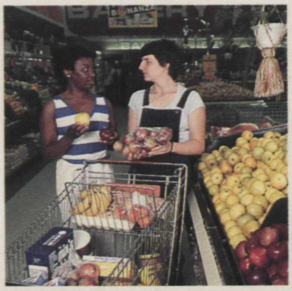
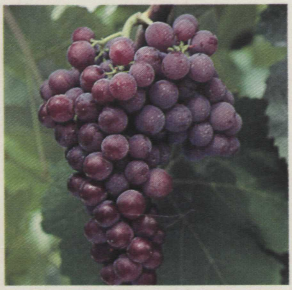
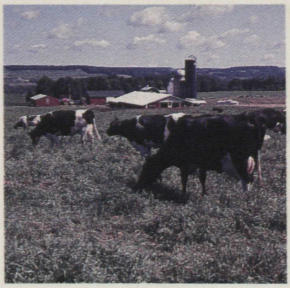
THE NEXT CENTURY

Proceedings of the Hatch Act Centennial Symposium

May 4–5, 1987


CORNELL
UNIVERSITY

Cornell University Agricultural Experiment Station
New York State Agricultural Experiment Station

The Next Century

PROCEEDINGS OF THE
HATCH ACT CENTENNIAL
SYMPOSIUM

May 4–5, 1987

Cornell University Agricultural Experiment Station
New York State Agricultural Experiment Station
Ithaca, New York

Cover photographs:

Top left: Photo by Don Albern, Cornell University Media Services

Top right: Courtesy of New York State Agricultural Experiment Station, Geneva

Center left: Rice plantlets regenerated from tissue culture. They have half the chromosome number of normal rice plants because they were developed directly from immature rice pollen. Courtesy of Elizabeth D. Earle, Department of Plant Breeding and Biometry, Cornell University

Center right: Groton, New York, photo by Don Albern, Cornell University Media Services

Bottom left: Photo by Don Albern, Cornell University Media Services

Bottom right: Green peach aphid, a major pest of potato, attempting to negotiate the surface of a potato plant leaf. Its feet and mouthparts are encased with sticky exudate from the glandular (secretory) leaf hairs (trichomes) of an aphid-resistant potato. Courtesy of Ward M. Tingey, Department of Entomology, Cornell University

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INTRODUCTION

Agricultural Research: The Next Century

N. R. Scott, Director for Research

Cornell University Agricultural Experiment Station

Agriculture has undergone tremendous changes during the hundred years since the Hatch Act was signed on March 2, 1887, and the New York State and Cornell University Agricultural Experiment Stations were established. A person who was present at that signing would be amazed at the agriculture and food system we have developed.

American consumers on the average now spend 14.4 percent of their disposable income on food, an all-time low. *Business Week,* in its May 4, 1987, edition, referred to our food system as "America's supermarket miracle" and to supermarkets as "a national food exhibition." Hatch-based research involving a unique partnership of federal, state, and private cooperation has been a major contributor to this revolution.

Reflecting on the last century of agricultural research, I focus on the words of Richard Lyng, secretary of agriculture, who wrote, "We salute the past, embrace the present, and anticipate the future." Cornell is proud to have hosted the Hatch Centennial Symposium, "The Next Century," in Ithaca, New York, on May 4–5, 1987. These proceedings capture, for both those who were able to attend and many who were not, the excellent contributions of our distinguished speakers.

Let's, for a moment salute the past by looking at the unsure start of the agricultural experiment station at Cornell University. Professor George Chapman Caldwell, whom President Andrew D. White had brought from the state college of Pennsylvania as professor of agricultural chemistry, played a major role in the development of the first experiment station. In 1874, President White announced the establishment of the university farm before the New York State Agricultural Society. A bill to form an experiment station supported by the State Grange was introduced into the New York State legislature in 1877. The state legislature did not act, but Professor Caldwell took the initiative by organizing an agricultural experiment station at Cornell in February 1879. Cornell University did not acknowledge this action with any financial support until 1881 and then allowed this support to dwindle to zero by 1886. A further lack of support for the agricultural experiment station at Cornell was evidenced by a failure of the Cornell administration to press a claim for the state agricultural experiment station in the state legislature. On June 26, 1880, the New York State legislature passed an act to establish the experiment station at Geneva, New York, "for the purpose of promoting agriculture in its various branches by scientific investigation and experiment." Known as the New York State Agricultural Experiment Station, it officially opened its doors on March 1, 1882.

From their official establishment in 1887 by the Hatch Act, state agricultural experiment stations have sought to integrate basic research with practical application to enhance rural life. The Cornell University Board of Trustees, in anticipation of the Hatch appropriation, authorized the Agricultural Experiment Station at Cornell University in the fall of 1887. On April 30, 1888, the Cornell University Agricultural Experiment Station was fully organized with the appointment of Professor Isaac P. Roberts as director. The first annual report of the Cornell University Agricultural Experiment Station contains the report of Director Roberts and those of the six departments: agriculture, chemistry, veterinary science, botany, horticulture, and entomology.

From these beginnings, we embrace the present. As we commemorate the Hatch Act Centennial, agricultural research at Cornell continues to be marked by great diversity from basic sciences represented by biotechnology to applied agricultural research. Total research support at Geneva and Ithaca during the year 1986–87 was approximately $54 million. Food and agriculture are still integral parts of the traditional research programs at the Ithaca and Geneva stations, but major shifts have occurred as emphasis has been directed to broader issues of society and family. Also, although Hatch funding of agricultural research was a major source at the beginning of the century, it now represents, at both the Cornell University and New York State Agricultural Experiment Stations, a relatively small fraction (approximately 10 percent) of total support for agricultural research. Although Hatch funding has moved from the primary source at the beginning of the century to a lesser position now, it has been extremely important as base funding of agricultural research. It remains so today, particularly as a source of funds to respond rapidly to changes, provide stability, support young scientists, leverage additional funding, bridge external funding, and pursue new initiatives.

The Hatch Act has been a central force in the development of an agricultural research system with an applied orientation which is both geographically and administratively decentralized. Today, as at the time of the signing of the Hatch Act, agricultural science is in the midst of a debate concerning expectations of researchers, funding sources, and administrators.

A century ago the challenge for leaders of agricultural research was to build a system consistent with conflicting goals and diverse values. Today we face a similar need to address differences in values and to revitalize the system to meet competing concerns of a new set of political interests and yet maintain the scientific strengths inherent in the Hatch Act. During the debate at the time and following the passage of the Hatch Act, individuals focused on "practical information" versus "original researches" in defining the mission of the state agricultural experiment stations. The goal of agricultural research with a utilitarian value, resulting in increased productivity and welfare of rural communities, was captured well by a Wisconsin farmer, who offered the graphic statement, "We do not want science floating in the skies, we want to bring it down and hitch it to our plows."

Our objective at the Cornell University and New York State Agricultural Experiment Stations is to bring the science of the gene, electron, economics, and human behavior to meet practical needs of agriculture and rural life. The title of this publication and the symposium from which it emanates is *The Next Century*. A number of forces are likely to create the need for substantial change in agricultural research during the next century: the growth of biotechnology, the electronics revolution, the concern for environmental quality, the need for systems integration, and the global interdependence of agriculture.

As we respond to Lyng's statement—"anticipate the future"—we are challenged to address the research agenda for the next one hundred years. Although I claim no special expertise in looking into the future, I do feel some company with other agricultural experiment station directors in suggesting that the agenda is likely to include:

- Resource- and energy-sparing technologies
- Low-input or alternative systems to improve profitability
- Enhancing and maintaining soil productivity

- Water quality and management
- Crop protection through integrated pest management (IPM)
- Emphasis on improved nutritional value and quality of crops and livestock products
- Greater food safety for the protection of human health
- Bioprocessing of agricultural products for storage, packaging, and distribution
- Electronic sensors, including robotics and microcomputing, for systems management
- Expanded uses of agricultural products for both food and nonfood applications
- New systems for aquaculture
- Expanded biotechnological advancements in plant and animal systems
- Global economic policies affecting agriculture
- Studies of rural communities

Although not inclusive and almost surely subject to dramatic change during the next century, this list does suggest new linkages, and efforts will need to be developed by agricultural experiment stations through interaction with farmers, consumers, state and federal governments, and industry. New partnerships will likely evolve and pave the way for a vastly different mix of funding and a balance of applied and basic research. Certainly, funding of agricultural research will continue to be broadly dispersed, but Hatch funding will continue to provide an extremely important base on which to build a total agricultural research program.

During the centennial year of the Hatch Act, the New York State and Cornell University Agricultural Experiment Stations have frequently reflected upon the past one hundred years and, drawing from this proud history, we turn to the next century. As John Naisbitt has written in *Megatrends*, "Things aren't going to get better. They are going to get different." Agriculture in the next century is going to be different, but we know agricultural research at Cornell University will continue to be a part of an investment that will make a difference. We are pleased to bring the output from our Centennial Symposium to you through this publication and commend it to your reading for its important insights for the next century.

Greetings from Cornell

Joseph M. Ballantyne, Vice-President for Research

Cornell University

The Hatch Act of 1887, and its predecessor and successor, the Morrill Acts of 1862 and 1890, have had major impacts on Cornell University and on higher education in the United States in general. Indeed, the Morrill Act of 1862, which enabled the establishment of land-grant universities to provide instruction in agriculture and the mechanic arts, crystallized Ezra Cornell's conviction into the actions that resulted in the founding of Cornell University as the land-grant institution in the state of New York.

Ezra Cornell's vision "to found an institution where any person can find instruction in any study" was in concert with the principles of the Morrill and Hatch acts, which elevated the study of agriculture and the mechanic arts to the same stature as the sciences and humanities in higher education.

Ezra Cornell's vision went beyond these acts by extending the benefits of higher education to every person, rich or poor, male or female. The Hatch and Morrill acts, and Cornell University in carrying them out, thus transformed fundamental principles underlying higher education in this country. Cornell became a model for the comprehensive American state university.

By providing for the establishment of and funding for agricultural experiment stations in the states, the Hatch Act established a firm foundation for the conduct of agricultural research to benefit the farmer. To quote an old pun, "It made agriculture a good field in which to work," and it ensured that agricultural research would remain in the "field" and not regress to the "ivory tower" mentioned by Dwight Eisenhower in 1956, when he said, "Farming looks mighty easy when your plow is a pencil and you are a thousand miles from the cornfield." Agricultural research has made it harder for the "wise-acre" to ruin the entire section.

Hatch funding laid the foundation for research in this university, as in many others. Today Cornell ranks third in the nation, spending over $200 million annually for research, of which agriculture and Hatch-related research is a major part.

More than $70 million is spent on research in our statutory colleges per year. All of this can be traced back to the initial funding under the Hatch Act. The first experiment station at Cornell was actually established in 1879, nearly ten years before the Hatch Act. Two years later, the Board of Trustees appropriated $1,000 for the station. By 1885, that appropriation had shrunk to zero. In its first ten years of existence, the Agricultural Experiment Station published only three reports, but they were very important.

After the passage of the Hatch Act, the Agricultural Experiment Station received $15,000 annually which created a solid foundation for the establishment of research related to the Hatch goals. When agricultural experiment stations were coupled with Cooperative Extension, provided in 1914 by the Smith-Lever Act, which brings the results of research to agricultural producers, a system for discovering and applying new knowledge was established that has made and continues to keep U.S. agriculture the best in the world. This result stands in contrast to most other engineering and industrial technology, for which the philosophy and policies of government support have not been as well developed and the primary spurs for development have been haphazard and mostly the result of wars and needs for national defense.

Our early public leaders were right in their policies and prophetic in their vision for supporting agricultural research. Through the Hatch and Morrill acts they created public policies that responded to George Washington's vision expressed in his statement to Congress in 1796: "It will not be doubted that with reference either to individual or national welfare, agriculture is of primary importance. In proportion as nations advance in population and other circumstances of maturity, this truth becomes more apparent and renders the cultivation of the soil more and more an object of public patronage. Institutions for promoting it grow up, supported by the public purse, and to what object can it be dedicated with greater propriety?"

What is agricultural research today? One person said, "Agriculture is people waiting to see what comes up." And another: "Agriculture is what happens when people go to seed." There is no doubt that "new seeds" or "new animals," which are being developed in today's experiment stations, will play a major role in tomorrow's agricultural production. But we do not have to wait as long as we used to, or be as haphazard in our tries as we used to be, to develop new seeds. Modern methods of biotechnology and molecular biology have brought speed and precision to the development of new varieties. Speeding up traditional methods, Professor Don Viands, here at Cornell, developed a wilt-resistant variety of alfalfa in just three years from initial request to commercial production.

Growth hormones help nature make the most efficient farm animals more efficient and promise major changes for the dairy and meat industries. The bovine growth hormone developed by Professor Dale Bauman can increase milk production efficiency and lower costs by 20 to 30 percent. Professor R. Dean Boyd's work on applying growth hormone to pigs gives 30 percent gains in feed efficiency and reduces feed costs by 24 percent. Fat in the resultant meat is reduced by about 50 percent, and muscle is increased 15 to 18 percent. Similar success is being enjoyed by Professor Donald Beerman in applying this work to lambs. These results have important implications for both producers and consumers as more efficient methods to produce leaner meat become more and more critical in addressing changing consumer desires. Such progress, of course, has major social implications, and people such as Professor Robert Kalter have been active in forecasting the potential social changes.

Hatch research also extends to many areas outside traditional agriculture, such as programs in our Colleges of Human Ecology and Veterinary Medicine and the Division of Biological Sciences.

Research on controlled-atmosphere storage of agricultural products has resulted in remarkable benefits to farms. We now enjoy "fresh" apples year-round because of research pioneered here. The same is true of cabbages that are stored under controlled conditions. We see these benefits in the grocery store every day.

Professor William Jewell's research on agricultural wastes and energy has led to the construction of anaeorobic digestion facilities on farms. Digesters have been designed up to a capacity of 400,000 cubic feet of manure slurry and produce 1 million cubic feet of gas each day, which is used to produce electricity in diesel generators.

Professor Jewell has also developed a new hydroponic method of wastewater treatment, using aquatic plants. The root mass of elephant grass and other plants serves as a photosynthetically powered wastewater filtration system.

Progress continues on many fronts, ranging from the development of high-yielding wheat and potato varieties to virus-resistant cucumbers, borer-resistant corn, and mold-resistant snapbeans, to processes at the most cellular level such as the role of biological "pumps," which move nutrients through plants, to the molecular structure of biological materials.

Research spawned by the Hatch Act is broader today than it ever was and has more tools at its disposal. It encompasses areas that were the traditional domain of mathematics, chemistry, physics, engineering, the social sciences, and the humanities. There are major interactions in interdisciplinary research with our Center for Biotechnology, which funds $1.1 million a year for projects in the experiment stations at Ithaca and Geneva; with our microelectronic Submicron Facility, which uses submicron artificial structures to explore the sense of touch of the bean rust virus, and shoots DNA-coated tungsten bullets from guns into plant cells; with the high-energy physics synchrotron, which uses radiation to reveal the crystal structure of biological materials; with the Mathematical Sciences Institute, which sponsors research on the application of statistics in fields such as biometrics; and with the Supercomputer Center, where people model the flow of pollutants in the ecosystem.

The future is indeed bright, but it is not without challenges. Hatch funding in recent years has not kept up with inflation. This is a serious problem because support for research in physical sciences and engineering has outstripped inflation. Federal agencies, which spend huge sums to clean up the environment, are spending almost nothing on understanding it. In the environmental area it is no joke to say that one "wiseacre" can ruin a section. Despite the challenges, it will be exciting to see "what comes up" in Hatch-funded research in the next century.

