefinitely on some 27 percent of U.S. cropland, although this erosion-prone land is concentrated geographically. Some experts predict that sediment delivered to the nation's waterways will nearly double by the year 2010 (Phipps et al., 1986).

For most of the past half-century, U.S. agriculture had access to low-cost energy and publicly subsidized, low-cost water for irrigation. As a result, farmers have made profligate use of both. Current levels of irrigation with average precipitation result in the annual "mining" of more than 22 million acre-feet of water from aquifers in the western United States. Nationally, nearly a quarter of the groundwater used by agriculture is not replenished. Falling groundwater levels are forcing major adjustments in agricultural production in a multimillion-acre area in the central and southern Plains states.

In addition to the physical and economic dimensions of water resource use, the quality of our water is a major problem. Groundwater contamination from agricultural as well as nonagricultural sources has become serious in many parts of the country. Irrigation practices have raised groundwater salinity in the western United States. Perhaps one-quarter of the lands currently under irrigation in the West heavily depend on nonrenewable water supplies, and the productivity of several million additional acres is threatened by rising salt levels.

Other water quality problems—dissolved oxygen; suspended solids carrying bacteria, nutrients, and pesticides; excessive phosphoric and nitrogenic nutrients—derive in part, occasionally in major part, from agricultural production practices. Growing public pressure to control nonpoint pollution could significantly increase agriculture's future production costs.

Approximately 1,000 new chemical substances are introduced each year in the United States. Comparatively little is known about the potential toxicity of many of those substances, about precisely how they are used, whether and how they enter the food chain and other ecosystems, and what their ultimate effects will be on human health and on other species. Controls on the use of pesticides in agriculture and forestry have become more stringent, and progress has been made in developing less toxic but effective pesticides and herbicides and integrated pest management systems that reduce chemical application rates. Nonetheless, pesticide and herbicide use remains pervasive in the production of major field crops.

Policy Implications

1. Agricultural development in the United States should now be viewed in the context of its interdependence in larger, highly complex environmental and ecological systems as well as economic systems. The goals of

enhancing agricultural productivity and output per se are increasingly coming into question.

2. Research and development (R&D) policies should be designed to maintain or enhance agricultural productivity while reducing the costs of environmental externalities.

CURRENT AGRICULTURAL AND TRADE POLICIES

The picture that emerges from the preceding overview is that of a diverse, science-driven, highly productive agricultural sector marked by increasing economic concentration, ever closer links to other sectors of the domestic economy, and growing dependence on export markets to absorb its products. Overlying the sector is a mosaic of pervasive and increasingly costly market intervention policies derived from a different era—policies that skew benefits toward large-scale operators and landowners, trap resources into agriculture, contribute to environmental degradation, and respond only with difficulty to changes in the world economy.

As a society, we face choices that will affect the future of agriculture and rural America and how people participate in it. The pragmatic issue is to identify the types of policies that will preserve the benefits of the current system, be sustainable in the long run, avoid the excesses and distortions of current policies, and yet be equitable. And those lofty goals must be sought within the constraints of the finite financial-budgetary resources that we as a society possess.

Any major recasting of current policies should be preceded by review and clarification of goals. Current policies, as a result of 50 years of amendments and tinkering, are rife with inconsistencies. Some promote development and adoption of productivity-enhancing technology; some inhibitit. Some promote conservation and maintenance of environmental quality; some encourage exploitation. The United States endorses liberalization of trade in agricultural products but constructs protectionist policies for some commodities. Some policies are predicated on a structure of agriculture that no longer exists. Some are built on the premise of a "closed," insular agricultural sector—a condition that has long since ceased to exist. It is time to reexamine the central objectives of our agricultural and rural policies.

Who are the intended beneficiaries of public agricultural policies—consumers, midsize producers, rural communities, landowners, farm workers? Is the goal of policy to stabilize supplies of raw agricultural commodities, raise farm prices above market equilibrium levels and transfer income, or to maintain a cheap food basket for the urban consumer? Only when the long-term goals of policies for agriculture and rural areas have been clarified and made more consistent can we hope to avoid the types of policy failures prevalent in the past several decades.

The organizers of this volume posited three policy goals for discussion: (1) sustaining the competitiveness of U.S. agriculture, (2) ensuring safe and sustainable agricultural production systems, and (3) providing a technology and policy foundation for increasing agriculture's contributions to the growth of the gross national product. Obviously other objectives are to be considered, but two goals particularly germane to the topics of this volume have been singled out for discussion in this section: first, that of enhancing efficiency in production and competitiveness in world markets, and second, that of enhancing long-term productivity growth in U.S. agriculture.

Enhancing U.S. Efficiency in Production and Competitiveness in World Markets

If U.S. agriculture is to continue its economic growth, it must do so in the context of globally interdependent world markets. To keep agriculture growing, policies must maintain or enhance economic efficiency in the production, marketing, and distribution segments of the food and fiber system through time. In turn, domestic prices must be free to move, at least in large measure, in accord with world market signals. Resources must be reasonably free to move in and out of the sector in accord with market signals within the sector and in other sectors that compete for the use of those resources.

The principles are simple enough in economic theory. The results in practice, however, would not be unmitigated joy and prosperity. Flexible domestic price policies of themselves are not sufficient to ensure competitiveness. "Free trade" is a useful but mythical construct of economists. Trade barriers abound in world markets. And even if domestic prices were "right," competitiveness turns, in a very important way, on underlying macroeconomic policies, exchange rates, and the operation of associated capital markets.

A U.S. agriculture fully linked to the global system would result in an unstable market—perhaps more unstable than that experienced in recent decades by U.S. farmers, vacillating farm policies notwithstanding, because the United States would abandon its role as the residual adjustor in international markets. Nor could the United States logically pursue policies begging others to liberalize trade policies to enhance U.S. competitiveness without reciprocally liberalizing its own protectionist policies and accommodating the associated major commodity and interregional shifts.

Although the United States could—and, some would say, should—lead in the development of policy reforms to rationalize agricultural policies, others argue that it makes little sense to do so unilaterally. Therein lies a major dilemma—how to achieve multilateral, systematic rationalization of policies across sovereign, national states with very different resource endowments and policy mechanisms, if not policy objectives. Multilateral policy rationalization through simultaneous, or even coordinated, policy adjustment among trading nations is a laudable goal, and the United States should exhibit leadership to that end. Some steps toward policy rationalization are in the best interests of the United States, whether or not we can convince our trading partners to act with us.

Finally, if the United States is to seek competitiveness in world markets, it must also be prepared to develop and execute policies that foster economic growth and development in developing countries and to do so on a continuing, predictable basis over a lengthy period of time. For many of the least-developed countries, development translates into development of their agricultural sectors, even when they compete with U.S. agriculture in third markets and in the United States.

Enhancing Long-Term Productivity Growth in U.S. Agriculture

If an acceptable goal of public policy is to enhance efficiency and competitiveness in U.S. agriculture, investments to enhance future productivity are essential. From an economic perspective, a society's standard of living, under circumstances in which resources are employed optimally and at capacity, can be enhanced only through advances in total factor productivity. There are those who contend, however, that the United States should slow productivity growth in agriculture in view of current and potential surpluses of commodities. For a number of reasons, this is a seriously flawed, myopic, and wrongheaded argument.

First, the "problem" (excess market supplies and low farm prices) is a result of many factors, including price policies that send distorted market signals and create rigidities in resource use, macroeconomic policies that repress economic growth and thereby demand for farm products, and barriers to trade that subvert principles of comparative advantage.

Second, R&D investments cannot be turned on and off like a spigot. And even if that were possible, reducing investment in productivity-enhancing R&D today would not slow productivity gains either today or in the short run. The productivity gains of today are the fruits of investments made decades ago. It seems plausible that if economic incentives exist, productivity will continue to grow from off-the-shelf technology whether or not there are additional investments in R&D. The argument to reduce current investments in R&D pertains to slowing productivity growth one to three decades in the future. That would be an unwise action, for reasons indicated above, in view of long-term growth in demand for food and fiber on a global basis, and because of the inherent instability in global agriculture, to say nothing of the errors that attend economists' projections of the demand-and-supply balance of world food.

Some attempt to differentiate between technologies that increase yield and those that reduce costs. This, too, is fallacious reasoning in the sense that each leads to the same end result under the competitive structure that characterizes agriculture—that is, increased output.

The argument does not rest solely on sheer market efficiency or on traditionally defined productivity enhancement, however. Enhanced productivity, like freer domestic prices, must be pursued carefully. Agricultural R&D policies, for example, have yielded unintended, nonmarket externalities, which have been noted throughout this volume. Investment strategies for R&D should take cognizance of such potential effects, attempt to foresee the possible magnitude of those effects, and to the extent technically feasible, develop technologies to minimize or avoid them.