Agriculture 2000: Tomorrow Starts Today

Theodore L. Hullar, Chancellor

University of California, Riverside

The purpose of this symposium is to look ahead, to sketch for ourselves and for others some of the needs, challenges, and opportunities that lie before us as we approach the year 2000. This is a time to look, even if dimly, to the future we will bequeath to those who will come after us and also to look to the situations most immediately before us.

Cornell University, through the quality and attention of its faculty and students, the effectiveness of its staff, its innovative and path-breaking programs, and the Cornell University and New York State Agricultural Experiment Stations, has always been connected to the future. Indeed, it has often created that future.

It is thus presumptuous, quite possibly in the extreme, to make pronouncements and suggestions about the future of agricultural research and its connections to the problems of our world. Nonetheless, I will make some observations and suggestions. There can be two foci to this discussion. The first can be issues and problems demanding our attention, research areas of particular interest to our scholarly activities and activities that promote new findings in our chosen disciplines. A second focus is the research system itself—the framework and the expectations in which we work. I have chosen the latter for my attention; for without a clear understanding of the context wherein we work, and without a system that maximizes our efforts, we will be less able to shape our future effectively.

On the subject "Agriculture 2000: Tomorrow Starts Today," I wish to ask two questions and to attempt to answer them. First, are we functioning as we should within this system that is the result of the Morrill acts and the Hatch Act of 1887? And second, do we manage this system that was initiated by those acts in the best way possible?

My response to these questions is as follows: The Hatch Act has served us well, and its operation should be continued; but that does not mean we cannot add to it. Institutions like the Cornell University and the New York State Agricultural Experiment Stations, and, I might say, the California Agricultural Experiment Stations, as well, and so many others, have all succeeded remarkably well. Nonetheless, I believe this is a propitious time to consider some major new directions for support and management of our agricultural research system; and, if we can establish appropriate linkages, also of our Cooperative Extension Service in relation to our agricultural experiment stations.

I wish to submit three proposals for our attention: first, an expanded competitive research grants program; second, a new way of formulating, conceptualizing, and managing our special grants program; and third, dramatically increased extramural funding by federal agencies to universities.

The competitive research grants program has become exceptionally common in this country, established through the efforts of Vannevar Bush and the beginnings of the National Science Foundation (NSF), and then the National Institutes of Health (NIH), shortly after World War II.

It came to agriculture in the late 1970s. For several years it was rather small, approximately $20 million or less, paling in significance beside the NSF and NIH programs. Recently it has been expanded to approximately $50 million. But is that enough, and is the program of enough scope and dimension to satisfy all our needs? My answer to that question is an emphatic no! The program must be expanded significantly, even dramatically, if we are to involve and capture the interest of faculty throughout our universities and even in our agricultural experiment stations for their own agriculturally oriented studies. This is the single most significant innovation that we can make today as we look to the future. Competitive research grants programs related to agriculture must be expanded to include all fields of inquiry relative to agriculture, not remain limited to the current small number.

Programs are needed in at least the following areas, and I am sure more topics could be added: molecular and cellular genetics; ecosystems, both natural and managed, such as agroecosystems; soil, water, and environmental sciences; engineering, of all manner and form, as it relates to agriculture; agricultural and environmental toxicology; economics and sociology; food and nutritional sciences, to name a few.

These program areas should be complementary to those of the National Science Foundation and the National Institutes of Health. There is no reason to duplicate, but there is reason to complement.

Each of these program areas should be funded at significant levels to encourage and attract participation from qualified university scientists throughout the higher education sector. At a minimum, in my judgment, this means at least a five- to tenfold expansion in the current competitive research grants program. Fivefold is only $250 million, bringing us approximately at parity with the current Hatch program. That would be a major supplement, of course, to the research already funded, in part by Hatch programs and state funds; but it has an even more significant virtue for agriculture as a whole. That is, it will serve to attract to agriculture scientists who heretofore have paid little attention to it.

The program, of course, should be managed according to the well-accepted principles of competitive grant programs, and it should give emphasis to multidisciplinary research, research grants, program grants, and, in some cases, training grants.

The second area that needs attention is a new special grants program. New approaches are needed for problem-oriented research, such as for groundwater quality. To fund this research, a new type of special grant is needed. Some of the principles that should be employed in this program include use of the National Research Council or a similar planning mechanism (we have them in agriculture) to establish six to ten categories of problems. The legislation for the current special grants program can be used, but the funding should come through competitive grants rather than through congressional targeting. There is congruity here with respect to the current national debate regarding facilities. A competitive grants program should be established for these special grants. Each group of investigators should be multidisciplinary in makeup, preferably from more than one institution, and well managed. Cooperative Extension should be incorporated into the group to facilitate information and technology transfer. The term of the grants should be sufficiently long, at least three to five years per grant, and of sufficient funding, at least $30 to $50,000 per investigator and preferably more, so that meaningful work can be done.

This type of special grant will require significant departure from the current special grants program, but there is precedent for it. The STEEP program in the Pacific Northwest is one example, and the current water quality initiative led by the Cornell Agricultural Experiment Station is another.

My third proposal is to increase substantially the support federal agencies extramurally allocate to university scientists for their research. For example, in fiscal year 1983, according to a published

National Science Foundation report, 66.5 percent of USDA research funds went for intramural research and only 32.7 percent for university research, whereas the National Institutes of Health funds were in the reverse proportions—23.9 percent went for intramural research and 56.1 percent for university research. Even more notable, only 7.4 percent and 18 percent, respectively, of the research funds of the Department of the Interior and the Environmental Protection Agency went to university research.

It would be inappropriate to suggest that there are differences in performance levels between federal and university laboratories. But one of the great virtues of university-based research is that it provides the opportunity to train young scientists and incorporate the best minds of the university on an as-needed basis, keeping the research production high and the government's overhead low. Both are principles of cost-effectiveness planning, and both mean increased involvement, which is certainly consistent with the current political views of federalism.

It is possible to consider a great deal more. It is possible to consider ways to fine-tune our internal university practices regarding the selection, rewarding, and promotion of faculty; and to consider the relationships on our campuses between persons involved in the agricultural experiment stations and those on the outside.

It is possible to do all of that, but it seems to me appropriate to ask ourselves questions such as those I have asked: What are some of the major issues within our grasp that we, today, can begin to deal with that will make a difference in our lives soon? I suggested three. There may be more.

DISCUSSION

Q. Dr. Hullar, would you care to give some economic evaluation of the impact of Proposition 65 on California agriculture?

A. Let me first describe Proposition 65. It is one of the innovations California has given to the national life. We have the initiative process in California. It is probably occurring in other states, as well. A proposition can be put on the ballot by obtaining about half a million signatures.

Proposition 65, in its simplest form, says there shall be no discharge into the environment of any material that produces cancer or is believed to produce cancer. The agricultural community believed that the proposition would have a devastating effect on California agriculture. I believe it is fair to say that it will cause significant perturbation. I think it is also fair to say that the passage of that act did two things: first, it slowed down all the other activities in California for dealing with toxic wastes in the environment. Not much attention is being given to those issues right now, and California, like other states, has significant problems.

Second, it has focused our attention on what risk is, how we assess and manage risk, and what acceptable risk is. I think that by the time the lawsuits have been settled and various people have spoken their piece on what constitutes a real intrusion into the environment by presumed carcinogenic materials and what acceptable risks are, it will have far less impact than we might believe at the present time. But it will have a perturbational and a psychological and emotional effect at the present time, and it is not going to bring homogeneity into a society—in this case the population of California—that is badly needed if we are to deal with problems such as toxics in the environment.

Q. Dr. Hullar, this is a follow-up on the previous question in more general terms. The land-grant system—some land-grant institutions more than others—has been criticized for not becoming involved in research on social and economic problems. Do you see any change in this in the future, particularly now that you have an agricultural economist in charge of agricultural research in California?

A. I think the criticism is probably justified. I do think that both Cornell and the University of California have begun to address that issue. The work of Bob Kalter and his colleagues on some of the economic implications of growth hormones has been mentioned, and, of course, in California we have the California Rural Legal Assistance suits regarding the mechanical tomato harvester, although that is really not a suit so much against the tomato harvester as it is against the general situation.

I do think our agricultural research system is changing. Unfortunately, I believe we are changing upon the inducement or the pressure of others, rather than through major initiatives of our own. That means that others are setting our agenda. My estimate is that change is occurring with the involvement of too few scientists, and that is because there is too little support, either from our campuses, themselves, or national agencies for funding. But I do think we are changing.

One of the reasons I put economics and other social sciences such as sociology on my list of competitive research grant categories is because I believe we have to increase research in those areas. We have to ask in advance what factors relate to the impacts. That is not to say, however, that we should ever let ourselves get into the situation of agreeing that we need social impact statements before research is done. And for those of you who are not following the CRLA suit in California, the issue in that suit is to require that the University of California conduct social impact statements before beginning research. That, I believe, is not only inimical to research but impossible.

Q. Ted, I had the same question you just answered. As you work with farm families and see the consequences of technology and the disruption to these families, shouldn't that issue be more properly addressed?

A. I would agree. I believe a major challenge in our agricultural experiment station work and in related work is to give increasing attention to the system in which we are functioning. For example, if we do something in northern New York, one looks at the entire system, rather than simply some part of the botanical world. And I believe that is a major reason why I would include ecological work in general, and also work related particularly to agriculture, such as managed ecosystems, because it helps us with our thinking about broader systems.

As many of us know who were here at Cornell several years ago, we tried to involve ourselves in the agriculture of Long Island, trying to think in systems terms about the alternatives for solving the Colorado potato beetle problem. It took us a long time to work through that because we had not yet accustomed ourselves to working in systems. That is another challenge for us.

I

The Role of Agricultural Research in the World Economy

G. Edward Schuh, Director

Agricultural and Rural Development, The World Bank

We approach the end of the twentieth century with a global agriculture that is in serious disarray and grossly out of balance. An important share of the world's food and agricultural output is produced in the wrong place, and the world's agricultural resources are used in a very inefficient manner. The low-income countries often use their treasure to import food that could be produced more cheaply at home, and developed countries use their treasure to subsidize the export of excess commodities that are produced at a very high cost.

Protectionism and distortions to trade in international commerce are widespread, and international political conflicts dot the landscape. The United States frequently finds itself hitting its friends in the back with export subsidies, while at the same time providing those subsidies to countries most people would judge to be our enemies.

This disarray and disequilibrium are in part a consequence of our global economic integration having far outpaced our political and institutional integration. The international system is made up of nation-states, many, if not most of which have strong mercantilist tendencies. Efforts to strengthen national political and institutional arrangements proceed apace, and less and less attention is given to strengthening international systems and institutional arrangements. National governments seek to gain an advantage at the expense of the rest of the world, and international cooperation has declined as an important motivating force.

In this complicated and confusing setting we also have a very unevenly distributed capacity for agricultural research. The developed, industrialized countries tend to have highly developed agricultural research capabilities, yet the developing countries—where the bulk of the world's population is located—have poorly developed and, in many cases, virtually nonexistent research systems.

An important international agricultural research system has emerged on the international scene, usually referred to as the Consultative Group for International Agricultural Research, or CGIAR. This system is rapidly approaching maturity in the sense that it is producing a small but steady flow of new production technology for the tropical food-producing countries. At the same time that system is coming onstream, many developing countries are beginning to see the importance of agricultural research and are taking significant strides to develop their national research capability. This list is by now fairly long, including Brazil, India, Indonesia, Philippines, and other countries.

We have learned a great deal about agricultural research over the last twenty-five or thirty years, largely as a consequence of scholarly research by people such as Vernon Ruttan. We have learned that the rate of return to society from investments in agricultural research is quite high, often on the order of 70 to 100 percent, and much higher than on other investments designed to promote economic growth and development.

We have also learned that much of the new production technology generated by agricultural research tends to be highly location-specific. Its global transferability tends to be fairly limited. Local research capability is thus needed on a global scale if the global economy is to benefit from the fruits of science and technology applied to agriculture.

As we look to the years ahead, we can expect to see the evolution of a global system of agricultural research. National agricultural research systems will be greatly strengthened as governments in developing countries see the payoff from investing in research and as they recognize that their potential for adapting new technology from abroad is limited. Associated with this trend will be major gains in general and technical education in the developing countries, with the result that the disparity in science and technology capability between the developed and developing countries will narrow.

Finally, we can expect the global economic system to become increasingly more integrated in the decades ahead. The integration that has occurred in the past forty years is rooted in technological developments in the transportation and communication sectors. The geographic spread of this technology can be expected to accelerate in the future, for the potential gains from this technology are enormous. At the same time, we can expect international trade to proceed at a rapid pace, despite our current conflicts, simply because the gains from international trade are so great.

With that background, let me now make five propositions as we look to the future. First, a major share of the increase in agricultural output in the decades ahead will be based on science and technology. Two imperatives will guide this trend. The first is that the area around the world in which agricultural output can be expanded by simply adding more land to production is declining rapidly. The easily settled lands have, for the most part, already been brought into production. The costs of settling new lands are rising, and increasingly more land has been put in production that should not be. New technology will ease some of these constraints, but at the same time, severe erosion and a decline in underground water supplies will cause other areas to go out of production or to be cultivated on a less intensive basis.

The second imperative driving this trend to increased dependence on science and technology is the evidence that investments in agricultural research have a very high rate of return to society. This evidence indicates that new production technology is a cheap source of economic growth, as policy makers in developing countries increasingly recognize. The high cost of infrastructure to bring land into production as the frontier moves farther and farther away from urban centers is also becoming increasingly obvious.

In addition, countries that take advantage of the international capital market to finance their economic development need to increase their exports to generate the foreign exchange needed to service their debts and to finance their growth more generally. Investments in agricultural research and the new technology it produces are the key to raising resource productivity and thus to gaining a comparative advantage in international markets. Moreover, raising resource productivity in agriculture is probably the only way these countries can offset the effects of declines in external trade as these terms of trade shift against the low-income countries. As we look at the international scene we see many reasons why we can expect to see this capability for agricultural research develop fairly rapidly in the low-income countries.

My second proposition is that in the same way as above, an ever larger share of the increase in income in the developing countries will come from agricultural research, or new production technology. Unfortunately, the important role that agricultural research plays in generating new and cheap sources of income is not sufficiently recognized. Instead, we tend to think of this new technology only as a source of production increases. This general tendency to misperceive the contributions of new technology to economic growth contributes to misguided policies and misguided political objectives, not the least of which is among U.S. agricultural interests.

On the policy side, the emphasis on production has seduced many countries into misguided goals of food self-sufficiency, while at the same time causing them to underinvest in research for their potentially important cash crop and export sectors. As an example of misguided political objectives, the pressures of U.S. farmers for the U.S. Agency for International Development and international agencies such as the World Bank to withdraw from helping to build research capability in the developing countries is equally stark. By failing to see the income-generating potential of new technology, these interest groups tend to see only the supply effects of agricultural modernization and fail to see the significant increases in demand for agricultural output that come with the income effects of that modernization. A parallel blind spot is their failure to see that future markets are likely to be predominantly in the developing countries and that they have a vested interest in the growth and development of those countries if those markets are to become a reality.

There are a number of fairly simple and well-accepted propositions behind my analysis in this case. First, the bulk of the resources in low-income countries is in agriculture, and these resources are characterized by very low productivity. Second, raising the productivity of these resources is the key to raising per capita incomes in these countries. Third, the benefits of agricultural modernization are widely diffused in the economy and not limited to agriculture. Fourth, these benefits tend to be reflected in lower prices to consumers and increased foreign exchange earnings, and that is why they are so widely diffuse. Fifth, the income elasticity of demand for agricultural output tends to be fairly high at low levels of per capita income.

Finally, the high income elasticity means that the demand for agricultural output can increase even faster than the supply of output when agriculture is modernized.

The bottom line is that countries and farmers in the industrialized world have a vested interest in the growth and development of the low-income countries. In particular, they have a vested interest in the modernization of the agriculture in these countries.

My third proposition is that comparative advantage on the international scene can be expected to change dramatically in the decades ahead. Comparative advantage is increasingly rooted in a country's endowment of human capital and less and less in its natural endowment of land and labor. Countries that invest in the development of new technology and in the education of their labor force can expect to gain a competitive edge on their trading partners. The important point is that more and more countries are recognizing this and responding accordingly.

To understand the forces at work, it is important to recognize that industrial technology is more widely transferable geographically than is agricultural technology. The key issue on the industrial side is the need to increase the level of general educational attainment. Most developing countries are making rapid strides in this area, and thus we see the manufacturing sector spreading rapidly throughout the developing countries. This is perhaps best exemplified by the newly industrialized countries, the so-called NICs, which include South Korea, Hong Kong, Singapore, Taiwan, Brazil, and Mexico. All these countries have pulled themselves up by their bootstraps in a fairly short period of time by adopting industrial technology from international sources.

New technology in agriculture, in contrast, depends on the development of local agricultural research capability. But that capability is building and we can expect it to come on at a faster rate in the future, aided and abetted by the international system now in place. It is difficult to foresee how these shifts in comparative advantage will work themselves out. The main point is that we can expect to see major shifts in trade patterns in the decades ahead, just as we have seen major shifts in the past two decades. We thus need to keep our eyes on the future and not on the past.

My fourth proposition is that international trade in food and agricultural commodities will grow in the future and at a fairly rapid rate. I realize that I stand almost alone on this issue, but my conviction is based on several factors. First, the slump in international trade in the first half of the 1980s was rooted in a slackening in international demand, not in a decline in international specialization. What is amazing is that trade, even in agricultural commodities, has held up as well as it has. The global economy has experienced a severe liquidity squeeze as policy makers have disinflated from the global boom and inflation of the 1970s. As the international economy recovers, and I believe it will, we can expect trade to recover, as well. And trade is already once again growing faster than world GNP.

Second, despite the popularity of self-sufficiency rhetoric, the forces driving international specialization are very powerful. The emergence of a large, well-integrated international capital market is chief among these forces. If countries are to take advantage of this market, and there is every incentive for them to do so, then they have to be willing to trade as well because only through trade can they service that debt. And despite the current resurgence of protectionism, the benefits of trade are there for all to see. We can thus expect to see that trade grow, driven in part by the rapid shifts in comparative advantage that I mentioned above.

Finally, an international agriculture increasingly rooted in science and technology will be an increasingly specialized agriculture. The reasons are obvious, although much of the accepted wisdom has it that the spread of technology will make everybody self-sufficient. I rest my case on the proposition that new production technology tends to have a greater payoff in parts of the world that have a strong agricultural endowment than in parts of the world that are less well endowed. The endowment I refer to, of course, includes the soil, the length of the growing season, and the climate generally.

I believe I can make my point by contrasting two regions of the world. The first is the Indo-Gangetic Plain in India, which has virtually a 365-day-a-year growing season, fertile soils, and abundant supplies of groundwater that can be reached at thirty-five to fifty feet of depth. When improved varieties and modern inputs are introduced into this area, not only is the payoff great, but it can be sustained over a long period of time because of the underlying potential. Contrast this situation with the semiarid northeast of Brazil. The soils are poor, the weather is dry and very unstable, and irrigation possibilities are limited. New production technology can make improvements, but the overall environment puts a limit on what can be done and on how far the process goes. And that part of the world happens to have 30 million very poor people.

None of this is to argue that new production technology cannot ease the constraints to expansion of output in areas such as the northeast of Brazil. It is to argue that new production technology will inevitably have a higher payoff in some parts of the world than in others and thus will tend to give those fortunate areas a comparative advantage in agriculture compared with other parts of the world.

My fifth and final proposition is that social and economic disadjustments and dislocations will be severe as new agricultural technology spreads worldwide. The shifts in comparative advantage I have identified above will require major reallocations of resources within national economies and implicitly on the global scene as commodity mixes change. Unfortunately, many of the world's poor are located in areas that may not have a longer-term comparative advantage in agriculture. Moreover, outmigration from agriculture typically requires geographic migration, with the result that intersectoral labor markets are not as efficient as they might be in bringing about the needed adjustment.

In summary, the spread of new production technology on a global scale—and the forces driving this spread are, indeed, great—can be expected to lead to major sectoral and geographical shifts in employment, in widening income differentials within national economies on the international scene, and in strong pressures for geographic migration of labor. Moreover, I suspect that increasingly these migratory streams of labor will spill across national boundaries, creating international political problems. The U.S. experience in that regard may be instructive.

What does this all mean for agricultural research? First, in an increasingly interdependent international economy, with rapid shifts in comparative advantage the order of the day, biological and physical research in the United States and other countries will increasingly have to be rooted in knowledge about agriculture in other parts of the world and in technological developments taking place elsewhere. Research designed to generate and sustain a comparative advantage in this country will have to be rooted in a global, not a national, perspective. We are currently poorly equipped to develop our agricultural research strategies in this larger context, in large part because we simply do not have the knowledge base.

Second, and this follows from the above, we need to commit an increasing share of our agricultural research resources to understanding developments on the international scene and to understanding how the international system works. Unfortunately, we still tend to think of the international economy as a collection of essentially closed national economies tied together with a little bit of trade. In fact, however, the global international economy is increasingly well integrated and with an international capital market that is far more important as the means of linkage than is trade. Total international financial flows in recent years have been running on the order of $42 trillion per year, and international trade flows were on the order of $2 trillion per year. If you want to know what is driving the international economy, look to the financial markets and not to the trade side.

We need to understand how this global economy works if we are to find our way in it and if we are to sustain our wealth, our per capita incomes, and our ability to influence the course of events in the international community.

Finally, as we look to the future, we need to give a great deal more attention to designing the institutional arrangements for the world that is emerging before us. At the national level we need to rethink how we finance and manage our agricultural research system, how we develop the knowledge base to keep our research effort a major contributor to economic growth, and how we deal with the large shocks that can be expected from the international economy. We need to design international rules and codes that will facilitate the international division of labor that can do so much to promote economic development worldwide. We also need to find better and more efficient means of bringing about international adjustments so that political disturbances do not break down the system. And finally, we need to find ways of international cooperation so that the benefits of growth development and new knowledge are widely shared, both among ourselves and with others.

As we look to the future, new production technology for agriculture will be one of the most powerful forces for economic, political, and social change on the international scene. Our ability to cope with these changes will largely determine how well both we and the rest of the world benefit from the new technology. If we continue to turn inward, as we have in recent years, concerned mostly with domestic problems, we can expect to continue to lose our place in the world. We have no alternative to taking a global perspective to what we do and to design both our research program and our institutional arrangements with that global perspective in mind. The next hundred years promise to be vastly different than the last hundred years. Our challenges are great, indeed.

DISCUSSION

Q. Dr. Schuh, you indicated that technology would act as an amplifier in boosting productivity, but you did not mention that this technology will require the use of large quantities of natural resources. We have to strengthen these resources. Can you respond to that?

A. Well, my basic point of view is that science and technology can substitute up to a point for natural resources and that in a relative sense a larger and larger share of the increase in output in the future will come from investments in agricultural research or productivity change. When you look at this cross-sectionally, or globally, however, it is pretty clear in my judgment that the well-endowed countries, or well-endowed areas, have the best of it in reference to new production technology. One has only to compare parts of Kentucky and Tennessee with Iowa, Indiana, and Illinois to see, not only where the immediate impact of the production technology is, but its sustainability over a long period of time.

I recently returned from India, and I was impressed by this same fact there, where large areas of the country consist of dryland agriculture. There is not water available for irrigation in most of those parts of India, so some measures can be taken about soil conservation and water conservation, and improved varieties can be developed. But the potential increase from improved varieties is ultimately going to be constrained by the weather—by the rainfall. But when that region is compared with the Indo-Gangetic Plain, where it is possible to pump up almost unlimited quantities of water, the faster the yield potential of the plants can be improved and fertilizer can be substituted for the standard qualities of the land, the more can be done. Over a period of time, I would expect the production technology to augment these disparities. That does not necessarily mean that it augments disparities in per capita income. That, of course, will depend upon how well the labor adjustment problem is managed.

Q. A substantial number of graduate students go through Ph.D. programs here who have strong interests in international agriculture. I would consider them well-trained and highly motivated, and many of them get some foreign experience before they finish up, and yet many of these people have been frustrated in trying to find opportunities to help with the problems you have been talking about. Now, the opportunities seem to be largely for young volunteers or mid-career people. Do you see any more chance of opportunities evolving, or should we stop encouraging people with these interests to get training?

A. No, I certainly would not want to discourage people from working in this area. I would like to make a couple of points about this, though. If you think to the future of our students coming out of American universities, they are going either to work abroad themselves, to work for a company that has a strong international involvement, or to work for a company that has a strong competitor from another country. So this knowledge base on the rest of the world is terribly important and desperately needed in this society. If anything, we are tremendously underinvesting in it. Now, your point is that the market does not respond very well for these people, at least in the beginning. I think some changes are going on that will help a great deal. I think it is becoming increasingly recognized in developing countries that if they really want to close the gap between the developed countries and the developing countries, they have to be more willing to accept capable people from other countries.

I think also that this country has a great vested interest in developing these relationships with other countries. We ought to be investing a great deal more in developing such relationships, and we ought not to be doing it with the idea that we are going to save the world from itself. It is in our own best interests; and if we had collaborative relationships and were doing the research on the rest of the world that I think we ought to be doing, there would be many job opportunities for these people. So I think a lot of this is directly in our own hands; but I think the picture looks a little bit better than it did five or ten years ago.

Q. You were talking about the integration of the global economy, and much of your presentation seemed to be a reeducation, perhaps, of science and technology; and I feel that science and technology should be looked at critically, as well as positively. I think there are positive and negative dimensions to it. But in thinking about increased productivity, especially in less developed countries, what about the other dimensions, such as social agents and land reform? In the Philippines, for example, the International Rice Institute has been there for a long time, and there have been gains; but ultimately what I think will make a big difference there is realistic land reform, as is true with most Latin American countries. I wondered if you could say a few words about the social relations as well as the science and technological relations.

A. In the case of land reform in the Philippines, I think politically land reform of some kind is necessary. The World Bank intends to participate actively in that. What worries me is that land reforms can be very disruptive in the short term. The Philippines does not have much of a margin to live with now, so that if it experiences a 20 to 25 percent reduction in food supply while it goes through this process, it could be very harmful and create a lot of other political pressures.

The other concern I have is that the Philippines might get locked into a pattern of landholdings such as occurred in Mexico and in Japan. One of the problems in getting any change in agricultural trade policy in Japan is that it is locked into very small farms. The economy has long since changed and those farms are no longer very relevant, but they are a very important political factor. In the case of Mexico, land reform has locked them into condemning people to misery, because the only way they can hang onto that little plot of land is to stay there and continue to tend it.

In general I would argue that there is a need for redistributing assets, such as land. Second, I would argue that redistributing human capital, by making human capital more widely available, probably has a stronger, longer-term effect. And third, I would say that combining the distribution of assets with the investment in new technology probably at least marks a beginning at offsetting the short-term consequences of such redistribution.

Agricultural Research: The Role of New Technology

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In our modern world the rate of information growth and technology change is accelerating rapidly. A spokesperson from the Commerce Department recently indicated that we will generate as much information between now and the end of the century as we have generated up to now. If this projection is anywhere near right, it sensitizes us to prepare for major change. We will need to alter our tactics and strategies to compete, whether our endeavors are in agricultural research and development or in any aspect of agriculture or other business.

Agriculture must change. Technology will, in part, cause this change. Some suggest that we may elect not to implement technology, but that is not an option if we are going to be competitive. If we do not implement technology that will increase our production efficiency, it will be implemented elsewhere in the world, thereby decreasing our competitive advantage.

Changes in All Agricultural Sectors

Changes are occurring in all sectors of the food and agricultural system—technology, farming, the agribusiness input industry, the food processing industry, consumers, and society. In technology we have relied heavily on chemical-based science and engineering. Biology and information-based technologies will become of increasing importance. The chemical and engineering technologies will be of decreasing importance. Technologies based on molecular and cellular biology will supplement organismal ones such as plant and animal breeding. Along with molecular, cellular, and organismal biology, ecosystems biology must be addressed and strengthened so that it can play a significant role.

Another major trend is occurring in biology. Biology has been and still is basically an experimental science. One may generate a hypothesis, but the probability that it will be validated in the laboratory is much less than 100 percent. I project that over the next few decades biology will move from a science dominated by laboratory experimentation to a science dominated by theory. A major proportion of the effort of future biologists will be used to generate "paper end points" from the huge base of molecular information that will become available in the laboratory. Experimental testing will be a minor portion of the total effort.

A major effort to sequence the human gene—some three or so billion pieces of information—is being planned. The Japanese have developed systems capable of sequencing a million bases a day. Genome sequences will become available in the next decade or so for a human, one or more animals, and one or more plants. We know the rules to project the linear sequence of the gene product, the protein. We do not yet know the rules to fold that protein up into its three-dimensional structure, but that will be learned. In time we may be able to project function based on the structure. Trends such as these will move biology from a mainly laboratory, experimental science to a mainly theoretical science sometime in the early 2000s.

There will be large amounts of information to be stored and processed, and systems will be needed to handle this information. This area holds major challenges and opportunities.

There is a strong and growing momentum in accomplishments in biology-based science and technology. We need only review the 1980s to document this statement. This momentum supports the expectation for major new products and processes in the 1990s and beyond. Nevertheless, we are very early in the era of products and processes derived from molecular and cellular-based biology. In fact, we are still mainly at the toolmaking stage. The first new products and processes will represent alternatives for those that now exist for crop agriculture. They will be useful but not revolutionary, for the most part. They are expected to reduce the cost of production such as for agrichemicals. The most exciting products will provide new capabilities such as self-nitrogen-fertilizing crops or higher value-in-use crops, either for use as foods or as products for major nonfood markets. These products of biology-based science will have major impacts on all sectors of agriculture: farming, agribusiness input, the food processing industry, consumers, society, research and development, and the international scene.

Changes in areas other than technology in the food and agricultural sectors are also occurring. Major changes are in process in the agribusiness input industries. Over the last few years the agrichemical, fertilizer, and equipment industries have been in a consolidation phase. Their technology is maturing—going stale to some extent—and the industries are being forced to consolidate. Two years ago there were about forty agrichemical companies worldwide. Now there are fewer than thirty, and by the turn of the century five or eight may remain. It is too early to identify the survivors in the agrichemical industry. Another example is fertilizer. There has been no significant major technology advance in fertilizers in the last twenty-five years. Fertilizers have become commodities.

The genetic-based industries in crop production are the centers of expected growth based on the biological sciences. Established and entrepreneurial companies are investing in these areas. One trend may be of major concern to the U.S. agribusiness input industry. European energy and chemical companies are acquiring U.S. seed companies, but U.S. energy and chemical companies are not pursuing this approach. Will the future major agribusiness input industry be controlled outside the United States?