In addition, the benefits of technology are not uniformly distributed within the farm sector. Technological change induces adjustments in resource use, which in turn create losers and gainers. Those effects, too, should be recognized in R&D strategies. Although society may seek to minimize those adjustments, it cannot have it both ways—it is impossible to achieve technological change that enhances productivity without adjustments in resource use. However, more effective public policies and programs can surely be devised to assist those negatively affected in the adjustment process, for example, through education, training, economic adjustment assistance, and macroeconomic policies that enhance employment and income prospects outside agriculture.

Finally, R&D strategies and policies for agriculture should be designed to encourage and facilitate diversity in production systems and in farm structure. With productivity growth in agriculture has come increased specialization, economic concentration in production, and a tendency toward monolithic production systems. The term "appropriate technologies" still has relevance if it is defined as diversity of technologies. The United States might well take lessons from some Asian countries in this respect.

TOWARD REFORM OF CURRENT POLICIES

Given all of the considerations discussed above, what changes in current policies are called for and how can the changes be accomplished? In attempting to answer these questions it is important to differentiate between short-term (1- to 2-year) and longer term (5- to 10-year) modifications.

In the longer run, commodity price support programs should be abandoned along with their numerous supply-management provisions. They have outlived their initial purposes in many respects; moreover, those programs run counter to the long-term economic interests of the farms that account for the major part of commodity production. Agriculture is simply too complex, diverse, and dynamic to be managed from Washington. If the United States is serious about enhancing efficiency and competitiveness in a long-term context, there is no feasible alternative to a major policy reassessment.

But scrapping commodity price programs is not equivalent to taking government out of agriculture. Without commodity programs and with increased reliance on trade, commodity markets could be highly unstable. Thus, there might well remain a role for government in assuming a downside instability risk with a price safety net set at, say, some fraction of a rolling average of world commodity prices. And a strong case can be made for retaining government-owned commodity reserves or drawing rights, not to manipulate farm commodity prices but to provide some minimum level of stability in domestic and world supply, to aid foreign development, and to provide food assistance abroad and food security at home.

To reduce instability in farm income, consideration should be given to an income stabilization plan financed in major part by farmers themselves. If markets do not ensure some specified average level of income or return on investment deemed appropriate relative to that for the nonfarm population, a negative income tax or direct income transfers could be used. In addition, industrial and development policies to encourage growth and employment in nonmetropolitan areas could be initiated and directed at areas where it appears that such development would be economically viable in the longer run. Other education-reemployment and adjustment assistance programs should accompany these development policies.

Major reform of the type suggested here is far more complex than we have intimated, and even crude estimates of the effects of such reform on farm prices and income, on agricultural structure and the shape of rural communities, or on consumer and taxpayer costs and benefits are not available. Were such assessments available, we might be persuaded to modify some aspects of our suggestions. Nevertheless, we believe that this is the direction in which policies must move if the goals we have discussed are to be attained.

We recognize that precipitous policy reform is not immediately feasible or even desirable. The political and economic shocks would be simply too great to bear in the short run. So how does the United States "get from here to there"? First, we suggest maintaining some consistency in policies. The Food Security Act (FSA) of 1985 is far from optimum long-term legislation. It does, however, send a clear signal of U.S. intent to compete vigorously in international markets and to stop bearing a disproportionate share of the adjustment burdens of the disequilibrium in world agriculture. The United States should, in the short run, "stay the course" with respect to those principles in the FSA.

Looking beyond the Food Security Act and the 1988 presidential election, and assuming that federal budget outlays for agricultural programs will be constrained at or below 1986 levels in the years immediately ahead, several adjustments to the FSA may be needed. Accelerated reduction and eventual elimination of target prices are an obvious mechanism of choice for assisting in the transition. Decoupling of program benefits from levels of current production would reduce false, nonmarket production incentives. To cushion the effects on viable but financially stressed farms while simultaneously reducing federal budget exposure, some form of targeting of commodity program benefits could surely be devised as interim adjustments. The current financial stress in some parts of agriculture, however, can best be dealt with by means of financial instruments, such as restructuring or debt-equity swaps, and by adjustment assistance programs.

A major dilemma associated with making the suggested policy reforms fully effective is the need to secure reciprocal multilateral domestic policy reform, although, as noted earlier, a case can be made for unilateral action. Reforms in domestic agricultural policies cannot be achieved by continued tinkering with trade rules in the General Agreement on Tariffs and Trade (GATT) negotiations, however. Negotiations through GATT or other forums that cover both domestic agricultural policies (the source of most agricultural trade policy disharmonies) and trade policies might yield dividends if appropriate incentives existed. If current policies are about to "crash," as the *Economist* suggests, that may be sufficient incentive to bring about serious discussion. Or, perhaps another "turn of the screw" by the United States in the form of extending marketing loans and other subsidy programs, distasteful as they are, may be necessary.

We concur with the part of the *Economist*'s prescription that suggests the United States must take the lead in policy reform. In formulating a strategy for GATT negotiations as they relate to agriculture, more is needed than mere suggestion that subsidies be frozen at current levels in advance of negotiations. The United States should indicate preparedness to negotiate on the nature of domestic agricultural policies themselves on a quid pro quo basis as a means of avoiding the scenario envisaged by the *Economist*. To emphasize its intent to do more than "rearrange the deck chairs on the *Titanic*," the United States might, as some have suggested, call for a ministerial summit meeting on agricultural policy. Given the intransigence among some trading partners, the polarization of political positions among some governments, and the limited success of such meetings in the past, nongovernmental leaders may themselves need to begin a process for forming coalitions of interests and policy options to reinforce governmental discussion and negotiation.

Nearly three generations of agriculturalists, bureaucrats, and agricultural economists have grown up with a text on agricultural policy written 50 years ago. It is time to turn attention to the realities of the late twentieth century, to set aside parochial, short-term interests, and to formulate policies anticipating the twenty-first century.

REFERENCES

Capalbo, S. M., and T. T. Vo. 1985. A survey of econometric evidence on productivity and the structure of agriculture. National Center for Food and Agricultural Policy, Discussion Paper Series RR85-03 (revised July 1986). Washington, D.C.: Resources for the Future.

De Are, D., and J. Kalbacher. 1985. Farm population of the United States, 1984. U.S. Department of Commerce, Bureau of the Census, and U.S. Department of Agriculture. Current Population Reports 58:17.

Economist. 1986. Dairy, prairie. 301(November 15):13.

Lee, J. 1986. Farm Sector Financial Problems: Another Perspective. Economic Research Service Agricultural Information Bulletin 499. Washington, D.C.: U.S. Department of Agriculture.

Phipps, T., P. Crosson, and K. A. Price, eds. 1986. Agriculture and the Environment. National Center for Food and Agricultural Policy. Washington, D.C.: Resources for the Future.

Smith, L. 1986. How to cut farm spending. Fortune 114(11):97.

Starsinic, D. E. 1985. Patterns of Metropolitan Area and Country Population Growth: 1980–1984. U.S. Department of Commerce, Bureau of the Census. Current Population Reports 976:25.

U.S. Department of Agriculture (USDA). 1985a. Economic Indicators of the Farm Sector, National Financial Summary. ELIFS5-2, Economic Research Service. Washington, D.C.: USDA.

U.S. Department of Agriculture (USDA). 1985b. Foreign Agricultural Trade Statistics of the United States, calendar year supplement. Economic Research Service. Washington, D.C.: USDA.

Implications of Technical Change for International Relations in Agriculture

Vernon W. Ruttan

The papers in this volume have identified the potential impact on agricultural output of a series of new and emerging technologies in crop and animal production and have expressed concern that institutional constraints may limit the benefits that will be realized from the potential new sources of productivity growth. The discussion of the implications of technical change for agricultural and trade policy reform in this paper is guided by the perspective that it is in the interest of the United States, and the world at large, to embrace the opportunities for abundance that are within our grasp. I am highly critical of policies that are designed to protect the world's producers and consumers from the benefits of abundance.

Limitations of space do not permit developing the argument for abundance in the detail that it deserves. The presentation,[1] therefore, is cast in a series of assertions about the changes in the economic environment, the changes in technology, and the principles that should guide U.S. research and commodity policies in a world in which abundance may, if appropriate policies are pursued, become pervasive. Rather than proceeding directly to consider the policy guidelines, however, I would like to conduct an exercise in what economic historians refer to as counterfactual analysis. Assume that a conference with the same title, same speakers, and the same audience as the one on which this volume is based had been held in December 1976, 10 years earlier.

In the mid- and late 1970s discussions of the issues being discussed in this volume were dominated by a pervasive pessimism regarding the adequacy of natural resource endowments and the supply of resource commodities and services. Until well into the 1980s, it remained unclear whether energy and other commodity prices would stabilize at near the high levels that prevailed at that time or whether they would continue to rise until well

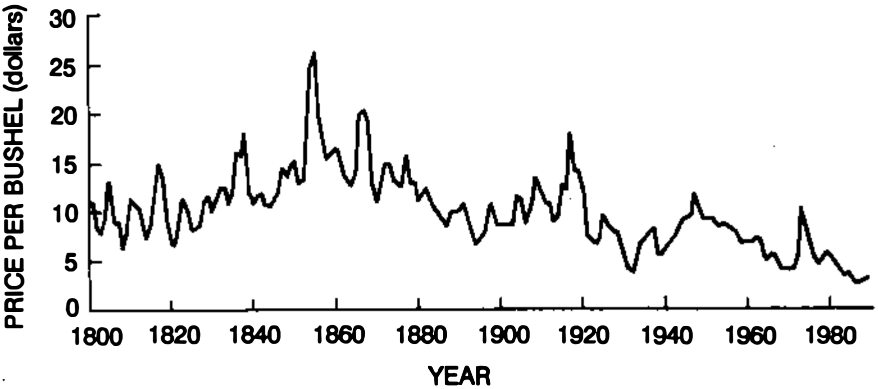

FIGURE 1 Real wheat prices since 1800 (in 1967 dollars). Source: Edwards (1985:5).

into the early years of the next century (Brown, 1981). But the historical record has not been consistent with the expectations (Figure 1). Experience has again seemed to confirm the optimistic hypothesis that a stretch of high prices has not yet failed to result in the location of new resources, improvements in the exploitation of old resources, and the development of technology to facilitate the substitution of more abundant for less abundant resources (Landsberg, 1967; Ruttan, 1971).

By the mid-1980s the fear of scarcity had largely dissipated. The new technology and the new productive capacity that had been generated by more than a decade of rising commodity prices began to disgorge their products into an economic environment that was experiencing a global recession. We were confronted by what seemed to be excess global capacity—in energy, in automobiles, in steel, and in agricultural commodities. The fear of scarcity was replaced by a fear of abundance. The slow growth of effective demand has obscured the fact that the rate of growth of basic food staple production declined in the developing countries from the 1960s to the 1970s and again in the 1980s.

Several years ago I participated in a review of the projections of food demand and supply that were made in the 1970s (Fox and Ruttan, 1983). One clear lesson emerged from those resource and technology assessments: The analysts who constructed and interpreted the futures models had great difficulty in insulating themselves from the short-run trends and events that dominated the intellectual and policy environment at the time the assessments were made. Large elements of subjective judgment enter into estimation of the "trend" and the "analytical" models and in the use of the models to simulate alternative futures. The simulations for the 1980s and 1990s were strongly influenced by the pervasive climate of "food pessimism" and, more broadly, of "technological pessimism" that dominated much of the decade of the 1970s. It seems clear that the model builders and futures simulators were influenced by an intellectual environment that would have regarded more optimistic projections as "out of touch with reality."

I now turn to the inferences that I draw for research and commodity policy from the papers that appear in this volume.

THE GLOBAL SETTING

> *It is essential, by the first decade of the next century, that agricultural research capacity be established for each commodity and for each agricultural production factor or resource input of economic significance in each agroclimatic region of the world.*

We are, in the closing years of the twentieth century, completing one of the most remarkable transitions in the history of agriculture. Prior to this century, almost all increases in food production were obtained by bringing new land into production. There were only a few exceptions to this generalization—in limited areas of East Asia, in the Middle East, and in Western Europe. By the end of this century, almost all of the increase in world food production must come from higher yields—from increased output per hectare.

In most of the world the transition from dependence on a system of agriculture based on natural resources to one based on science is occurring within a single century. In most of the currently developed countries the transition did not begin until the first half of this century. Most of the countries in the developing world did not begin this transition until mid-century. And many, particularly in sub-Saharan Africa, are only now beginning to put into place the agricultural research and extension capacity needed to begin the transition.

Agricultural technology, particularly biological technology, is highly location-specific. In those countries and those regions that do not make the research investments necessary to gain access to scientific and technical knowledge, farmers will be unable to provide the agricultural commodities necessary to make effective use of their particular resource endowments or to meet the elementary needs of their consumers.

Since the mid-1960s, we have put in place a set of international agricultural research centers under the auspices of the Consultative Group on International Agricultural Research (CGIAR). In the developed countries the private sector accounts for an increasing share of the new knowledge and the new technology that generates productivity growth in agriculture. It is now time to take the additional steps needed to complete a truly global agricultural system. That system must be able to ensure an effective flow of information among developed and developing countries, among centrally planned and market economies, and between the public and private sectors (Ruttan, 1987).

GREATER ABUNDANCE

The long-term outlook is for a continuing decline in the real prices of agricultural commodities. Most of the world's consumers can expect to have access to agricultural commodities on increasingly favorable terms.

The judgment stated here is based on two fundamental assessments. The first is that food demand, resulting from population growth and income growth, can be expected to level off at about 20 percent of its biological food-production potential (Weber, 1986; Weber and Gebauer, 1986). The second is that a large number of countries have now established the agricultural research capacity, and the capacity to supply the requisite technical inputs, to sustain agricultural production.

At the end of World War II effective agricultural research capacity existed only in relatively developed countries. That capacity now exists in a number of major developing countries, including India, Brazil, and China. And the implications of the papers that appear earlier in this volume are that before the end of this century the developed countries will be entering into a new period of productivity growth based on advances in biotechnology, or more broadly, biological technology. At the very least the broader geographic bases on which science-based agriculture now rests should imply greater stability as well as greater competition in meeting global food needs.

Some qualifications should be appended to the current projections of the speed of technical change, however. In the developed countries advances in agricultural technology will be driven primarily by advances in biological and information technology rather than by advances in mechanical technology. Advances in animal health and animal productivity will come first, followed by advances in plant protection and, only later, in plant productivity. But nothing in the papers presented in this volume or in the recent rash of technology assessments leads to the expectation that, over the next several decades, productivity gains—measured in terms of decline in real costs of production—will be comparable to the gains achieved since 1940. This is a result of (1) the reduction in farm labor and work animal inputs associated with advances in mechanical technology and (2) the advances in crop yields and animal feed efficiency resulting from advances in plant and animal breeding and in crop and animal nutrition. We can expect few additional gains from advances in mechanical technology. The cost of saving an additional worker-day by adding more horsepower per worker has largely played itself out in countries like the United States, Canada, and Australia.

In the developing countries the major gains in crop and animal productivity over the next several decades will continue to come from conventional sources. For crops, this means from conventional crop breeding, from more effective management of water resources, and from greater use of plant nutrients. For animals, it means continued efforts to enhance feed efficiency through improved animal health, improved feed quality, and improved management. Those countries that are not able to establish viable agricultural research capacity in the public and private sectors will not be able to draw on even these conventional sources of growth.

The picture just drawn may be slightly overoptimistic in terms of the rate of productivity growth—or of cost reduction—that can be anticipated. A particularly serious concern is that the increases in crop yields during the last century of experimental breeding have been achieved primarily through selection for a higher harvest index—by redistributing the dry matter between the vegetative and reproductive parts of the plant (Jain, 1986). The harvest index has risen from the 20 to 30 percent range to upward of 50 percent for several major grain crops. Based on the failure under experimental conditions to push the harvest index much above 50 percent, concern is growing that a plateau is now being reached in yield potential. If this is correct it means that future gains will have to come from increases in total dry matter production—from enhanced photosynthetic capacity. We do not yet have examples of enhanced photosynthetic capacity for conventional food and feed crops. One option that might become feasible is to move toward direct conversion of biomass into plant parts. But this option has only been explored at a theoretical level (Rogoff and Rawlins, 1987).

THE NEXT WORLD FOOD CRISIS

The long-term secular decline in agricultural commodity prices will continue to be interrupted periodically by periods of short upward movement in commodity prices.

It is useful to reflect on past experience. Writing immediately after World War II, Professor Merrill K. Bennett of the Food Research Institute at Stanford University noted that there had been three waves of food pessimism during the previous century and a half (Bennett, 1949:17):

> The first one was touched off by Malthus's famous *An Essay on the Principle of Population* . . . published anonymously in 1798. The second wave came in the late 1890's in connection with the German controversy about the relative merits of agrarian and industrial national economies. Perhaps an ephemeral shortage and high price of wheat was a contributing factor. It was in 1898 that Sir William Crookes delivered his famous address "The Wheat Problem" to the British Association for the Advancement of Science. . . . But again interest in the global food-supply problem waned only to be stimulated for a third time for a few years after World War II.