Food processing is also changing. Consolidation in the food processing area has occurred in recent years. Food processing is the energy-intensive part of the agricultural food system. Biology-based science should decrease the need for processing by improving the value of the crop for its end use.

Consumers and society are also changing. At a recent meeting of the National Research Council Board on Agriculture a common comment was the concern by consumers and producers about the healthfulness of food. The red meat industry and others, because of decreasing consumer purchases, are becoming concerned about the healthfulness of their food—the content of fat, calories, cholesterol, and chemical residues. Safeway Supermarkets will not sell apples sprayed with a certain agrichemical, Alar; the Heinz Company will not purchase crops for baby foods if chemicals with suggested oncogenicity have been used during crop production.

Society is becoming unwilling to continue to subsidize agriculture. Society is concerned about the environment. A recent survey indicated that the environment is one of the areas in which society is unwilling to accept compromise. Social and ethical concerns will have to be more closely integrated into our agricultural system even at the research level.

Government policy is changing. Patenting of living compositions in the United States first occurred in 1980 with the Chakrabarty case. A seed was issued a patent a couple of years ago with the Hibbard case. In recent weeks the Trademark and Patent Office announced that a patent would be issued for an animal in the Allen case for oysters. Clearly, an increasing proprietariness is being associated with biological entities.

Government policy is developing for regulation of biology-based products and processes. These products from molecular and possibly cellular technologies will be subjected to greater safety requirements than have traditional products by organismal technologies.

Career choices are also changing. In the foreseeable future biological sciences are going to attract the brightest young people in the same way that physics, chemistry, and engineering did before the 1980s. Another major change occurred in the 1970s. Leading biological scientists found application work to be an honorable endeavor, which was not the case before the 1970s. Both of the above trends are highly positive for agricultural technology. Agriculture is enriched because a large percentage of its researchers received their training in basic sciences outside of agriculture. I expect agriculture to attract a wealth of outstanding researchers in this and the next decade; we may obtain some of the most creative individuals.

Biobased Science and Technology

These new technologies—the molecular and cellular ones—based on biosciences are very young. They are early in the technology generation curve and are best viewed as in the toolmaking stage. Products and processes from such technologies are just beginning to appear in the marketplace for the health care industry, and one would expect that those for agriculture will follow in the 1990s.

Diagnostics, vaccines, and therapeutics, such as insulin and growth hormone, the great expectation of tissue plasminogen activator for early treatment of heart attack, the potential of colony-stimulating factor, erythropoietin, and interleukins for AIDS and cancer document the reality of these products for health care. These biologically based agents are moving through the regulatory clearance system at two to three times the rate of traditional synthetic pharmaceuticals.

An increasingly complex set of biologically based products and processes will be available to the consumer, and information will be essential for management to select optimally from this sophisticated, complex set of options for particular uses. The same will still be true for agriculture. Consequently, managing these products is going to become more demanding. Furthermore, product lives are going to be drastically shortened as the rate of technology generation accelerates and new products appear at an accelerated rate. Management is going to have to change dramatically to compete in such a dynamic technical-product-market environment.

With molecular biology, we can direct changes in contrast to the random changes that are, for the most part, the product of organismal biology. In general terms, we can add genetic capabilities, we can delete them, we can modify them, we can amplify them, we can decrease them, we can synthesize them, and we can regulate them. In sum, we can design genetic capabilities for the result that we want in managed ecosystems. We have the capability to measure and trace genes in most precise ways. We have, for the first time, extremely potent capabilities for directed genetic change.

There will be a sequence of products for agriculture. Microbial products such as bovine and porcine growth hormone may be such early products. Others are new or improved vaccines, diagnostics, and therapeutics from microbes. The next ones will be transgenic products in which foreign genes are incorporated within plants or animals to make them healthier, more efficient, or higher quality for end use. In the more distant future, chemicals will be designed to regulate genes so that they function at the time of need. Genes may well be designed and products may have advantages over those of natural genes. In the crop area, agrichemicals, fertilizers, seed, and microbes will eventually fuse in many cases into a single input, seed. This development should decrease costs of production.

There have been major scientific accomplishments in the 1980s. Microbes can make animal lymphocytes to perturb the immune system beneficially, as well as hormones, proteins, and enzymes. Synthetic vaccines have been made, for example, for foot-and-mouth disease. Transgenic animals, at least at the laboratory level, have been produced—super rodents—and this technology is being applied to domestic animals. In the crop area, ice minus bacteria has been tested for decrease of frost damage on strawberries and potatoes. The press provided a disservice to this last case by giving the impression that these low-risk experiments were highly dangerous.

We can improve biological nitrogen fixation by use of microorganisms. Less than three years ago we could not put foreign genes into plants and have them work. That was accomplished initially with single genes. Now we are using multiple genes and making them work coordinately with each other to produce products that have to interact to get a positive readout. We project that in the 1990s self-nitrogen-fertilizing plants will be developed.

Chemical-, disease-, and insect-resistant plants have been made. Herbicide-resistant crops may enable greater options for crop rotation, improved weed control, and decreased cost of weed control. Atrazine-resistant tobacco has been field tested. Tobacco mosaic and related virus protections have been incorporated in plants. Insect resistance using Bacillus thuringiensis toxin in plants has progressed to early field tests. Within recent months, it has been reported that cell-culture techniques can be used to regenerate cereals—a major forward step.

There are examples in the food processing area. Industrial yeasts are key in food and beverage making. Those yeasts have been genetically engineered so that now light beer can be made in a single step as opposed to the multiple-step commercial process. Site-specific mutagenesis, the ability to change genes in a directed and specific way to make them function as desired, has been accomplished in several systems. Computer modeling is being used to design proteins for increased effectiveness. These examples occurred in only the first seven years of the 1980s.

Out of this scientific-technology evolution in molecular and cellular biology, we can begin to identify potential products. There are always hazards to product identification in areas of new technology. For example, no one in the 1930s recognized that synthetic fibers or polymers like nylon would mainly be used for carpets. Therefore, one projects products with substantial trepidation, recognizing that we have a powerful science but what the resulting products will be is problematic.

The initial products will be alternates to or improvements of existing products, such as substitutes for some agrichemicals for plant protection. Maybe a major product by the turn of the century will be self-nitrogen-fertilizing crops. Nitrogen fertilizers annually cost $20 billion. The plants are capital-intensive. They require large amounts of fossil energy at high cost, and a third of the fossil energy that goes into crop production up to the farm gate is for the fossil energy used to make nitrogen fertilizer. In addition, transportation of fertilizer nitrogen is expensive because of long distances from plant to farm, and multiple applications are often required. Fertilizer nitrogen is inefficiently used—only about 50 percent—and unused material often contaminates streams and groundwater.

The alternate biobased system is biological nitrogen fixation. All seventeen genes are known. Their products take nitrogen out of the air and convert it to usable ammonia fertilizer. The genes occur in only a few selected microbes. I predict that by sometime in the early

1990s these genes will be in transgenic plants, producing a product that converts nitrogen into ammonia so that the plants can, to a degree, be self-nitrogen-fertilized. How far have we gone in this complex technology? We have crossed three of what I call the five key technology hurdles in the last three or four years. Based on recent progress, self-nitrogen-fertilizing crops may be a commercial potential by the late 1990s. We must remember, however, that predicting products several years into the future is hazardous.

Let's look at higher value-in-use foods. Canadians used organismal biology in converting rapeseed to canola. This technical accomplishment created a major new crop for Canada, and canola is now the major edible oil in that country. It has the status of generally regarded as safe (GRAS) in the United States. It has certain characteristics that may make it more attractive than soybean as a food oil, and it will be interesting to see how soybean and canola compete in the years ahead. With molecular technology almost any oil crop can be made to produce any kind of oil that is desired. For example, soybean, canola, or sunflower could be made to produce the equivalent of palm oil or jojoba oil if that is what the customer wants. The same is true with respect to protein, starch, flavor, color, appearance, and other characteristics. The ability to change the quality of a crop is an opportunity that is unique to biology-based technology and not to chemotechnology or engineering.

Customers may want animal products with altered composition such as low-fat pork. Researchers usually do not consider customers' needs. We must recognize and respond to them. Failure to do so is one reason why we are losing out in competition in the international marketplace. The customer is the ultimate decision maker.

Crops for the nonfood market represent a major opportunity. The move by many countries from inadequacy to self-sufficiency suggests that the historic breadbaskets of the world, the United States, Canada, and Australia, may decline in importance in the future. Accordingly, we need to look at nonfood markets for crops that can be grown on our excess land. One of the keys for major nonfood markets is to improve solar energy conversion. Solar energy conversion is less than 1 percent for most of our crop plants, and if we are going to think of major potential uses in the nonfood market, that number has to be significantly increased.

Impacts

What might be the future impact of these biology-based technologies on the various sectors of food and agriculture? Production efficiency will be improved so that U.S. commodities will be competitive in world markets. In the commodity business, you have to be the low-cost producer if you are to be successful without subsidies. Farmers will have specialized crops with increased value-in-use so as to command higher prices. Farmers will also produce alternate crops for the nonfood market. Cropping systems will be close to environmentally neutral, or maybe environmentally restorative, in contrast to the products available up to this time that are based largely on chemotechnology. The agribusiness input industry will be given the opportunity for new high value-in-use proprietary products or processes that can be marketed both nationally and internationally. New jobs should be created to replace those that will be lost from existing maturing and consolidating industries.

There will be decreases in energy costs in the food processing industry. Specialized farm crops for specific uses in the food processing industry will cause vertical integration. The natural components such as natural flavors and colors in the food arena will increase. The consumer will continue to have an abundant supply of low-cost or lower-cost foods of higher quality and healthfulness. Domestic self-sufficiency will continue for those foods in which our costs are competitive. If our costs are not competitive, imports will replace domestic supply and we will be vulnerable to supply by a foreign source.

Summary

In agricultural research various skills—molecular, cellular, organismal, and ecosystem biology—will be integrated to focus on major agricultural problems and opportunities. We must restructure so as to minimize the barriers to both research productivity and training inherent in our current departmentally and discipline-based structure. Furthermore, we may need to integrate social and economic research with biological research and other needed skills such as those in physical and engineering areas. We will need to join our academic, government, and industrial components if we are to compete successfully in a world in which it will be increasingly difficult to remain competitive. Biology-based technologies will produce major changes during the second hundred years in all components of agriculture. It should be exciting for our descendants to celebrate the second centennial in 2087.

DISCUSSION

Q. Dr. Hardy, you have raised some very exciting possibilities, and you stress the importance of management and interdisciplinary approaches. My question is, What are the challenges and opportunities in training today's student at both the undergraduate and graduate levels to do the innovative management training communications that are going to be needed to explain what's going on in the scientific community to a suspicious, critical, and nonscientific public?

A. Clearly, we have to train students who will be comfortable with change and who will welcome change as opportunity. We have not done that in the past. We have trained students in disciplines, subdisciplines, and subsubdisciplines. In my earlier days at DuPont I observed many of these students. They often do well in their first assignment but are very poorly prepared to move to new areas as problems and opportunities change. How might we train individuals who will be comfortable with change, who will welcome change, and who will have experienced successful change during their training period? In a Ph.D. program a possible approach would be for students to spend two years in a major area, then to move to a separate and different discipline for a year so as to learn some of the capabilities of that discipline, and to return to their original discipline for the final year. In such a sequence, they would have the potential to bring new approaches to the problem they worked on in the first two years. Such a program would be challenging even for the best students, and if it were an option for them, it might prepare them for more successful careers. Undoubtedly there are many other ways to modify our highly traditional training procedures. It is important that students be trained in the fundamentals—math, chemistry, physics, and biology are the most important for a student to be successful. A graduate with such training then can move to those areas as they become popular and exciting and obtain the specialization as needed.

Retraining will become standard in government and industry. It will allow people to be useful contributors on a continuing basis. We haven't done that in the past. Many companies—DuPont, IBM, General Electric—have had to use early retirement incentives not because they had too many employees but because the employees were no longer competitive in their fields. In conclusion, if you are writing a recipe for competitiveness, the first item is competitive people.

Agriculture and Federal Science Policy

Alvin L. Young

Office of Science and Technology Policy

A century ago the leaders of this nation had a vision. That vision was the establishment of a national network of scientific research stations. Today that network consists of fifty-eight experiment stations and more than twelve thousand scientists and engineers. The efforts of this vast research system have had profound influence upon United States and world agriculture.

I think of four great scientific accomplishments of this nation during this past century:

- The invention of the telephone and the subsequent communication network
- The advent of the automobile and the airplane and their impact on the mobility of our society
- The discovery of the secrets of the atom and the changes it has brought to our lives
- The quest for space, the thrill of watching men on the moon, and the access to space that the space shuttle program has provided us

Each of these great accomplishments occurred in different generations. Many of us had an opportunity to see more than one in our lifetime. These are the science accomplishments that made newspaper headlines, but it was the accomplishments that did not make headlines that have allowed Americans to devote so much of their attention to other pursuits. I speak of the great changes that have occurred in agriculture in the past century. Let me suggest four important accomplishments, and again, these are my four:

- The founding of genetics and hence a scientific basis for breeding of agricultural plants and animals
- The mechanization of agriculture

- The understanding of mineral nutrition and the use of fertilizers
- The discovery and widespread application of organic pesticides for the control of pests.

Experiment stations have been great contributors to these scientific accomplishments during their century of operation. These discoveries have permitted a few to feed many. Our American farmers account for less than three-tenths of 1 percent of all the farmers in the world. Yet today each American farm worker produces enough food and fiber for himself and eighty others, more than one-third of whom live in some other part of the world. As a consequence of the success of the American farmer, Americans spend only slightly more than 16 percent of their income to purchase food, and the quality and diversity of that food are greater than ever before in the history of humankind. It is unfortunate that at a time when such production capabilities exist for the developed countries of the industrialized world the citizens of most less developed nations still spend at least half their income on food, and the quality and diversity are much less. I wish it were possible for all nations to acquire the tools, the crops, the fertilizers, and the pesticides that were developed in the Green Revolution so that those tools might provide a bountiful harvest for all people. Unfortunately, social, economic, and political factors often prohibit the adoption and application of new agronomic technology and the distribution of the yields. Thus the quest for peace and the efforts to eliminate starvation are linked.

The changes that are occurring in our nation and our world mean that we, like those of past generations, must build for future generations. Much of the credit for making our agricultural industry the most productive in the world must go to the agricultural programs of our land-grant universities. These universities, through their research and their education programs, provide the knowledge for progress. That knowledge is linked to agricultural producers through the technology-transfer programs of the Cooperative Extension Service. Thus scientific knowledge, dissemination of that knowledge, and human capital are keys to future success. Yet for agriculture, great challenges lie ahead in our search for new knowledge and in our ability to attract young men and women.

How do we sustain a national commitment to agricultural research? To blame economic failures in the farm sector on technology, and many do, would condemn us to a bleak future—for it is our investment in the new sciences such as biotechnology that will return our agricultural sector to a vital and healthy economic condition. The value of investing in future agricultural science and technology has not escaped the attention of other nations.

Our rate of investment in agricultural research has stagnated in the past fifteen years, but many other countries have substantially increased their agricultural research and development investments. In the past two decades, every region of the world (Western Europe, Eastern Europe, the Soviet Union, Latin America, Africa, Asia, and North America) has increased its agricultural expenditures. Some regions, for example, Western Europe and Asia, have increased their expenditures more than sixfold. During the same period the United States did not even double its investment. In fact, the increase in agricultural research expenditures was smallest for North America. Moreover, the total annual national expenditures for agricultural research for Western Europe exceeds that of U.S. federal and state expenditures.