In the late 1970s, Keith O. Campbell, the iconoclastic Australian agricultural economist, noted that world food crises had been appearing with greater frequency (Campbell, 1979:2):

> Since World War II there have been several such occasions. The first was the immediate post-war years, when some countries experienced delays in getting their farming industries back into full production. The second occurred in the latter half of the 60's, before the full impact of the "green revolution" became evident. The most recent one followed the widespread crop failures of 1972–1973 and 1973–1974 and the consequent running down of cereal reserves in North America.

Professor Campbell might well have stressed successive years of drought in the Sahel region in Africa and its impact on our thinking about food crises, which extended well beyond the quantitative significance of food production in the Sahel region.

Can we now, buttressed by the anticipation of rapid technical change and greater institutional capacity to respond to regional food crises, accept the presumption that the world will no longer be confronted by lags or decline in food consumption sufficient to generate the price responses necessary to signal a food crisis? It is not difficult to develop a scenario in which the significant parameters are the research and commodity-policy responses of both developed and developing governments to anticipated surpluses. These, combined with improvident stock policies, the reemergence of rising energy prices, and a period of bad weather in North America, South Asia, or Africa could again result in a short period of dramatically higher commodity prices.

DISEQUILIBRIUM IN THE GLOBAL MARKETPLACE

Strong economic and political forces will almost certainly lead to greater rather than less agricultural protectionism, particularly in the densely populated, new industrializing countries (NICs), where agriculture is losing comparative advantage relative to the countries with more land-extensive systems of agriculture relative to their own domestic industrial sectors.

In the international economy that emerged toward the end of the nineteenth century, agricultural commodities and other raw materials were exported from the most recently settled countries in the temperate zone and from the tropical-colonial areas to the developed countries. Industrial products were exported from the developed countries to the less-developed world (Lewis, 1969, 1980). This system broke down after World War I. The interwar period was characterized by great instability and by slow economic growth. Protectionism contributed to and was reinforced by the Great Depression of the 1930s. The period since World War II has been characterized, at least up to about a decade ago, by unprecedented rates of growth in production and trade. Yet both developed and developing countries have pursued policies that have intensified the disequilibrium in world agriculture. Between 1950 and 1980 the developed countries significantly reduced the barriers to international trade in industrial products. The decline in industrial protectionism has been accompanied by an increase in agricultural protectionism. This has been the result, by and large, of nontariff barriers imposed to ensure the effectiveness of domestic agricultural programs.

The change in sectoral patterns of protectionism is illustrated with particular clarity by recent historical experience in East Asia. Many observers have credited the export-oriented industrial policies pursued by Japan, and later by Taiwan and Korea, with creating an economic environment that has been exceptionally favorable to economic growth. It has also been noted with a good deal of puzzlement that these same countries are now pursuing import-substitution agricultural policies. It is clear that these policies have imposed rather large welfare losses on all three economies. Does economic rationality vanish at the edge of the rice fields? A series of studies by Kym Anderson, Yujiro Hayami, and several colleagues has helped to clarify the economic and political forces that have given rise to the transition from earlier agricultural-export and import-substitution industrial regimes to the current industrial export-promotion and agricultural import-substitution regimes (Anderson and Hayami, 1980; Balisacan and Roumasset, 1980).

During the first decade after World War II, Japanese farmers received prices that were only slightly above world market prices. Since the mid-1950s, however, nominal rates of agricultural protection (producers' price-border price) have escalated rapidly. The transition to agricultural import-substitution policies in Korea and Taiwan came somewhat later. In the 1950s, both countries were pursuing industrial import-substitution policies. Nominal rates of protection for most agricultural commodities were negative. During the early 1960s, Korea and Taiwan shifted from industrial import-substitution to export-oriented policies. Nominal rates of protection for agriculture turned slightly positive in the 1960s and escalated rapidly in the 1970s in Korea and Taiwan.

Anderson and Hayami and their colleagues have attempted to explore the sources of demand and supply for the rapid emergence of protectionist agricultural policies. In Japan, the demand for protection was based on the economic cost to rural families and communities and resulting political stress that would have accompanied rapid structural adjustment. Japanese agriculture lost comparative advantage (measured in terms of labor productivity—relative to both Japanese industry and U.S. agriculture) rapidly after the early 1950s. The loss of comparative advantage in Korea and in Taiwan in the late 1960s and 1970s was even more rapid (Anderson and Hayami, 1980). The costs of structural adjustment would have been borne largely by a single generation of rural people.

A number of factors also shifted the supply curve for protectionism to the right. Economic growth rapidly reduced both the share of the consumer budget accounted for by food purchased in the market and the tax burden of producer subsidies. It was advantageous to Japanese commercial and industrial interests to accede to policies that would maintain the farmers' commitment to the conservative Liberal Democratic Party (LDP). The situation in Taiwan and Korea was not unlike that in Japan. In addition, both countries faced external political stress that provided further impetus for the government and the industrial and commercial interests to ensure rural commitment to political stability.

The conclusions that Anderson and Hayami (1980) draw from their East Asian analysis have been tested against the experience of a large number of developed and developing countries. The evidence they examined suggests that as economies grow they tend to change from taxing to assisting or protecting agriculture. This change occurs at an earlier stage of economic growth the weaker the country's comparative advantage in agriculture. These changes also occur more rapidly the faster the rate of economic growth and the faster the decline in agricultural comparative advantage. This conclusion is reinforced by the results of the analysis by Bates and Rogerson (1980), who found that as the share of agricultural population declines its desirability as a political coalition partner rises.

The implications for other developing countries seem clear. As other developing countries enter into a period of rapid industrial growth, they are also likely to adopt increasingly protectionist policies. This change in policy is likely to occur at relatively low levels of per capita income, as in Korea and Taiwan, in countries where comparative advantage in agriculture is weak or rapidly eroding. The impasse in current GATT negotiations do not inspire confidence that the growth of agricultural protectionism in the world economy will be significantly reversed in the next several decades. The one bright spot in this picture for agricultural exporters is that many of the NICs will experience such rapid growth in demand for agricultural commodities that they will import substantial quantities of agricultural commodities even as domestic production expands rapidly in response to price incentives. But as the income elasticity of demand declines as the NICs economies mature, the protectionist policies will remain in place to generate surpluses—as in the European Economic Community countries during the past decade.

AN EXPORT-ORIENTED AGRICULTURE

An agricultural policy environment that is strongly export-oriented is in the interest of the U.S. economy and of the producers of major agricultural commodities. It is in the U.S. interest to move toward a policy environment in which agricultural commodities move across national borders at least as freely as financial resources.

A decade of sustained depreciation of the U.S. dollar against other currencies was an important factor in the growth of U.S. agricultural exports during the 1970s (Figure 2). The weak dollar was particularly important in the growth of corn and soybean exports during this period. A strengthening dollar, combined with a global recession in the first half of the 1980s, both depressed U.S. agricultural exports and encouraged imports of agricultural commodities and processed foods (Longmire and Morey, 1983). The rising value of the dollar also had the effect of stimulating production in a number of other developed and developing countries (Office of Technology Assessment, 1986a). Since 1985 the U.S. dollar has declined substantially against other major currencies, but somewhat less against the currencies of several major importers of U.S. agricultural commodities and against competitive suppliers of agricultural commodities.

What are the implications for U.S. agricultural commodity trade? The trade pessimists have pointed to an initial lag in the response of U.S. agricultural commodity exports to the decline in the value of the dollar. This should be neither a surprise nor a cause for undue pessimism. Historical experience suggests that changes in the terms of trade impinge on the trade balance with a considerable lag—typically about eight quarters or more (Orden, 1985). Unless the trade-weighted index of the foreign-exchange value of the dollar has declined over the past several years the agricultural trade balance has become more favorable.

The most important reason for strengthening the export orientation of U.S. agriculture is, however, not the short-run gains in export volume that can be expected over the next several years. The major commodity-producing sectors of U.S. agriculture—corn, soybeans, and wheat—are world-class industries. They have retained and strengthened their competitive position while both the traditional and high-technology industrial sectors of the U.S. economy have become, on balance, net importers of the products that they

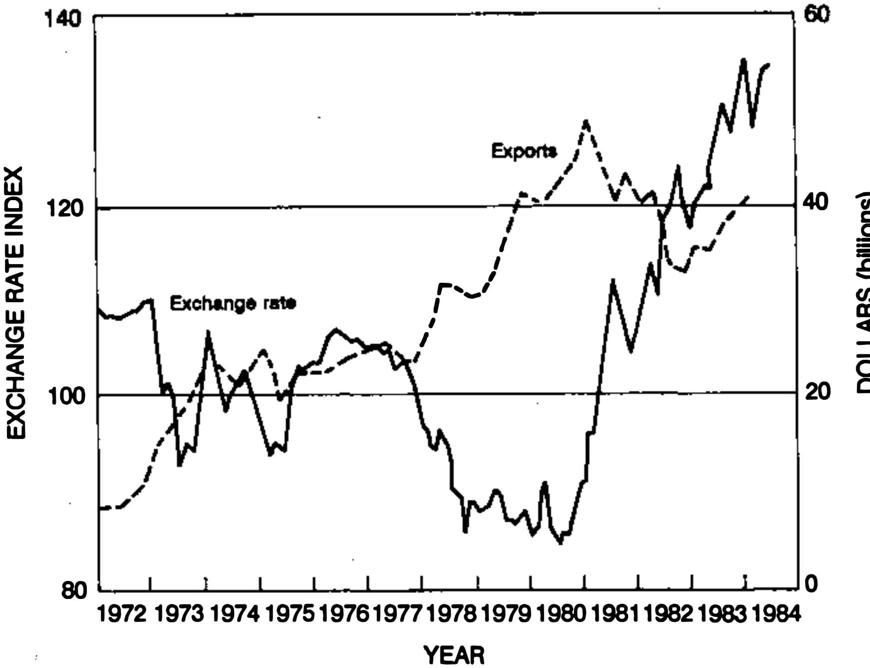

FIGURE 2 U.S. weighted rate versus U.S. agricultural exports. Source: Schuh and McCoy (1986:18).

produce (Table 1). The sectors of U.S. agriculture that have received the greatest protection from external competition have continued to lose comparative advantage. The most effective way to ensure that U.S. agriculture will strengthen its capacity to meet the needs of U.S. consumers, generate income growth for commodity producers, and contribute to national economic growth is to protect it from protectionism.

It is encouraging, therefore, that a commitment to the liberalization of agricultural trade was taken at the September 1986 Punta del Este meetings by placing agricultural commodity and trade policies on the agenda of the next round of negotiations on the General Agreement on Tariffs and Trade (GATT). This move was strongly supported by Australia, Argentina, Canada, Thailand, and the United States. But the negotiation experience had confirmed Hathaway's (1986) caution regarding the ability of the GATT process to move the protectionist policies of the developed industrial countries very far toward greater liberalization. The GATT members, including the U.S. representative, have been confronted with the difficult fact that agricultural commodity trade policies reflect the operation of domestic political forces.

TABLE 1 Agricultural and Manufacturing Exports and Imports (billions of dollars)

Exports-Imports	1980	1981	1982	1983	1984	1985	1986	1987
Agricultural								
Exports	41.8	43.8	37.0	36.5	38.2	29.6	26.6	29.1
Imports	18.9	18.8	17.3	18.1	21.5	22.0	23.1	22.6
Balance	22.9	25.0	19.7	18.4	16.7	7.6	3.5	6.4
High-tech manufacturing								
Exports	54.7	60.4	58.1	60.2	65.5	68.4	72.5	84.1
Imports	28.0	33.8	34.5	41.4	59.4	64.8	75.1	83.5
Balance	26.7	26.6	23.6	18.8	6.0	3.6	–2.6	0.6
Non-high-tech manufacturing								
Exports	106.0	111.4	97.2	88.3	98.1	99.5	107.4	116.0
Imports	110.8	122.6	123.5	137.1	182.4	204.7	233.7	254.3
Balance	–4.7	–11.2	–26.3	–48.7	–84.3	–105.2	–126.3	–138.3

SOURCE: U.S. Department of Commerce (1985:119,131); 1986 data are preliminary estimates.

DECOUPLING INCOMES AND COMMODITY POLICY

Since the end of World War II there has been a gradual evolution of policies designed to decouple income protection for farm families from commodity prices. The movement has been induced by fundamental economic forces resulting from rapid technical change in U.S. agriculture. These productivity advances strengthened the U.S. comparative advantage in international commodity markets.

Proposals for decoupling income support for farm families from the stabilization of agricultural commodity prices have attracted the attention of economists and policy officials since the mid-1940s.[2] In March 1949, Secretary of Agriculture Charles Brannan presented to Congress a program designed to allow supply and demand to determine market prices. Acceptable incomes for farm families would be ensured through a program of supplemental payments based on the difference between the market price and the support price. Brannan referred to the proposed legislation as a "program for abundance." The plan was greeted by a storm of protest. Only the Farmers Union and the American Federation of Labor/Congress of Industrial Organizations (AFL/CIO) supported the payment limitations and the cheap-food provisions.

The attraction of the concept of compensatory payments did not die with Brannan's Plan. It emerged again in the feed-grain provisions of the Agricultural Act of 1962 in the form of production payments based on the difference between the price support level and the price that would allow wheat to move into international trade without a direct subsidy. In the Agricultural Act of 1964 this provision was extended to include maize and cotton (with payments going to handlers in the case of cotton). In the Agricultural Act of 1973 the concept of a "target price" was introduced as a device for determining the size of the income support payment. The target-price concept had the effect of further institutionalizing the direct or deficiency payment approach (Cochrane, 1979).

It seems apparent that increased reliance on direct payments in agricultural commodity programs, beginning in the mid-1960s, was induced at least in part by the growing integration of U.S. agriculture into world commodity markets. The effects of the overvaluation of the dollar, which began in 1949 when a number of European countries undertook major devaluations, were initially masked by the Korean War. By the mid-1960s, however, program costs, from acquiring stocks or removing land from production, had become excessively burdensome.

The benefits from a direct payments program, when initially proposed by Brannan, were primarily in terms of agricultural adjustment and income distribution. By the mid-1960s the gains could also be measured in terms of economic growth and higher farm income. After the initial defeat of the supply-management proposals, Secretary of Agriculture Orville Freeman, and his aides Willard W. Cochrane and John Schnittker, responded skillfully and effectively to design and manage program changes that, by the late 1960s, brought agricultural commodity production and prices close to equilibrium levels for the first time since the end of the Korean War.

The Agricultural Act of 1985, mislabeled the Food Security Act, moved a short step beyond the legislation of the mid-1960s toward decoupling income support from commodity prices. The act represented a calculated attempt to use higher program benefits to farmers to purchase lower commodity prices and greater competitiveness in world markets. But the cost was excessively high—in the range of $25 billion per year. That is approximately double the annual level of expenditure under the 1981 act, which in turn cost several times as much to administer as any previous farm program. The provision of the 1985 act that purportedly puts a ceiling on the payments received by individual farmers leaks at the top. The distribution of benefits is obscene by any standard.

REFORMING COMMODITY AND INCOME POLICIES

Agricultural commodity policy should be directed to realizing the gains from the technology-driven productive capacity that will be-

come available over the next several decades. To achieve this objective it will be necessary to complete the decoupling of income protection for farm families from commodity prices.[3]

Despite the jumble of target prices, loan rates, and deficiency payments, the basic principles guiding the more specific program provisions of the 1985, and predecessor, commodity price support programs are relatively simple. The major field crop programs—those for wheat, corn, cotton, and rice—operate by "renting land" from farmers. The "rent" that induces a farmer to idle enough land to participate in the program is referred to as a "deficiency payment." It is calculated as the difference between the loan rate and a "target price" (or between the market price and the target price if the market price and the target price exceed the loan rate) multiplied by the normal yield on the eligible portion of the farmer's historical "base" acreage. The loan rate is the price at which the government stands ready to acquire and store farm commodities. The high program costs under the 1985 act have resulted from the large number of participating farmers who were attracted by a relatively low loan rate and a high target price.

There is no way that a program that attempts to limit supply or enhance prices by renting land from farmers, or through direct purchase of farm commodities, can avoid incurring excessively high costs. And there is no way such a program can avoid directing its benefits to the largest farmers. Most of the land, or the commodities, must be obtained from the 15 to 20 percent of all farmers who account for 60 to 80 percent of production.

Before I attempt to specify the elements of an appropriate agricultural policy, a comment is in order on one nonsolution to the price-depressing effects of more rapid growth of supply than of demand for agricultural commodities. There have been frequent assertions, both in the popular press and in agricultural policy circles, that the agricultural research system should shift its priorities from output-enhancing to cost-reducing technologies. Anyone who is familiar with how a private enterprise economy works should easily recognize that any technology that reduces unit costs of production will also induce increases in production. While the impact on production of a reduction in unit costs is not symmetrical with an increase in unit price the effect is similar (Reilly, 1986).

A first step that should be taken in any program designed to take advantage of the resources and the technology available to U.S. farmers is to eliminate the price support loan rates. Elimination of the loan rates would permit dismantling of this obsolete system of acreage allotments and "bases" on which the loans are calculated. It would permit production to shift to those areas where costs are lowest. It would permit agricultural commodities to move into international trade at market prices. The United States would no longer be forced to occupy the role of residual supplier in world markets or to hold a price umbrella over producers in other countries.