The productivity gap between the United States and other countries' agricultures is closing. Whether we like it or not, we now find ourselves on a global technology treadmill that means we must keep investing to maintain productivity growth, to retain our predominant position relative to other agricultural exporting countries. The greatest challenge is to grow plants and raise animals that will be in demand in foreign markets not only because they are of high quality but also because they sell at a lower cost to the consumer because they cost less to produce. We must pay attention to increasing the quality of existing products and generating new foods and new fibers.

When I mentioned the great changes that have occurred in agriculture in the past century, I did not list biological-based technology, or biotechnology, because the biotechnology revolution has just begun. The tools are being developed. The coming generation will feel the full impact of that revolution. Biotechnology means a total change in the manner and the time frame in which we will produce food, fuel, fiber, and chemical feedstocks.

It is amazing to imagine the possibilities of plants genetically engineered to be resistant to insect pests and pathogens; crops resistant to herbicides; vaccines produced through biotechnology protecting animals against disease, primarily chronic problems, and recovering much of the $14 billion lost each year to diseases; and developing trees that will grow 50 percent faster, extending our forestry resources for improved market competition. Some have speculated that the biotechnology industry has the potential of accounting directly or indirectly for 70 percent of our gross national product in the future.

The biotechnology revolution is worldwide, and we started it. Many other countries recognize the opportunities, and even small nations are investing heavily, counting on it possibly for their economic survival. The question is whether the United States will maintain international leadership and continue to capture the markets or whether we will pay royalties to other countries that decide to make the investment and arrive first.

An even more fundamental question is whether the American agricultural research system is prepared to provide the scientific and technical talent and to produce the new knowledge we need to remain preeminent in an age of rapid technological change and intense competition. For those who can influence the direction of agricultural research, this is a crucial question. Both questions are crucial to our nation.

Knowledge is the most precious commodity in the world. Knowledge is gained through research; and in agriculture it depends on having the talent to conduct that research, having modern laboratories and greenhouses, and having access to field experiment stations. The agricultural scientific community must attract and train the men and women whose skills will be needed in such areas as molecular genetics, systems analysis, engineering, plant sciences, international marketing, animal health, human nutrition, and more.

The present revolution in science and technology is unprecedented in both scope and pace. Never before have virtually new scientific fields emerged so rapidly and in such numbers. Nor have we seen such close overlap in mutual dependencies between science and technology. Never before has teamwork between disciplines been so essential to sustaining the pace of research. The further development of science and technology requires the continuous generation of new knowledge and talent. Universities are the source of this talent, as well as the most fertile source of new knowledge and fundamental discovery. Talent and knowledge are the essential foundation for industry to meet the challenges of an increasingly competitive world. Our agricultural universities and our agricultural research systems remain unmatched in the world. But as we increase our reliance on them, we cannot take their strength and health for granted.

Recently, the White House Science Council released its report on the health of the universities and colleges of this country. A major theme throughout that report was the critical need for investment in research facilities and instrumentation on our campuses. The report pointed out that in the last fifteen years tremendous problems have arisen because we have failed to invest in the facilities and the instrumentation so crucial in this changing era of technology. We have begun programs in government to address those needs, but it will require many years of federal and state commitment before we have adequately rebuilt and updated our universities' research infrastructure. Companies like DuPont and Monsanto and many other large companies have undertaken major investments in research programs, simply because the university systems have not had the facilities and the instrumentation that are crucial to making new discoveries.

The science adviser to the president would say that the federal government has the commitment to provide for long-term, high-risk research. And the federal government can best do that in its universities and the federal laboratory system.

In the past few years there has been a tremendous drop (more than 30 percent) nationwide in the enrollment of students in agricultural and natural resource programs in colleges and universities. This means that fewer agriculturally trained researchers and teachers will be available in the future. We must halt this decline in enrollment. Clearly, technological changes are occurring at incredible speed. Computerized information systems are creating a revolution in the dissemination and analysis of research results that can be used in the management of farm operations and the marketing of farm products. Yet the most critical challenge is the development of our nation's human resources—our young men and women who will carry the burdens of our mistakes and the glories of our successes.

Biotechnology's opportunities depend upon basic knowledge of mechanisms in living systems. Biochemical dynamics within single cells and animals and plants must be understood in detail before we can fully exploit genetic engineering. The architecture of the genome and the principles of gene expression and regulation must be known to make biotechnology successful. We are now upon the threshold of elucidating the human genome—a fantastic science project, not only for this country but for the rest of the world. I have no doubt but that we will proceed with the elucidation of the human genome, and to do so will take tremendous resources. I do hope, however, that as we undertake commitments to developing the human genome we do not forget the importance of our plants and animals. These policy decisions rest not only with the federal government but with the entire science enterprise.

Research is the source of this knowledge, and it requires well-educated and well-trained scientists. In addition, there is an almost explosive need for new, extremely expensive instrumentation to replace or succeed current instrumentation that is old and wearing out.

The end goals in every aspect of genetic engineering and biotechnology research are products for commercial development. The future that I have outlined will not come cheaply. It must include a coordinated federal framework for research guidelines and regulation that speaks to the environmental release of genetically engineered organisms.

For the past three years the Office of Science and Technology Policy, the United States Department of Agriculture, the National Science Foundation, the Environmental Protection Agency, and the Food and Drug Administration have been helping to prepare for this biotechnology revolution. That proper guidelines are set is crucial; if we strap too tough a regulatory program in place, industry will go elsewhere to do its testing. Many foreign countries offer the opportunity for companies to come and do research that they may not be able to do in this country. We have to provide the guidelines within which industry can work and within which our people are assured that we are being responsible.

In addition to the efforts to establish appropriate agency guidelines for the conduct of research and testing, we propose to establish a program in biotechnology that will identify the most forward-looking research scientists and research programs and support the best. Fellowships, through the USDA and other agencies, have been and continue to be made available to identify and support the most promising science and biology graduates in this country, directing them into biotechnology in agriculture. Essential equipment and modifications of laboratory facilities will be supported in promising research institutions on the basis of merit and the potential of their programs. Finally, transfer of research results to the marketplace will be of high priority. These actions are just beginning.

This year we begin a new plant science initiative directed toward interdisciplinary research. It is no longer agricultural science but science for agriculture that we have to be concerned about. So we have asked the National Science Foundation and the Department of Energy to join with USDA in funding this new concept of interdisciplinary plant science centers established throughout the United States on our college campuses. This would be a competitive program directed at trying to solve the very difficult issues that are before us in plant science to capitalize on these new technologies for this country. Last year we invested only about $110 million on our campuses and put out about $4.5 billion on those college campuses. Of that, some \$2.4 billion are in biological sciences, yet less than 5 percent is in plant science. This administration is trying to channel more funds into critical areas.

It is obvious that to succeed as a nation we must marshal all of our resources in agriculture. Hence federal and state funding must be coordinated with the efforts of the private sector. The plant science centers will work only if the private sector works with us to create opportunities for our most innovative scientists from all sectors of society to work together in interdisciplinary research to solve the complex problems that face our agricultural enterprise.

It worries me that agriculture receives less than 2 percent of the federal research and development budget, a budget that runs to \$50 billion. The feeding and health of our citizens and the well-being of our society depend upon agriculture, and yet we put less than 2 percent of our research and development budget into it. The problem is that in a time of agricultural surplus, the public, the Congress, and the administration find it difficult to justify increases in agricultural research funding. Many policy makers believe that surplus comes about as a consequence of research. Yet the future of American agriculture will be shaped by biotechnology with the objectives of improved efficiency of production to increase competitiveness and the development of new products; U.S. agriculture is a strategic element in international trade; and other nations are increasing resources to improve agricultural production and efficiency.

National science and technology priorities are many. We have recently talked about a new supercollider in physics, a space station, and the human genome. But we must not forget agriculture. It is very difficult to impress on anyone in Washington the importance of increased funding for agricultural research. But we must. The constituency must help change that picture, and it is the constituency that must speak up.

One hundred years ago our forefathers enacted the Hatch Act of 1887. They did so knowing that the challenges were great, the opportunities unlimited. As it was then, it is today. Let us hope that in one hundred years a future generation will marvel at the contributions we were able to make. We must have funding, involvement, commitment, and dedication if agricultural research is to make the contributions that are so crucial in the next one hundred years.

DISCUSSION

Q. I'd like to ask a question on the subject of competitive research grants. There has been a major increase in agricultural science, about $40 million or so, because of specific biotechnology initiatives, but that does not seem to have been subsequently increased, and there does not seem to be much prospect of an increase in the future. In contrast, there are changes being made regularly in the National Science Foundation budget (this year, for example, I think there's under a 17 percent increase), and of course we all recognize that that increase is sensible. What do you see, given the current federal science policy, as the projection for increases in competitive grants, or even in formula support such as Hatch research funds in USDA and in other federal agencies?

A. I think as it currently stands, the chances are not very good. I'm being very honest. I see what's happening at the National Science Foundation, and wish we could do the same for agriculture. But the rhetoric involved in the National Science Foundation increase stresses preparing us for industrial competitiveness. Never was a word said about agriculture. And the messages that I have been receiving leave agriculture out. The recent increases in the budget were not reflected in USDA's competitive agriculture program. Neither the Congress nor the administration sees the need, and it goes back to my comment about the constituency having to bring that need up.

The focus on surplus is getting the most attention now. I use a little expression, "What is USDA today?" This is the heart of the problem. USDA today is $12 billion in food stamps and USDA is $11 billion in interest payments. Last year USDA was $27 billion in subsidies. And what was left? A couple of billion dollars for all the programs, including Dr. Jordan's Cooperative States Research Service, funded at $240 million.

We are so concerned about putting money into other pockets that we are not looking to the future for agricultural research. In agriculture we are keeping a maintenance program going, and that's what concerns me. So I am not very optimistic, unless the constituency makes a major effort in getting the commodities together and recognizing that we do not need a commodities-oriented program but plant science programs, animal science programs, and groundwater programs.

I

Social Implications of Agricultural Research

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How many times have we heard the phrase *two blades of grass* repeated over the years? Indeed, it was the title of a book describing the history of American agricultural research. Yet there is a certain irony in that the phrase was borrowed from Jonathan Swift, whose dislike for what we now call modern science was clear. The phrase appears when Gulliver is visiting Brobdingnag, and one of Swift's characters favorably compares someone who would make two blades of grass grow where one had grown before with "the whole race of politicians." Yet from this it is wrong to infer that Swift was sympathetic to science. In fact, later in the same work, Gulliver visits Laputa. The scientists there have been working on a system that will transform all of agriculture and manufacturing. Unfortunately, there are many details still to be worked out, and until those details are adjusted, the entire society is in a state of disarray.

It is easy for us to dismiss Swift's critique as merely a desire for the status quo. Yet it appears to me to go deeper than that. Indeed, Swift's was one of numerous "utopias" that emerged at that time. A more positive note was struck by Sir Francis Bacon, who, in *The New Atlantis,* forecast a world governed by the House of Salomon, a group of scientists organized into an association that bears a striking resemblance to the modern agricultural experiment station. Yet Bacon's utopia, like those of More and Campanella, has a strikingly authoritarian character. In it, scientists uncover truths about the natural world that they then dispense to the larger society as they see fit. Moreover, politics no longer exists in that world for it has been reduced to administration. And, certainly, democracy both as practiced today and in its idealized form, has no place in that world. In short, both Swift and Bacon provide us with what is still the ultimate conundrum of modern science: Can its utopian ideals be realized without its dystopian consequences? Can two blades of grass grow where one grew before, without nature taking her revenge? Can we remake the natural world according to our image without irreparably harming it? These are not trivial questions, for today we are faced with a series of dilemmas that will affect not only our generation but those yet to come. As Hans Jonas (1984) has eloquently put it, now that we can alter the very nature of nature, we must bear the burden of responsibility as never before.[1]

In an attempt tentatively to answer these questions, I shall first examine the context in which the original goals of the Hatch Act were formed. Then I look at the contemporary scene, focusing first on the world economy, then on the United States, and finally on U.S. agriculture and agricultural research. I conclude by proposing some new directions for the second century.

The World of 1887

In 1887 the world was about to become one. The steamship had conquered the oceans and the railroad the land. Wheat prices, only two or three decades earlier a local matter, had become uniform worldwide (Friedmann, 1978). Prices had been modified so as to reflect only differences in the distance between the vast wheat-growing areas and the consuming areas of Europe. Indeed, the United States, Russia, India, Argentina, Canada, and Australia were all in a race to see who could provide food for the growing European population. Whereas farmers of previous epochs had been sheltered from world prices for staple crops, now they had to face the full thrust of the world market. Public agricultural research was sought, for it was believed that it would help to meet the new international competition.

American elites were also concerned about what was perceived as the increasing turmoil in Europe. In contrast to the wars and civil unrest on the Continent, the United States appeared tranquil. Yet labor unrest in the cities and Populist demonstrations in the countryside were seen by some as harbingers of worse things to come. The development of public agricultural research was to help resolve those problems. By offering higher profits to farmers through increased production at lower per unit cost, and lower food prices to wage laborers in the city, civil unrest might be quelled or even avoided.

Public agricultural research was also to ensure a more prosperous farm sector. It was to help the thousands—indeed, millions—of new farmers deal with the new conditions encountered in the United

States. In particular, it was to develop the techniques that would permit farming in the newly opened arid lands of the West. It was also to ease the toil and drudgery of farming and reduce its risks.

When the Hatch Act was passed in 1887 it incorporated all these desires because it was "to aid in acquiring and diffusing among the people of the United States useful and practical information on subjects connected with agriculture, and to promote scientific investigation and experiment respecting the principles and applications of agricultural science" (Knoblauch et al., 1962:219).

These ideas were not limited to the United States. Nearly every nation of Europe, the European colonial empires, and Japan mounted a large-scale public research effort in the last decades of the nineteenth century. In 1900 the United States had fifty-one agricultural experiment stations; the British Empire, ninety-four; the French Empire, eighty-four; Russia seventy-two; and Japan, fifty-five (Busch and Sachs, 1981).

In short, as is true of all social change, the development of experiment stations was desired by different people for different reasons. Competing and even conflicting goals were concealed within them. This has not changed over the century of their existence. The current scene offers its own challenges and problems.

The Current Situation

The National and International Scene

The advent of rapid air transport, long-distance communications, and computers has changed the global economy over the last several decades. It is now possible to produce parts of a good in several countries, assemble them in another country, and sell them in still another. Capital markets and the markets for an increasing number of commodities are now worldwide. This has undermined the Treaty of Westphalia that established the system of nation-states as the guardians of national interest, and it has left fixed capital and workers more vulnerable than ever before. U.S. producers are now faced with worldwide competition for everything, and they are increasingly vulnerable as a result of the comparatively high wages paid here. Over the last few years wages of many have dropped precipitously. Owners of less mobile capital—including farmers but also owners of mines and other fixed investments—have found that they are unable to protect themselves.