Income support payments to farmers should be based on the difference between the market price and a "target price." The target price might be initially set at a level that would cover production costs on an efficient family farm. The price should be computed using a formula that would reflect cost reductions and inflation rates. The payments should be subject to a limitation that reflects a much greater sense of equity among farm and nonfarm recipients of transfer payments than the current $50,000 per farm limitation. The elimination of the loan levels would permit a refocusing of the debate on an equitable target price level and payment limitation.[4]

A somewhat more radical alternative would be to design a "buy-out" provision similar to those employed by many business firms to encourage early retirement. Program costs could first be capped, along the lines suggested in the 1986 Boschwitz-Boren congressional proposal, by taking the current base acreage and average yield as a basis for a once-and-for-all calculation of income payments per farm, up to a reasonable payment limit. A second step would be for the government to offer farmers an opportunity to "sell out" the capitalized value of payment benefits. New entrants into farming, whether by purchase or inheritance, would not be eligible for the direct payment benefits.

Neither of the above program alternatives would fully resolve the issue of intersector equity. Equity would require that income transfers designed to protect levels of living in agriculture against price instability be consistent with the transfers used to protect workers in other sectors against employment instability. If the principle of intersector equity were to be adopted as a policy guideline, it would imply the adoption of something like an "earned income credit" to protect the subsistence needs of families and individuals regardless of the sector of the economy in which they work.

The programs proposed here could not be expected to resolve fully the problem of inefficient markets. Agricultural markets are inherently unstable. A combination of inelastic short-run demand and supply relationships will continue to impose great instability on agricultural prices and on the incomes of the farm people who produce agricultural commodities. The producers of agricultural commodities can be expected to continue to exert their considerable political resources to maintain programs that dampen the fluctuations in agricultural prices.

Much of the price instability faced by agriculture is a product of inefficient or perverse macroeconomic policy. Failures in macroeconomic policy are particularly serious for the agricultural sector because of the persistent tendency for U.S. agricultural prices to "overshoot" in response to monetary, fiscal, and other exogenous shocks (Andrews and Rausser, 1986). In this respect the behavior of the U.S. agricultural sector and many less developed countries that depend on commodity exports for foreign-exchange earnings is quite similar.

The appropriate focus of reform is in the areas of monetary, fiscal, and trade policy. Such reform is important, not only to farmers, but to every other productive sector of the U.S. economy. Reform would help to limit interventions in agricultural commodity markets to the maintenance of the reserve stocks necessary to protect both producers and consumers, at home and abroad, from the most extreme price fluctuations. It would also help to limit interventions into agricultural land markets to those activities needed to achieve desirable levels of soil conservation and environmental amenities.

It cannot be emphasized too strongly that the slow growth in the global economy during much of the 1980s was the primary source of depressed agricultural commodity and agricultural input markets. Resumption of 1960–1980 growth rates in the less developed and centrally planned economies would create new opportunities for the expansion of agricultural trade. It is time for the developed market economies to accept their responsibilities for creating a macro-policy environment that will enable the world's consumers and producers to realize the opportunities for abundance that are now being denied them.

NOTES

1. Two reports were exceedingly useful in preparing this paper: Office of Technology Assessment (1986b) and McCalla et al. (1986).
2. The material in this section draws on Ruttan (1984).
3. The material in this section draws heavily from an earlier paper (Ruttan, 1986).
4. It has been argued that "other nations see our (U.S.) loan rates and land retirement programs as implicit export taxes. In contrast target prices appear as an implicit export subsidy. . . . Target prices encourage surplus production while the loan program diverts this additional output into public stocks . . . on balance, U.S. exports are implicitly taxed and the programs lead to stock increases" (McCalla et al., 1986). The proposed elimination of the loan rate would remove the implicit export tax. The proposed ceiling on the direct payment would limit the production impact and the implicit export subsidy. Several proposals were put forward in the late 1970s for the establishment of a grain export cartel by the major exporting nations (Schmitz et al., 1981). In my view, any short-run gains that the United States might realize as a participant in a cartel would be at the expense of long-run gains in comparative advantage and market-share.

REFERENCES

Anderson, K., and Y. Hayami, eds. 1980. The Political Economy of Agricultural Protectionism. Sydney: Allen and Unwin.

Andrews, M. S., and G. C. Rausser. 1986. Some political economy aspects of macroeconomic linkages with agriculture. Am. J. Agri. Econ. 68:413–417.

Balisacan, A., and J. A. Roumasset. 1980. Public choice of economic policy: The growth of agricultural protection. East-West Center, Honolulu. Photocopy.

Bates, R. H., and W. P. Rogerson. 1980. Agriculture in development: A coalition analysis. Public Choice 32(5):513–527.

Bennett, M. K. 1949. Population and food supply: The current scare. Scientific Monthly 68(January):17–26.

Brown, L. R. 1981. World population growth, soil fertility, and food security. Science 214(November):995–1002.

Campbell, K. O. 1979. Food for the Future: How Agriculture Can Meet the Challenge. Lincoln: University of Nebraska Press.

Cochrane, W. W. 1979. The Development of American Agriculture: A Historical Analyses. Minneapolis: University of Minnesota Press.

Edwards, C. 1985. U.S. Agriculture's Potential to Supply World Food Markets. Economic Research Service, AER 539. Washington, D.C.: U.S. Department of Agriculture.

Fox, G., and V. W. Ruttan. 1983. A guide to LDC food balance projections. European Rev. Agri. Econ. 10(July):325–356.

Hathaway, D. E. 1986. Trade negotiations: They won't solve agriculture's problems. Choices (Fourth Quarter):14–18.

Jain, H. K. 1986. Eighty years of post-Mendelian breeding for crop yield: Nature of selection pressures and future potential. Indian J. Genetics 46(Suppl.):30–53.

Landsberg, H. H. 1967. The U.S. resource outlook: Quantity and quality. Daedalus 96(Fall):1034–1057.

Lewis, W. A. 1969. Aspect of Tropical Trade, 1883–1965. Stockholm: Almquist and Wicksell.

Lewis, W. A. 1980. The slowing down of the engine of growth. Am. Econ. Rev. 70(September):555–564.

Longmire, J., and A. Morey. 1983. Strong Dollar Dampens Demand for U.S. Farm Exports. Economic Research Service, Foreign Agricultural Economic Report 193. Washington, D.C.: U.S. Department of Agriculture.

McCalla, A. F., T. K. White, and K. Clayton. 1986. Embargoes, Surplus Disposals, and U.S. Agriculture. Economic Research Service, Staff Report No. AGES80910. Washington, D.C.: U.S. Department of Agriculture.

Office of Technology Assessment. 1986a. A Review of U.S. Competitiveness in Agricultural Trade—A Technical Memorandum. OTA-TM-TET-29. Washington, D.C.: U.S. Government Printing Office.

Office of Technology Assessment. 1986b. Technology, Public Policy, and the Changing Structure of American Agriculture. OTA-F-285. Washington, D.C.: U.S. Government Printing Office.

Orden, D. 1985. The macroeconomics of trade sectors: The case of U.S. agriculture. Department of Agriculture Economics, Virginia Polytechnic Institute and State University, Blacksburg. December. Photocopy.

Reilly, J. M. 1986. Cost-reducing and output-enhancing technologies: A note. Natural Resource Economics Division, Economics Research Service, U.S. Department of Agriculture, Washington, D.C. Photocopy.

Rogoff, M. H., and S. L. Rawlins. 1987. Food security: A technological alternative. BioScience 37(December):800–807.

Ruttan, V. W. 1971. Technology and the environment. Am. J. Agri. Econ. 53(December):707–717.

Ruttan, V. W. 1984. Social science knowledge and institutional change. Am. J. Agri. Econ. 66(December):549–559.

Ruttan, V. W. 1986. Toward a liberal program for agriculture. Forum Appl. Res. Pub. Policy 1(Summer):81–85.

Ruttan, V. W. 1987. Toward a global agricultural research system: A personal view. Res. Policy 15(December):307–327.

Schmitz, A., A. F. McCalla, D. O. Mitchell, and H. C. Carter. 1981. Grain Export Cartels. Cambridge, Mass.: Ballinger.

Schuh, G. E., and J. L. McCoy. 1986. Food, Agriculture, and Development in the Pacific Basin. Boulder, Colo.: Westview Press.

U.S. Department of Commerce. 1985. U.S. Trade: Performance in 1985 and Outlook. International Trade Administration. Washington, D.C.: U.S. Department of Commerce.

Weber, A. 1986. Assessing Food Production Potentials in the Final State of Stationary Populations. Department of Agricultural and Applied Economics Staff Paper 86–49. St. Paul: University of Minnesota.

Weber, A., and N. Gebauer. 1986. Fertilizer use and grain yields in world agriculture: A cross section analysis. Quar. J. Int. Agri. 25:193–216.