At the same time, global debt has reached astronomical proportions. Many Third World nations that borrowed during periods of rapid economic growth are now finding that they cannot pay even the interest payments without forcing unbearable hardships on their people. Moreover, the bankers have been slow to face up to this fact. They still operate under the delusion that the huge debts of the 1970s will be paid off, even as restructuring goes on endlessly. One result of the debt is that it has boosted agricultural export production. Indeed, in nations with little in the way of industrial exports, it is not surprising that a crisis of this magnitude would encourage heavy subsidies to the production of agricultural commodities for export because that is the only way foreign exchange can be earned. Thus even a commodity whose price is as depressed as sugar is subsidized so as to earn foreign exchange for the Dominican Republic. This exported production, of course, increases the ferocity of competition with U.S. farmers.

All of this is happening at a time when an administration elected in part because of a concern with the federal debt has increased that debt by more than all the previous administrations put together. The root of the debt, of course, is that we have lived for more than thirty years with a wartime economy. One-third of federal spending maintains the war machine, and the annual worldwide military spending is approximately the equivalent of the worldwide debt. The debt blocks new government initiatives in many areas, including agricultural research. And what new research money is made available is concentrated very heavily on military "needs."

U.S. Agriculture

It will come as no surprise to anyone that U.S. agriculture is facing its most severe depression since the 1930s. In particular, the family-sized farms of the Midwest, whose owners went heavily in debt during the 1970s in response to rising land values and increasing world demand, have been failing at a disturbing rate. Indeed, unlike the farm crisis of the 1930s, which was spread over nearly the entire country, the current farm crisis is felt heavily in some regions and is hardly noticed in others.

Ironically, this crisis coincides with the highest farm subsidies in history, in both the United States and Western Europe. Both the United States and the European Economic Community now subsidize agriculture to the tune of $30 billion each per year, and yet the problems of overproduction and declining incomes are far from being resolved. Indeed, a recent issue of the *Economist* suggested that it is ironic that farmers of the northern countries, where obesity is a serious problem, are being subsidized to produce too much while those of many southern countries, where famine is a problem, are being discouraged from producing beyond their personal needs. In any case, it is clear that the current policy of subsidies is intolerable. The day of reckoning is surely not too far off.

Related to declining farm incomes is an increasing concern by farmers over the cost of farm inputs. Though the farm machinery industry as a whole has not done too well over the last several years, input costs show no sign of declining. Indeed, they are rising even in the face of the declining purchasing power of farmers. The desire for decreased input costs has even created some strange bedfellows, as when the American Farm Bureau Federation testified in support of the Organic Agriculture bill as a way to lower costs (Hawley, 1984).

What ought to be of most concern to those of us in the scientific community, however, is that farmers have begun to realize what we have known for a long time: that the technology treadmill does not benefit all farmers to the same degree and that some farmers are done a disservice by new technology. This new awareness is apparent in the pressure put on the Agricultural Research Service to stop research aimed at increasing soybean production and to focus instead on marketing the product development. Similarly, opposition from farmers to the proposed use of bovine growth hormone has developed in nearly all the states with significant dairy industries. Whether farmers will be successful in blocking its use remains to be seen. But the precedent has been set; some farmers have said that there are certain technologies that they do not want produced.

Contemporary Agricultural Research

Changes in the world economy and world agriculture have not been without their effects on agricultural research. Perhaps the most dramatic consequences can be seen in Britain, where the staff of the Agricultural and Food Research Service has been cut from six thousand to four thousand in three years and most public sector plant breeding has been abandoned (Day, 1985). Let us consider briefly some of those changes as they have affected the United States.

Since the end of World War II a new group of research institutions has been developed on the federal level. Initially, the National Institutes of Health and the National Science Foundation, and more recently the Departments of Energy and Defense, have become major research-granting agencies. Moreover, unlike the Cooperative State

Research Service, nearly all the newer agencies support grants to individual researchers. In addition, private agricultural research dollars now far surpass those of the public sector, moving agenda-setting into private hands. As experiment station researchers have become more adept at obtaining money from these agencies, and as Hatch and state funds have not kept pace, experiment stations have begun to lose their special character, and station directors—for better or for worse—have seen their power erode away.

The search for new sources of funds has of late turned many researchers and administrators toward the corporate sector. The coming of biotechnology has hastened this move as it appeared that so-called basic research could lead almost immediately to product development. Yet corporate ties carry several severe defects. First, the corporate sector has relatively little money to give to public sector researchers, and it is all concentrated in certain areas where large profits appear to be lurking. Second, the corporate sector has its own agenda, which may or may not be consonant with that of the experiment station or farmers. Third, the corporate sector need not confine its largesse to the land-grant universities. In fact, many of the major private universities are better equipped to do this research than are the land-grant institutions.

The current wisdom has it that research and educational institutions can, almost by their very presence, generate instant economic development. This, of course, was one theme behind the Hatch Act, though no one thought the changes would occur overnight. Indeed, when one looks at the developments in the Boston area or the San Francisco Bay area in California, it appears that such is possibly the case. But the world always turns out to be more complicated than it appears at first sight. In the last five years many states have supported the creation of agricultural biotechnology centers at land-grant universities. A wide variety of institutional arrangements have been tried, usually involving university, industry, and state participation in either nonprofit or profit-making institutes. On numerous campuses buildings have been or are being constructed to house the scientific staff necessary to support these new endeavors. This would all be well and good if each state could find enough molecular biologists, enough private sector funding, and enough venture capital firms to support such a center. Simple arithmetic shows that they cannot. Some states will undoubtedly be winners in the game of allocation of public funds, but many will be losers.

Over the years the proportion of funds at state agricultural experiment stations originating in the state governments has increased and the proportion originating in the federal government has decreased. This has tended, perhaps, to make the state stations somewhat parochial in their outlook as the narrow interests of state commodity groups have been center stage. The current emphasis, however, is on basic research. This emphasis is desirable in that basic research has often suffered in the experiment stations (Busch and Lacy, 1983), but it is undesirable to the extent that it is limited by and large to molecular biology. Moreover, molecular biology is unlike research on crops; it knows no geographic boundaries. Therefore, the states are being asked increasingly to support research that cannot be kept within the boundaries of the state for even a short time (Bonnen, 1986). At some point, this is going to become painfully apparent to state legislators and farmers. And the question will be raised: Why support research with state dollars that is not clearly of benefit to the state? Unfortunately, there is no easy answer to this question.

The farm population has been declining since the mid-1930s. Today, less than 2 percent of the population live on farms. Even as late as 1979, 38 percent of scientists came from farm backgrounds (Busch and Lacy, 1983). This is already changing dramatically as a result of much lower percentages of freshmen from farm families entering our land-grant schools. The molecular move has accentuated this change because few land-grant universities have had programs in this area. Our next generation of agricultural scientists will lack the direct contact with the soil (or other equivalent experience) that was so important in directing research in the past. They will be much more oriented to the goals of the system of "pure science" than to farm or rural constituents. In light of the mission orientation mandated for our agricultural colleges, this poses a problem of considerable scope.

Extension has long been under attack. The failure of extension to generate internal critiques has only worsened an already bad situation. Current events threaten to pass extension by. Extension funds are virtually stagnant or declining in most states. Extension still clings to the rule of at least one agriculture agent, one home economics agent, and one 4-H agent per county despite the vast improvements in transport and communications. As a result, in states with small counties extension agents are poorly paid and turnover is high. In addition, the farmers often have more education than the agents. The move to biotechnology is also a move toward the increased privatization of agricultural research, which means that there will be less information for extension to extend than has been the case in the past. Indeed, the private sector extension service such as farm supply dealers is growing at the expense of extension. Yet the private sector cannot do what extension has done. It cannot be a relatively objective evaluator of new technologies. It cannot provide political support for public agricultural research. Without a public extension service, we shall all be the poorer.

New Directions

The problems that I have cataloged are not likely to go away by themselves. We now stand at a crossroads in agricultural research and the larger institutions in which that research is embedded. Indeed, revolutionary changes are needed if the land-grant system is to move forward and renew its commitments. It has been noted that all revolutions must draw heavily upon the past. I propose some revolutionary changes in the land-grant system—revolutionary in both senses, a move in new directions and a reaffirmation of the past goals.

Dealing with the Farm Crisis

Our land-grant universities have been virtually silent with respect to the current farm situation. Though agricultural research has existed for a century, we have little backlog of research that prepares us to deal with the social and economic realities of farm programs out of control, massive bankruptcies, and unstable commodity markets. In part, this is a result of events of the 1940s (Busch and Lacy, 1983). In part, it is simply a failure to provide adequate funding to the social sciences, a point recognized by the Pound Report in 1972 but not addressed to date. Indeed, given the enormous importance of agriculture to the health and welfare of this nation, not to say the world, it is shocking to find that there are only a handful of food and agricultural policy centers in the entire nation, most of which contain only agricultural economists, as if agricultural policy were a purely disciplinary concern. Without a doubt, the development of a strong, independent, multidisciplinary agricultural policy analysis community, which will say things we may not always like to hear, must receive higher priority than it currently has.

An Agenda for Public Agricultural Research

Public agricultural research cannot afford merely to become the handmaiden of private agricultural research. Nor can the public agenda be the mere residual of private research. We need a clearly defined public agenda that includes areas that, by virtue of its very constitution, the private sector will not do but that are vital to the economy, health, and welfare of our nation and the world. This agenda includes, but is not limited to, research on minor crops, the development of new uses for agricultural commodities, examination of environmental issues posed by the new biotechnologies, rural development research, analysis of the bases of human nutrition, development of biological control mechanisms for pests, and research on many of the social and economic issues plaguing agriculture.

Of particular importance is research on the impact of the current restructuring of agriculture. Evidence suggests that the industrialization of agriculture is bringing in its wake the establishment of industrial models of labor relations. The full-time, year-round hired farm work force is growing, yet we know little about it. Undoubtedly, changes in immigration law, restructuring of the tax laws, and the growing numbers of semiprofessional workers involved in applying chemicals and yet to be developed biologicals will have a profound effect on the agriculture of the next century.

Agriculture as a System

For too long we have viewed agriculture through the blinders of disciplinary overspecialization. The move to include studies of natural resources and ecology during the 1970s stayed the tide for awhile, but the current molecular thrust may move us even further in that direction. Moreover, the shift from institutional to project support for science and the use of publications in scientific journals as the major reward mechanism has discouraged broader approaches.

One alternative is to view agriculture as a system. Such an approach does not deny the validity of disciplinary knowledge, but it does set it within a larger context. The recent introduction of agricultural systems into the curriculum by the National Agriculture and Renewable Resources Curriculum Project is a step in the right direction. But without support for more interdisciplinary, system-oriented research and a redefinition of extension along system lines, this initiative is likely to be stillborn.

A possible strategy for implementing this approach would be to set aside a significant portion of Hatch and state funds for this purpose, as a counterbalance to the centrifugal forces of other funding mechanisms. Indeed, if extramural grant funding is to be the order of the day, then perhaps not every researcher needs to have a Hatch project, as is the case in many states today.

Another strategy is to restructure our reward systems for scientists. We need to ensure that scientists are rewarded not only for doing good disciplinary research but for contributing to the resolution of specific food and agricultural problems. This can only be accomplished by rejecting a uniform measure of scientific performance (journal publications) and developing a multidimensional measure that includes extension effectiveness, teaching quality, service to society, and teamwork.

Ethics and Public Policy

Still another area in need of support is that of ethics and public policy. Here, too, there has been support for new curricula, but research in this area is poorly supported and often goes unrewarded. Indeed, the land-grant universities have a long and not too satisfactory history of occasionally punishing people who do research in this area (Lacy and Busch, 1982; Hardin, 1955). Yet the current problems that face agriculture—the farm crisis, the level of support for farm programs, the restructuring of the research system as well as the seed industry, the loss of crop and animal germplasm, increased difficulty of entry into farming, growing concentration in the ownership of farmland—are unlikely to be resolved in a manner consonant with the public good without serious, long-term research in this area. To undertake this research new disciplinary expertise must be brought into our agricultural colleges (Bonnen, 1986). Ironically, support for bringing ethical concerns into our agricultural colleges comes most strongly from the agribusiness community.

Technology Assessment

It is curious that despite a long history of research on marketing in agricultural economics and the diffusion of innovations in rural sociology,[2] relatively little work has been done to assess the consequences of new agricultural technologies before they are developed (e.g., Friedland and Kappel, 1979). Of course, researchers have only rarely had no idea of the probable impacts of their research; if that were the case, it would hardly qualify for Hatch funding. Most social science research in this area has been confined to taking potshots at scientists over their failure to forecast what appear ex post facto to be obvious shortcomings of technical research. Surely we can do better than that. Indeed, the new biotechnologies offer us the opportunity to assess a group of new technologies before they are fully developed. Moreover, farmers' concerns over bovine growth hormone and soybean production research are, I believe, only the tip of the iceberg. It is likely that such concerns will surface more often in the future. Having a mechanism in place by which new technologies can be assessed in advance would avoid the more unpleasant sides of such controversies.[3] Ironically, the most sophisticated approach to developing an institutional structure for technology assessment in agriculture to date is contained in the proposed injunctive order against the University of California brought by the California Agrarian Action Project (*CAAP* vs. *The Regents of the University of California*, 1987). Although this document was prepared as part of a legal action against the University of California, and hence has an adversarial character, it bears serious consideration. Simply put, its authors propose that an institutional structure be developed to monitor and assess the effects of public agricultural research on the constituents of the system. Although this may seem unpleasant medicine to some, it could be a viable tool for building new and diverse constituencies for public research.[4]

A Renewed Land-Grant Act

Over the past century our land-grant universities have evolved from predominantly agricultural institutions into comprehensive universities. In the process, the mission written into the Morrill, Hatch, and Smith-Lever acts has been confined more and more to the agricultural colleges. This has had the effect of impoverishing both agriculture and the other disciplines. Yet if the land-grant universities are to live up to the goals embodied in these acts, they can no longer depend only upon the talent within the agricultural colleges. With few exceptions, our agricultural colleges do not contain the historians, poets, and philosophers that can help us discern where we should go in the future.[5] They do not contain the planners who can design the towns and villages of the future. They do not contain the scientists whose discoveries in other fields have relevance to agriculture. They do not have the knowledge of other cultures so necessary to technical change in an ever-shrinking world. Yet the larger universities in which these colleges are located do have the persons with the skills and knowledge necessary to deal with these questions. In short, the colleges of agriculture need to draw upon the resources of the entire university. Such a concerted effort is considerably different from the current situation wherein university faculty are often asked to respond to the latest fad or the most powerful interest group in the name of "applied research." The land-grant universities need a new land-grant act to reaffirm their original mission and to modify it to meet new needs and issues. Only in this way can they really contribute to agricultural and economic development and to the well-being of all. Agriculture is simply too important to do otherwise.

Agriculture in an Urban Society

We must recognize that agriculture today is embedded in an increasingly urban world. In the United States, in Western Europe, and even in the Third World, more and more people come into contact with agriculture only through their stomachs. This problem should be of grave concern to us. I submit that it is imperative that we begin to educate not just agriculture students but all students and the public as a whole as to the importance of agriculture to both our nation and the world (Schuh, 1986). By this I mean not the monologue of public relations films and talks that, though they may have their place, gloss over the complex issues and convince only the convinced, but the opening of a dialogue with many publics about the nature of agriculture, of food, and of agricultural research. We already have some of the mechanisms in place to do that—our undergraduate courses, extension services, and, recently, the Kellogg programs. We even have a precedent in the philosophical discussions with farmers conducted by extension in the 1930s. We lack only the will to carry it out.