Trade and Agricultural Policy

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The pace of technological change in agriculture is accelerating throughout the world, and this should in theory have changed our thinking about national agricultural policies as well as about international trade policies. When I looked back recently at something I had written on technology and agricultural trade in 1969, however, it seemed the policy issues have not changed very much. At that time, I observed that major distortions in world production and trade patterns would be brought about by increasing import protection in national markets, combined with relatively high commodity support prices and continuing, technology-driven improvements in agricultural yields and productivity (Malmgren and Schlechty, 1969).

THE LEGACY OF THE 1960s

Looking at the current world pattern of production and trade and the tendency toward oversupply, it seems that the situation we face today was already foreseeable at the end of the 1960s. As an example, by the end of the 1960s, the introduction of the Common Agricultural Policy (CAP) in the European Community (EC) had already roughly tripled import protection for the European Common Market. Internal price supports were maintained at roughly twice the level of world market prices. In the 1960s, EC officials had argued that exports from the United States and other major agricultural suppliers would continue to rise, regardless of the CAP, but it had already become evident that this would not be the pattern of the future. From the late 1950s, when the CAP went into effect, to 1968–1969, EC yields in total grain production had risen by 34 percent and total grain production had increased by 20 percent.

The rising EC production inevitably generated pressures to expand European agricultural exports. At its inception, the CAP provided for so-called restitution payments to offset the artificial price effects of the import levy system on exports. Thus, for a commodity like poultry, exports were to benefit from a restitution payment equivalent to the import levies on the feed grain incorporated in the exported bird. As internal production grew, however, the restitution payments lost their logical link to import levies. During the 1960s the CAP regulations were amended to provide that restitution payments could include an additional amount sufficient to "meet the competition in the markets of destination."

The EC export-restitution system thus became an adjustable export subsidy and was used to unload surpluses into world markets. Quite naturally, production continued to grow in many product areas based on high support prices and rising yields, and exports continued to expand. Production grew faster than consumption for all the major commodities—cereals, milk, beef, sugar, and wine. By the 1980s, the EC had reached the point that total production of cereals exceeded total consumption. The operation of the system was so successful that the EC even became a net exporter of sugar, severely damaging many developing countries in a product area in which the EC itself should have continued to be a net importer by any kind of rational economic reasoning.

This kind of massive distortion in the world marketplace is not simply reversible by changes in agricultural policy mechanisms. The higher yields and the new technologies on which they are based are already in place, and land values have risen to reflect the internally distorted prices. Contraction of production would necessarily be a slow process under any plausible scheme aimed at bringing the EC farm economy in line with the world market.

The same kinds of consequences were foreseeable for Japan and other countries characterized by high internal food and feed prices. Japan's rice support prices today are eight or nine times the world market prices, and Japanese surpluses have thus far politically precluded any opening of domestic agriculture to world market forces.

In recent years, the increases in world production and the closed nature of many national economies have intensified competition among exporters in the remaining world markets and forced traditional exporters of cereals to increase their productivity and cut their costs even faster than would have occurred under normal circumstances. Thus, it was basically quite clear at the end of the 1960s that the combination of technological advances and the types of national policies being practiced would generate a global tendency toward overproduction year after year.

The underlying tendency toward overproduction became painfully evident in the United States in the early 1980s as artificially driven production and price trends interacted with a very strong dollar to depress U.S. agricultural exports. Coming at a time of slowdown in world growth and austerity programs in developing countries with high debt, the adverse effects on U.S. exports were amplified.

THE U.S. AGRICULTURAL TRADE POLICY RESPONSE: QUICK FIXES

Hardly anyone in the mid-1970s would have projected the stalling of the great U.S. agricultural export engine in the 1980s. The same could be said of the recent competitive failures of some other major sectors of the economy, but the problems in traditional manufacturing industries seem more readily understandable—U.S. agriculture used to seem, somehow, a source of power that could not be matched in the global marketplace. In previous decades, U.S. trade negotiators had a certain macho tendency in asserting their will in meetings on agricultural issues with representatives of other governments. No one representing another nation was willing to confront the United States and deny its objectives, that is, no individual nation. Those who represented the EC countries as a group, and who understood the long-term dynamics of the CAP, were far more aggressive in opposing U.S. trade strategies and negotiating tactics. The EC did perceive the United States as a giant, but it perceived itself as a giant as well.

As long as I can remember, from my own years in trade policy, U.S. trade negotiation objectives in agriculture have varied according to short-term considerations—the current level of crops, the level of carryover, the amount of world storage available, and the conditions in world markets—and have been especially sensitive to discontinuities, like the entry or exit of Soviet and Chinese purchasing and the entry or exit of particular politicians in the various capitals of the world. The United States has had little high-level interest in long-term trends in agriculture, and it has not had a coherent long-term global trade strategy. Instead, U.S. agricultural trade policy in the past 25 years has been characterized by improvisation, experimentation, and ad hoc solutions to imminent problems (e.g., special agreements with the Soviet Union and China, flirtations with export controls, and episodic retaliation with export subsidies of our own).

The lack of continuity or consistency in U.S. trade policy has had little to do with party politics. Trade policy responds to the problems at hand—to the complaints being raised by farmers and agribusinesses in any particular year. When there are surpluses, we give greater thought to food aid and world food reserves, and we emphasize export subsidy issues in trade negotiations. When there have been world shortages and inflationary pressures in food and feed, as in the early 1970s, we think of multilateral cooperation to manage markets—as the Nixon administration did in the early 1970s, despite its ideological opposition to any kind of market intervention by governments.

In the Kennedy Round multilateral trade negotiations of the 1960s, the United States made major efforts to negotiate changes in the world trade environment for agriculture. The United States sought to lower EC import protection and export subsidies, in the view that elimination of border measures would bring about downward pressures on the dramatically high EC support prices. As a counterproposal, the EC suggested that negotiations be framed in terms of the level of government support for agricultural commodities, rather than focusing solely on border measures. More precisely, the EC suggested negotiating reductions in the margins of support, or the *montant de soutien*. At that time, the EC proposal was vigorously rejected by U.S. officials, ostensibly on the grounds that the EC had in mind the establishment of global "target" prices or reference prices for measuring the margins of support. In reality, U.S. officials wished only to liberalize the external trade restraints and distortions. They had no interest in negotiating domestic policies.

By the end of the Kennedy Round, in May 1967, the best that could be achieved was an international wheat agreement setting floors for wheat prices and committing countries to joint efforts to take some cereals off world markets through food aid. The focus of the Kennedy Round trade talks in 1966 and early 1967 had been on keeping world prices from dropping unexpectedly in an environment of strong demand at that time. By July 1967, when I became chief U.S. negotiator for settling the implementation arrangements, the internationally agreed price floors had begun to lose significance to the United States because the world market looked like it was shifting into a period of oversupply relative to commercial demand. One of my assignments was to cut trapdoors through the price floors that had just been agreed by trade negotiators of the United States a few months earlier, so that exporters could adjust downwards in certain circumstances. The International Grains Arrangement (IGA) of 1967 was therefore designed to allow downward adjustments, but on the basis of multilateral consultation. By 1968 the United States no longer had any interest in minimum prices or in international cooperation or consultation. By 1969 the United States was far more interested in using its natural competitive edge to fight other exporters on the basis of low prices, and the IGA became a historic document of no relevance to government policy.

In the Tokyo Round of trade negotiations in the 1970s, agriculture was looked at in many ways, but governments were ultimately unable to agree on any kind of serious multilateral consultative framework for managing agricultural policies, and export subsidies proved impossible to address. Domestic policies still seemed sacrosanct and the trade problem once again seemed, to the United States, to be simply a matter of persuading other nations to drop all border impediments.

THE CLIMATE OF THE 1980s

By the latter 1980s, the climate had become somewhat different. Now the U.S. domestic farm programs are creating serious budgetary difficulties and there is a need for reorientation. The United States therefore has become interested in negotiating national farm support levels. The EC governments have found themselves in a similar position. Some significant work has been carried out in the Organization for Economic Cooperation and Development (OECD) to establish measures of national support. Perhaps this more comprehensive, more logical approach could lead in some positive direction, since most governments of the world find themselves in a budgetary squeeze.

The United States also has been renewing an attack on what it deems to be unfair trade practices of other countries—with special emphasis on access to particular markets and ending export subsidization. Defining what is unfair in the current highly distorted world agricultural marketplace, however, is very difficult. Fairness is an elusive concept. What fairness usually means is that one wants the other party to adopt one's own rules in order to achieve a "fairer" distribution of benefits ("more for me, less for you"). Indeed, the history of the General Agreement on Tariffs and Trade (GATT) since 1947 has been a history of failure to reach international consensus on what the rules of fairness should be in agriculture. It was the United States itself that originally wanted the international rules on agricultural trade to be separate from the rules for industry, and ambiguous, leaving leeway for domestic farm policy flexibility. Moreover, it has been the United States that over the years continued to seek to keep its own domestic farm policies outside the reach of trade negotiations. From 1955 to 1956 the United States sought and obtained a GATT waiver covering most of U.S. agricultural policies, and since that time there has been little interest in Washington in giving up that waiver.