Learning from Other Countries

Since the end of World War II, agricultural research institutions in the United States have assumed that they were the best in the world. They were probably right until very recently. But times are changing. Many nations that received help from the United States in the 1950s, 1960s, and 1970s have developed the educational and research infrastructure necessary for excellence. From them we could learn much. For example, Morocco's Institut Agricole et Veterinaire Hassan II has developed a novel system of field training for its students. Students are sent out to villages to live and work with farmers each year. Working in groups, they are asked to take careful notes on everything from the quality of the soils to the meal patterns of the households they visit to the changing weather. This information provides them with a holistic picture of agriculture to supplement their more specialized course work in which people, plants, animals, climate, and soil all interact.

Another innovation is the recently formed National Academy for Agricultural Research Management in India, which provides new scientists and faculty members with introductory courses on the goals of the research and educational system. It provides short courses for faculty on a regular basis to keep them abreast of new developments in their fields. It provides courses for administrators on the art and science of administration. Finally, it has its own research staff that studies issues of research policy and management.

Both of these innovations could be usefully adopted by the United States. Indeed, the lack of a farm background on the part of more and more of our undergraduates and faculty, as well as the growing complexity of research administration, demand innovations such as these. Other nations have developed other institutional forms from which we could learn, as well.

Agricultural Research for Africa

Joe Willett, in a recent paper, has proposed that we focus a substantial portion of the resources of the land-grant universities on resolving the problems of Africa. Unlike the rest of the world, this continent has not kept pace with population growth. Per capita food production is declining. In addition, the fragile environment of sub-Saharan Africa is being eroded away by population growth and misuse of agricultural land. At present, the United States does not have the knowledge necessary to resolve the complex problems facing Africa. Yet the challenge is there. Africa needs research, education, technologies specially designed for its environment, and help in building its own educational institutions. The U.S. land-grant universities could take on this mammoth task of the next two or more generations.

Conclusions

In conclusion, the problems that face us now are no different from those that faced us a century ago. A century ago we were faced with the shrinking size of the world. So we are today. A century ago we were faced with a set of human needs that could be resolved through research. So we are today. A century ago the world economy was subject to wild fluctuations. So it is today.

Yet, on the other hand, the problems that face us are entirely different than those of a century ago. Markets for nearly everything are worldwide. Most of our citizens have no direct contact with agriculture. The population of the world is growing rapidly, and there are few agricultural frontiers left. We are no longer an isolationist nation but a world power with the demands and responsibilities that such power entails. And, like the residents of Mark Twain's Hadleyberg, we are less innocent. We know that progress is not inevitable, that science can occasionally fail us, that utopian dreams and dystopian nightmares sometimes become indistinguishable. This very lack of innocence is perhaps of greatest significance, for only the knowing can be responsible for what they do.

As the state agricultural experiment stations enter their second century, their leaders do so knowingly. Let us insist that they use that knowledge responsibly.

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Notes

1. The relationship between science, utopia, and development is the subject of Busch and Chatelin (forthcoming).

2. Buttel (1985) distinguishes the production sciences from the impact sciences and argues that the latter have played a subordinate role in the land-grant universities.

3. Of course, no ex ante technological assessment can predict all the consequences of a new technology; however, since technology is always developed for a purpose, an assessment of these purposes and of persons potentially affected is always possible.

4. Among the untapped constituencies are farm workers, small and part-time farmers, environmental groups, backyard gardeners, organic farmers, and consumer groups.

5. It should be remembered that Alfred C. True, second director of the Office of Experiment Stations, forerunner of the Cooperative State Research Services, was a scholar of classical Greek.

Agriculture-Environmental Issues

Jack Doyle

Environmental Policy Institute

The Environmental Policy Institute (EPI) is a nonprofit, public interest organization that focuses on energy and natural resource policy at the state, national, and international levels. Like the agricultural experiment stations, we are celebrating an anniversary, our fifteenth.

Over the years we have worked with Congress, the federal agencies, and, most important, organizations of local citizens in trying to effect constructive changes in public policy.

Throughout much of our work, dating from the early 1970s, we have had a special interest in agriculture, and particularly its economic viability. Agriculture is important to us because farmers and ranchers work more closely with the environment than any other single group in the nation. Only the federal government has more control. We have always thought that live-on-the-land ranchers and farmers are potentially the best resource stewards we have. So we think it makes sense to help make agriculture viable and profitable and to keep farmers in business.

In this hundredth-year celebration of the Hatch Act, and more broadly, the entire land-grant complex, we have come to a critical crossroads for agriculture and agricultural research for three reasons: biotechnology, the present state of agriculture—particularly the continuing loss of farmers—and the rising public concern for how food is produced, its quality, and the social and environmental side effects of agricultural production.

This cluster of recent developments and concerns presents a special opportunity for the land-grant complex to take beneficial actions for agriculture, the environment, and public health, all at once. Biotechnology should enable us to approach both production agriculture and environmental side effects with a new efficiency, particularly since much economic, environmental, and public health benefit can be collapsed into, or captured by, the right set of genes. When I use the term *biotechnology* here, I mean it in the broadest possible sense, embracing classical genetics, gene splicing, and, most important, new biological knowledge. Also in my definition of biotechnology, I include what I call "common sense biology"—what we have learned from plant breeding, pest adaptation, soil microbiology, crop rotation, ecology, and the other biological disciplines.

Let us take one example of a research opportunity in agriculture that would include benefits for the farm economy, the environment, and public health and safety. The land-grant complex could use biotechnology and common-sense agricultural research to improve the profitability of farmers by reducing their cost of production. One way this could be done, for example, is through the development of disease- and insect-resistant crops and livestock. In fact, if disease- and insect-resistance research were named the number one priority of the land-grant complex, I would be pleased.

I know that much good work has been done by the land-grant institutions in disease and resistance research, but we could do much more on that front. So why shouldn't USDA and the land-grant complex seize the high ground on this issue and turn it to their advantage?

Obviously, achieving disease and insect resistance on a broad and continuing scale across plant and animal agriculture would contribute to farm productivity, farm income, environmental protection, and public health and safety. Fewer pesticides would be needed. Pest-management strategies would be genetically rather than chemically based.

Why shouldn't the number one stated goal of both USDA and the land-grant system be to achieve disease and insect resistance in all commercial crops and livestock? This would be a way of restating the agricultural research mission in biological rather than chemical terms, a way of maximizing agricultural productivity and return on investment for the farmer, and also a way to back off from the over-emphasis on high-yield and production volume. High-yield agriculture is part of the problem. In some cases, the genes of disease and insect resistance have gone by the wayside because they interfered with the genes of yield. And historically, we all know that chemicals were always a cheaper and easier way to fight pests than breeding and genetics. But then, at the outset of the synthetic pesticide era following World War II, we did not foresee the problems that would come, and we did not add up all the "externalities" as economists call them—the costs to society.

But the new biology offers us a way out of the pesticide era, and the land-grant complex could take the lead. The question is, Will it? I see a couple of troubling developments that might preclude the closing of the pesticide era and the role of the land-grant complex as a leader in that process.

First is the entire complex of biotech research activities designed to integrate the chemical and genetic approaches in agriculture. Whether it is research to make crops genetically tolerant to herbicides, honeybees resistant to insecticides, or crops and livestock responsible to certain growth regulators or partitioning agents, the net effect of this research will be further to capitalize, and further to entrench, the chemical and supplement approaches in agriculture. The result would be a continuation and, in some cases, an increasing use of pesticides rather than the opposite. Is this what we really want from agricultural research in the age of biology?

In Iowa, where pesticides and fertilizers have been showing up in municipal wells and groundwater, public sentiment for increasing controls on the use of agricultural chemicals is growing. A poll taken last September shows that 58 percent of those surveyed believe that farm chemicals are the biggest threat to water quality and that 78 percent favor limits on their use. Earlier this year, a bill was introduced in the Iowa legislature to begin taxing pesticide use to fund research into alternative farming practices that would reduce the use of pesticides and fertilizers. The bill would also give the state supremacy over the federal government in setting tougher groundwater standards.

To prolong the old and outdated chemical approaches in agriculture with biotechnology by making crops herbicide resistant, for example, is going the long way around the barn and potentially could make agricultural research even more unpopular with the general public than it is already. Yet disease- and insect-resistance research that results in fewer pesticides could gain praise from the public for being safer, more environmentally benign, and more efficient for the farmer.

The second set of problems that may preclude the land-grant complex from pursuing "smart biology" rather than product-oriented biology is the growing coalescence of the university and industry. I recognize that a certain degree of contact and interaction between university and industry is necessary, but with regard to agricultural chemicals, and now biotechnology, it has gone too far. The land-grant complex is in danger of losing all public confidence as a neutral arbiter and an objective evaluator of new technology. And further, the land-grant complex is no longer a creative spur to the private sector, or the source of public domain items that the farmer could use as a measuring stick of true product worth. In short, the land-grant complex is no longer a leader, it is a follower.

Critics of this view may say, give us more public money and we'll be pure again. We will serve the public interest more broadly. I do support increased public funding of the land-grant system and have said so in writing and in congressional testimony. Yet I hope that in our latest enthusiasm to fund biotechnology and in our national fervor to be efficient and competitive, we do not end up funding only the "better" institutions. That would be unfortunate for agricultural diversity and agricultural opportunity.

I hope that in the land-grant and agricultural experiment station complex not only the Cornells and the Californias become well-funded centers of agricultural wisdom, but that all the land-grant institutions—including the 1890s schools—share equally in the new biotech funding, simply because, when it comes to common-sense biology, Cornell and the University of California do not have a corner on the market. For a nation that professes to believe in the practice of pluralism, and one that abides in the economic wisdom of the diverse portfolio, to put all of our research eggs into one or a few baskets would seem to make us more vulnerable than productive in the long run.

Now I will turn to the issue of biotechnology and economic consolidation in agriculture. Biotechnology is revolutionary for agriculture and the food system because it lodges control over food production in the genes. Food production, of course, has always been empowered by the genes, but we have not been able to see them, precisely select them, or move them across traditional species barriers. Now we can, and day by day we are learning which traits in crops and livestock individual genes control, how to turn those genes on and off, how to splice them into other organisms, and how to amplify gene products.

So first, we have an awesome new technology that operates at the genetic level of the food system—the most fundamental level of food characterization. This means that the production and quality commands in the food system begin with the genes and, most important, with those who hold the genes.

Second, coupled with the new genetic technologies is the legal power to own genes. Legal developments in the biological realm over the last six years or so have shown that seeds, genes, microbes, and now animals, can be patented, as can certain techniques used in genetic manipulation. This means that an inventor or a commercial interest can have a property right in genetic material. Economically, it means having an exclusive marketing right, a limited monopoly for seventeen years or more on genetic inventions and genetic technologies.

In the realm of agriculture, obviously, many genes are involved. There are genes that control yield in corn, stalk strength in barley, protein levels in wheat, and photosynthetic efficiency in soybeans. In livestock, there are genes that have to do with fat content, lactation rates, feed-to-meat conversion rates, growth, and disease resistance. It is possible to imagine a classification system of sought-after traits, including, for example, agronomic traits such as those for higher yield or harvestability in crop production; food processing traits such as those governing less water or more "solids" in certain fruits and vegetables; food quality traits such as those controlling higher protein levels in crops or lower fat content in livestock; and finally, traits pursued for their public health or environmental benefits such as genetic alterations to crops and livestock that would dispense with the need to use pesticides or antibiotics in the agricultural environment. But which traits will be pursued first?

"Of all the technologies coming to agriculture," says the Congressional Office of Technology Assessment in a 1986 study, "the biotechnologies will have the greatest impact because they will enable agricultural production to become more centralized and vertically integrated." We are told there will be more consolidation at the farm level. The work of Bob Kalter on bovine growth hormone here at Cornell reinforces that. In the farm supply industries—seed, feed, fertilizers, and agrichemicals—massive restructuring is going on, some of which is motivated by what biotechnology may do to traditional farm suppliers. Representatives from the agrichemical industry will attest to these changes. And there is enough activity in biotechnology research and contracting in the food processing industry to illustrate that industry's interest in further capturing its raw material base. Meanwhile, in research reports from the field and the laboratory, we can see the near horizon of agriculture's future: orange juice from tissue culture in California, cotton fibers from cultured cotton cells in Texas, and research in Australia aimed at producing shearless sheep. Quite simply, genes will become a substitute for labor and resources in agriculture.

If the core reality of biotechnology in agriculture is to consolidate and centralize food production, what does that mean for the rest of society? How do we make a technology like this—one that can be lodged in so few hands—accountable? Who makes it accountable and responsible? Or do we leave problems of accountability to the market? It seems to me that the land-grant system, through its research and its example, ought to be playing a role in making and keeping this technology accountable and moving it forward in a beneficial direction. Lest my message be misunderstood, I must emphasize that I am a believer in agricultural research, the land-grant system, and biotechnology, within reason. One of the promises of biotechnology is that it can move us out of the pesticide era quicker than anything we have heard about before. And I am heartily in favor of that. But this delivery into a new age of biology was talked about as early as twenty-five years ago, when Rachel Carson wrote *Silent Spring*. One could rightly conclude on the basis of this past that today's promise of biotechnology is nothing more than hot air and that it is not happening quickly enough or moving in the right directions. Certainly, if we look around and all we see are people using biotechnology to make crops and forest trees resistant to herbicides, or bees resistant to insecticides, what should we conclude?

But let me not be misunderstood. These are exciting times for agricultural research, the nation's land-grant universities, and the agricultural experiment stations. The revolution that is occurring in the biological sciences is awesome and astounding; the potential for understanding the environment and the elements of agricultural productivity is present as never before. But it is possible that the public role in directing this new technology, and in realizing fully all of its benefits, could be jeopardized precisely because the opportunity to rejuvenate and reiterate the promise of the Hatch Act and Morrill Act was missed in the 1980s.

The nation needs the land-grant complex to be part of our social conscience, to offer the viable alternative, and to be a bulwark against commercial domination. So let us use this one-hundred-year celebration of agricultural research to restate and reaffirm those purposes for the future.

DISCUSSION

Q. Either you stated or you inferred that most of the plant breeding being done in this country today is being directed toward increases in yield with disregard for the development and introduction of plants with resistance to disease or insects. There is not a plant breeder in this country that I know of that is worth his salt who does not have these as two of his main objectives. Maybe you are not aware of this.

A. No, perhaps I did not emphasize it strongly enough. I did say that I recognize that there has been and there is ongoing a great deal of work in disease and insect resistance. I have talked about the difference between single gene resistances and multiple gene resistances, which is an area in which I think the more durable resistances are important. But I think that the opportunity is here for the land-grant universities to capture the imagination of the public for launching a major effort in disease- and insect-resistance work in the land-grant system. And I think there are public benefits to come from that, and, yes, there is work going on, but I think it could be dramatically increased. Certainly with the tools of biotechnology we ought to be able to do it more durably and more quickly.

Q. Similarly, I am surprised that you do not recognize a hundred years of both objective testing in the field of the products of industrial efforts and in the selection of varieties of crops and livestock and so on and, at the same time, a cooperative effort in the last hundred years. These have had a level of compatibility through that hundred years. There is a right way and a wrong way to handle that relationship, nobody would deny that, but I would ask, don't you see one hundred years of success in that regard?

A. I do, but I can think of some changes that I am not sure have been beneficial for society and for agriculture. I think it is important that some public domain items come to the market from the public sector, as there were with open-pollinated varieties of crops. That is no longer a fact of life in the land-grant system. I do believe that much fine work has gone on in the land-grant institutions. I think there is an opportunity to go much farther, and there is a place for industry-university cooperation, but I think there also is a need for neutrality in our land-grant system for public domain research that will help spur the private sector.