The United States has traditionally wanted to keep as much freedom of action as possible, on the premise that U.S. agriculture was so strong that the ability to move freely was an advantage. If you are the proverbial 800-pound gorilla, you can do anything you wish. Needless to say, this attitude has not established in the minds of other governments an image of U.S. fairness. When the United States from time to time goes further, to negotiate special deals with the Soviets, the Chinese, the Egyptians, and others, the other exporting nations tend to perceive the United States as a bully. Is an 800-pound gorilla aware of what fairness is?

IMPOSING INTERNATIONAL DISCIPLINE ON NATIONAL AGRICULTURAL POLICIES

As we enter the 1990s, the world market environment seems to be very different. Now, it is clear that there is a need for some kind of international discipline over national farm policies. Now, the U.S. agricultural engine does not look quite so dominant. Now, there is clear recognition that domestic policy must change because of the escalating budgetary costs.

There is some talk among trade negotiators of putting the world trade situation under control by reaching urgent agreements on agricultural trade in a year or two. Frankly, based on past experience, major multilateral commitments in such politically sensitive areas as agriculture take several years to shape. Domestic politics in each country must be adjusted, and apportionment of votes in negotiating forums may even have to be adjusted. Structural changes have to be carried out carefully and slowly, lest the political reaction be to resume traditional price support solutions.

The Kennedy Round of global trade talks took six years from its inception in 1961 to its conclusion in 1967. The Tokyo Round took six years also, from 1973 to 1979, but the preparatory work actually began earlier, and the negotiations could be said to have lasted about 10 years. The results of these two rounds were implemented over several subsequent years. In other words, trade agreements come into being very slowly. It is not possible to change world trade rules quickly. On the other hand, it is possible in a short period to work out consultative arrangements among governments to manage current international market problems, if the framework is flexible. But trade negotiators do not really have the political power in their own countries to bring about fast changes in basic agricultural policies.

In my view, therefore, it will only be possible to change direction and move away from the current destructive course if a more direct attack is mounted on global agricultural problems and national agricultural policies. It is not sufficient for governments to negotiate trade policies and border measures. At the Tokyo Economic Summit in May 1986, President Reagan suggested high-level attention be given to the need for putting order into world trade in agriculture. This suggests that the U.S. government is open to the initiation of new international modes of consultation and cooperation. The Economic Summit is one of the few frameworks that could work, because officials would be working within guidelines set by top political leaders rather than by trade negotiators. What I visualize in the summit context is the creation of a "Group of Seven" for agriculture (similar to the successful international consultative groups concerned with monetary and financial affairs, the Group of Five and the Group of Seven).

Trade issues are symptomatic of national policies, and fast progress cannot be made on trade issues without dealing with the mutual incompatibilities of the national policies themselves. In other words, there is a need for parallel talks among governments—trade talks, on the one side, and agricultural policy talks, on the other. The major governments cannot politically alter their basic agricultural policies unless they all act together—and manage together the adjustments brought about by fundamental revisions in policy. Moving to a more liberal trade environment requires active management of the transition, and the transition will take several years. A new round of world trade negotiations began in 1986 in Geneva. In that context the trade negotiators can work on the trade rules for the 1990s. The policy negotiators could spend their time devising the means to get there.

Failure to make progress in changing national policies will inevitably drive the cost of farm programs up. Technology will allow faster and more vigorous responses to complex support programs and even generate new substitutes if quantitative limitations are sought on particular commodities.

CONCLUSION

We are in the midst of a time of change in our historical paradigm. We are in the midst of an information revolution, a materials revolution, a manufacturing revolution, and an agricultural-biotechnology revolution. The convergence of these technological forces and the accelerated pace of change the world is experiencing will necessitate new ways of conducting our national and international economic and diplomatic activities in the next few years.

New competitors are emerging in every sector—from new sources around the world, and even from old industries with new man-made materials to substitute for materials from the ground. Overcapacity exists in many sectors, not just in agriculture.

Global competitiveness will be rearranged along with rapid diffusion of technology. World competition will intensify. The economic gains will go to those who adjust to the new realities most quickly—rather than to those who are theoretically the most efficient at the moment.

Fast-changing technology, short product life cycles, and large economies of scale with capability for batch processing shift the emphasis in competition from efficiency of production of standard goods to speed of response to changing consumer requirements. It means greater interaction between producers and consumers in adapting products and know-how on a continuing basis. Competitiveness will come to be defined in terms of speed of response and technical capability to alter what is supplied. This is already becoming evident in manufacturing, but it will also be true in many areas of agribusiness as well.

We desperately need policy changes to cope with the technological challenges ahead. To try to slow change, or resist technological forces, will simply drive up the costs of inevitable structural adjustment. It is better to ride the tiger and be in the new markets first. As in industry, our agricultural future will depend on a willingness to accelerate change rather than try to stand in its way. In the context of the new, historic paradigm, the victory goes to the swiftest, not necessarily the most, efficient.

REFERENCE

Malmgren, H. B., and D. L. Schlechty. 1969. Technology and neomercantilism in international agricultural trade. Am. J. Agri. Econ. 51(5).

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ROBERT A. MILLIGAN Milligan is an associate professor and department extension leader in the Department of Agricultural Economics. He has been on the faculty at Cornell since 1975 and has been a member of the biotechnology research team since 1983.

THOMAS W. PARTON Since 1979, Parton has been head of the agricultural division of CIBA-GEIGY Ltd. He joined the Geigy Company in Manchester, England, in 1954 and has served the company in Canada as group company head and in England as head of the photographic group.

DAVID E. REED Reed recently became manager of product development for Norden Laboratories, Lincoln, Nebraska. Before joining Norden, Reed was vice-president of clinical affairs for IMRE Corporation. Also, he was the former director of product development at Molecular Genetics, Inc., specializing in the area of veterinary virology. Prior to joining Molecular Genetics, Reed was professor of veterinary microbiology at Iowa State for seven years and also worked seven years at the State Diagnostic Laboratory in Brookings, South Dakota.

GEORGE E. ROSSMILLER In 1987, Rossmiller was named director of the National Center for Food and Agricultural Policy, Resources for the Future. He replaced Ken Farrell. Rossmiller joined the center as a senior fellow in 1986. Previously, he served as senior economic adviser and director of the planning and analysis staff, Office of the Administrator, Foreign Agricultural Service. His areas of interest include agricultural policy, international trade, and macroeconomic linkages.

VERNON W. RUTTAN Ruttan is regents professor in the Department of Agricultural and Applied Economics at the University of Minnesota. His major interests are within the areas of agricultural development and research policy. He is the author of *Agricultural Research Policy* and *Agricultural Development* (with Yujiro Hayami). He has served as a member of the Board on Agriculture.

GÜNTHER SCHMITT Schmitt is a professor in the Department of Agricultural Economics at the University of Göttingen, Federal Republic of Germany. He recently completed a year as a visiting professor at the Department of Agricultural and Applied Economics of the University of Minnesota, where he did research on the determinants of agricultural policy decisions in the United States and on the economics of research policy.

HOWARD A. SCHNEIDERMAN Schneiderman is senior vice-president for research and development and chief scientist of the Monsanto Company. He holds a presidential appointment to the National Science Board. His term will expire in 1992. He remains a professor on leave at the University of California, Irvine.

G. EDWARD SCHUH Schuh was director of the Department of Agriculture and Rural Development at the World Bank at the time this article was written. Before assuming that position in 1984, he was head of the Department of Agriculture and Applied Economics at the University of Minnesota. He served as the deputy under secretary for international affairs and commodity programs at the U.S. Department of Agriculture from 1978 to 1979 and as senior staff economist to the President's Council of Economic Advisors from 1974 to 1975. He currently is dean of the Humphrey Institute of Public Affairs at the University of Minnesota.

M. ANN TUTWILER Tutwiler is a trade policy associate at the National Center for Food and Agricultural Policy, Resources for the Future. Before joining the center, Tutwiler was a staff economist with the Economic Research Service, U.S. Department of Agriculture. She earned her master's degree in public policy from the Kennedy School of Government at Harvard.

THOMAS N. URBAN Urban is president and chairman of Pioneer Hi-Bred International, Inc. He joined Pioneer in 1960.

THOMAS E. WAGNER Wagner is director of the Edison Animal Biotechnology Center at Ohio University, where he has been since 1970. Among his areas of research are control mechanisms in the regulation of genetic expression and genetic recombination of eukaryotes. In 1980, he directed the research group that transferred the first functional cloned gene into an intact mammal.