Q. As a representative of big decisions in the public interest (and obviously that is a very important thing, in a balanced way, so that we do not deny the benefits to the public that will help them out in full understanding in certain areas), you will get agrichemicals and cancer in this country. What percentage of cancer in this country can we blame on agrichemicals, and what can we blame on food, taking agrichemicals out of the picture to aim at the right issue?

A. The data may not be entirely in on rates of cancer resulting from particular agricultural chemicals. Such cancer is often latent over long periods of time, and I am not sure that we have all the data attributing cancers particularly to agricultural chemicals. Nonetheless, we should be, as a society, moving forward to try to reduce the total load in the environment in areas in which we know we have a problem. Certainly the agricultural research establishment has a responsibility to public health and safety to move forward in that area where it can. I think now with the tools that we have at our disposal we can certainly move faster in that way than we have in the past.

Q. My name is Jerry Perkins. I am with the *Des Moines Register,* and I just came from Iowa State. You might be interested in knowing that the Iowa legislature has amended extensively that very tough groundwater protection bill to the point that its sponsor said that he may withdraw his support for the bill. He feels that it has been loaded down and changed to the point that he no longer will claim his own child, so to speak.

A. I heard it called in the *Des Moines Register* the "Lobbyist Relief Act of 1987" or something like that. So it does not surprise me.

Q. It was called that in our editorial piece.

A. The counsel in state governments probably has mentioned that there will be other similar pieces of legislation coming, and I raised that issue because I think when you look at the public and consumer sentiment on a number of these issues, whether it's proposition 65 or whatever, there is an increasing public concern about quality and toxins in the environment, and I think we have an opportunity with this biology to move in some beneficial directions.

Comment: I think the issue of environmental carcinogenesis is extraordinarily tough for us to have to deal with. The new technologies offer us an opportunity to get away from agricultural chemicals, but I think at the same time there will still be a role for agricultural chemicals for many years to come. Although we are going to be doing a lot of work with genetic engineering and some of these prospects, I am very concerned that we not indict agricultural chemicals unfairly. Maybe we have been irresponsible at times, but I think clearly there is a wave across the land to try to correct some of the misuses we have made of agricultural chemicals. But I can clearly see a lot of use for them in the future.

The Future of Agriculture in New York State

The Honorable Stan Lundine

Lieutenant Governor, New York State

Agriculture is obviously our oldest industry, and I think it is safe to predict it will be our longest lasting. Our children and grandchildren will experience millions of new advances in this tremendous and dynamic field. At some distant time I think there will be fewer and increasingly brilliant farmers with specialized knowledge—experts in computer techniques that we have not even thought about today. And no doubt they will complain, with some justification, that they are not being paid enough for their products. As a congressman I usually found that whatever field of agriculture farmers were in, that was a common complaint.

Agriculture has a rich history in this country. The country was founded by great farmers and planters—George Washington, Thomas Jefferson—but it was also founded by ordinary people who turned the wilderness into rich farmland. These people, whose strong rural values of hard work, independence, and self-reliance became the nation's values, are part of the great fabric and tradition that we know as American agriculture. As much as we love and cherish that history, we cannot head into the future looking at farming through the rear-view mirror. We have to face forward and respond with intelligence and innovations to changing conditions.

A hundred years ago, when the agricultural experiment stations began, farming was a relatively simple operation. If you had a few cows or chickens and a good plow horse and grew a few dozen acres of crops, you could get by. You learned farming by doing it, and the way you farmed did not differ very much from your neighbor's or your parents'.

All that changed in the twentieth century with dizzying speed, and more changes are obviously coming ahead. Today, we have computers, chemicals, powerful tractors, expensive equipment, knowledge of animal and plant biology unknown to previous generations, and well-planned production and marketing strategies—all of which are essential to success.

With every passing year the modern farmer has more and more in common with people in other high-technology fields. And every year it becomes more important that more New Yorkers realize that a healthy farm economy is crucial for the well-being and overall economy of our state and our nation.

Despite New York's tradition of being a state with an industrial, service, and commercial economy—a state known for its great factories and leading computer companies and Wall Street and the concrete canyons of Manhattan—farming is the biggest industry.

New York's 48,000 farms directly employ about 191,000 people, with an annual gross income of about $300 million. New York's more than 1,300 food processing and manufacturing plants employ about 65,000 people, with a payroll exceeding $300 million a year. Companies providing supplies and services to farmers, along with food processors and distributors, wholesalers, and retailers, provide another 400,000 jobs.

Beyond that, agricultural expenditures indirectly support hundreds of thousands of other jobs in the state's economy. We want more people inside and outside the state to know these facts. We want more people to know that New York leads the nation in the production of cottage cheese and cream cheese and that we are the nation's second largest producer of apples, tart cherries, fresh market sweet corn, and maple syrup. We want people to know that we are the nation's third largest producer of milk, ice cream, cheese, grapes, cauliflower, fresh market cabbage, and snap beans. All of these are fine, high-quality products, as fine as are available anywhere in the world.

Our challenge is to sell more of them to our fellow New Yorkers and indeed to consumers throughout the Northeast and to people all over the world. With our state's 18 million people, we have a tremendous market right here. We do not have to cross the continent to reach this great market, we only have to go down the highway.

Our governor from Queens, which is not known for its farms, has grasped the importance of the agricultural economy in the state. It was Governor Mario Cuomo's vision that led to the Agriculture 2000 study issued in March 1985. The study has been nationally recognized as setting out well-documented state agricultural strategies that identify the many challenges and opportunities of the future. The governor and I are determined that this will not be just another study that will gather dust on the shelf. Here is an outline for a plan of action that we intend to implement. Already the governor has launched many of these programs.

- The seal of quality program promotes high-quality New York farm products.
- Another program increases the purchases by New York State institutions of our own farm products.
- The state agricultural research and development program funds applied research, feasibility analyses, and demonstration projects that have near-term application.
- FARMNET helps farm families with financial, family, and legal concerns connected to agricultural problems.
- The New York Wine/Grape Foundation and other grape industry initiatives, including allowing the sale of wine coolers in retail food stores, have given a boost to this industry.
- The state's integrated pest management program helps farmers reduce the use of agricultural chemicals through alternative biological management practices.
- The governor and legislature have provided $5.1 million for the construction of a food processing laboratory here at the Cornell College of Agriculture and Life Sciences and provided another $20 million toward the Biotechnology Center at Cornell.

We have nominated a new agricultural commissioner, Don Butcher, who led the Ag 2000 profile and who is, we believe, very well qualified to carry on the work that Joe Gerace has begun to lead the way for a strong and healthy future for agriculture in New York. But it cannot be solely a government venture. What is fundamental to what Governor Cuomo and Stan Lundine really believe, whether it is in agriculture, industry, or any other subject, is that it takes cooperation to get the job done. In this case we need the researchers, the university people, farmers, food processors, and those in the agribusiness industry to work together with government to achieve our fundamental objectives.

We need retailers, wholesalers, a vast variety of the people involved in this industry to work together, so that, as in the nineteenth century, when farmers came together and raised barns as a team effort, we can have a team effort to move this agricultural economy into the 1990s and, indeed, into the next century as a healthy, vibrant, growing force in this country. And we believe, very strongly, that we must pay attention to the basics, agriculture and industry.

Unless we produce, we will find it very hard to succeed. And unless we produce in America, I do not think we will be able to reverse the trade deficit and have more prosperity for our children, just as we have had more prosperity than the generation that preceded us. So we believe that we have to adapt to changing markets, we have to work with producers and work in a cooperative, team venture with all those persons involved in the agricultural industry. A lot of innovation is going on. Some farmers, for example, on Long Island, are growing vegetables used in Oriental cooking. Still other processors are aiming at the kosher market, and there are all sorts of specialties that we are working with our agricultural industry to target, as well as taking a strong interest in the grape and dairy industries and other basic industries of New York State.

The variety and quality of New York farm products was brought home in a dramatic way at our inauguration in January. We insisted that only New York products be served at the big reception in the concourse under the great mall Governor Nelson Rockefeller built in Albany. I do not think anybody who visited that ceremony went home complaining about the lack of choices in food. It was a great celebration for New York and a great demonstration of the variety and the high-quality standards of our agricultural products.

We should not have to import as much as we do. We should be doing a better job of marketing what we already have and adapting to changing conditions. No matter how good our food is, we want to reach the maximum number of consumers through better marketing practices. We need to use agencies such as the misnamed Urban Development Corporation. We are trying to rename it the Empire State Development Corporation, because it no longer is just an urban agency, it is an economic development agency. In addition, the Job Development Authority and other New York State agencies are working on the challenge of boosting our entire agricultural business and industry in New York.

We need to remain at the forefront of developments in biotechnology, and that is why we have made investments here at Cornell, the state's principal agricultural research institution. We need to do even more to harness the resources of our great universities, the Cooperative Extension Service, and the other outreach agencies. We need to be advocates for sound farm policies in Washington.

We know the potential for the agricultural industry in New York, and we look forward to working with you, with the people in the food production business, with farmers, and with everyone involved in this great industry to propel it into the future.

We think that innovation is necessary here, as it is in any other economic area. We firmly believe that we have a foundation to build on, that we have a sound agricultural industry in New York, and that we need to work with it and have foresight to achieve the objective of increasing our standard of living and leaving a better situation than we inherited.

Governor Cuomo has proclaimed May 4 and 5 Cornell University Agricultural Experiment Station Centennial Days in New York to honor this outstanding institution and the agricultural leaders and scientists gathered here from around the country. He and I believe very strongly in what you are doing and in the future of the great agricultural industry in our state.

A Proud Past—
A Promising Future

John Patrick Jordan, Administrator

USDA Cooperative State Research Service

Cornell University has produced an extraordinarily large amount of the leadership in agricultural research in the last century and continues to do so today. Across the country the agricultural experiment stations have made major contributions in human nutrition, but it was here at Cornell that national dietary guidelines were set. Who can forget the impact of the Cornell Kitchen, with its guidance to both layout and the preparation of food? In animal nutrition, who can forget Milt Scott's contribution in selenium or those of the Cornell faculty in folic acid and riboflavin, to name but a few? Discoveries about the inheritability of traits in genetics is another cornerstone. Across the country and here at Cornell major contributions have been made in plant nutrition and plant genetics. The Einset seedless grape, released in 1985, is a good example.

In the field of physiology, we have seen the development and improvement of semen extenders, and we have seen the unfolding of the bovine growth hormone or bovine somatotropin story. The scientists at Cornell have done their work well. They have studied the basic principles undergirding the effect of this particular hormone, and they have done their work well in another sense. People at this institution turned the problem over to economists early on, so that they, too, could examine the potential societal impacts of this discovery and do it early enough to warn the agricultural community and influence public policy. I have no doubt that this was an important consideration behind the dairy buy-out program.

During this century we have witnessed the birth of a new discipline, biotechnology, in the land-grant universities and in other institutions of higher learning. We have seen the application of science to the resolution of real world problems, including the development of cherry and grape harvesters here at Cornell and the publication in 1929 of the *Principles of Child Guidance*. We have learned to understand the importance of having a standard temperature related to cold storage of apples.

Did we, in the process, create some problems? Indeed we did! We learned that we put more chemicals on the soil than the soil was able to use fully, and thus there were runoffs. Water and air pollution resulted from some of these activities. With the advent of irrigation, we saw increased soil erosion and soil salinity. We put the biological system under considerable stress as, for example, in increasing markedly the production of milk by the individual cow. And in the process of change, we saw stress levels in people increase and we have been forced to find ways to address stress.

What have we done and will we do to rectify these problems? We will continue to push back the frontiers of ignorance. We will continue to strike a blow for knowledge, and we will continue to increase the intellectual capital of humankind because we understand that we start with three basic resources in addition to financial ones. We have natural resources, human resources, and knowledge resources.

Are we addressing the promise of solutions to problems not yet recognized? Yes, we are. James Wilson was secretary of agriculture from 1897 to 1913, a span of sixteen years, under three presidents. He put it well when he said, "The future holds many important discoveries still to be made." It is for that purpose that the state agricultural experiment station has prepared a nationwide strategic plan with input from many industrial and agricultural groups taking several hundred priority problems and boiling them down to twenty-one major initiatives.

The promise of solutions, even to problems not yet recognized, was the subject of the motion picture *Unfinished Miracles* released in 1976. The system, together with the Cooperative State Research Service (CSRS), in 1987 released *New Beginnings,* another motion picture/videotape. The promise of future solutions was also the basis for a slide tape show entitled "The State Agricultural Experiment Stations: The Catalyst for American Agriculture."

Although higher education in what is now the United States of America had its beginnings in the 1630s, there was nothing uniquely American about its course of study or curricula for over two hundred years. Education in the seminaries and colleges of America was based on a good solid tradition from Germany and England and was outstanding in the liberal arts.

In the sciences, there was heavy exposure to mathematics and introductory courses in physics and chemistry, but in biology, most of the focus was on natural history. Nobody had proposed to apply science to the resolution of real world problems in agriculture. That proposal awaited the 1840s and an Illinois gentleman by the name of Jonathan Baldwin Turner, who thought it was time for the United States to build institutions of higher learning dedicated to the agricultural and mechanic arts. Even though our nation was engaged in its most devastating and destructive war, his idea was converted into an act of Congress authored by Justin Smith Morrill and signed into law by President Abraham Lincoln on the second day of July 1862. Thus was born the land-grant tradition.

But it soon became clear that it was not enough, for our nation was dealing with depleted soils, and, as it moved westward, it was faced with decreasing rainfall and many new soil conditions that had not been experienced in the eastern United States. By the mid-1870s, two states, Connecticut and California, established agricultural experiment stations patterned after those in Germany. Many other states followed, including New York, where the Geneva station was established in June 1880. By the latter part of that decade it became clear that a nationwide network of state agricultural experiment stations would be extremely valuable. Congressman William Hatch of Missouri proposed that such a system be organized and at least partially funded by federal dollars. The act was passed and signed into law by President Grover Cleveland on the second day of March 1887. From that date forward, a nationwide system was established, and the Ithaca station was opened in October of 1887.

But this, too, was not enough. It became clear that farmers and ranchers who lived closest to the experiment stations derived the greatest benefits from them. A new idea was brought forth—why not extend the university into every county in the United States, fielding a group of agents who could bring to the farmers and ranchers the results of research conducted at the land-grant universities? This idea began to unfold in some states at the turn of the century, and in 1914 the Smith-Lever Act was passed by the United States Congress establishing such a system on a nationwide basis.

Many important additions to the system were made beginning with the black land-grant colleges in 1890, home economics programs, forestry programs, and veterinary medicine. All of these are now full partners in the system.

But the key to the future lies in the human capital that is produced through that system. The first group of National Need Fellows was brought into the system over the last three years. The average graduate record exam (GRE) score for these fellows is in excess of

1,300. This is in contrast to the nationwide average of approximately 1,000 for medical students, 1,081 for engineers in all branches of engineering, and 964 for graduate students in the agricultural sciences. Not only is the average score on the GRE exams exceptionally high, but in one area, biotechnology, the average GRE exam for the fellows exceeds 1,400. Clearly, this program is attracting the very best graduate students in the United States to study agriculture.

Why do we need a special program to attract high-quality students to study agriculture? I asked this question of a group of North Carolina State University students recently. Their answer was that there is a perception that agriculture is a mundane and unexciting field and that modern science is not done in agriculture. These students were outstanding undergraduates who had been attracted to agriculture by a special program conducted at North Carolina State University. They pleaded for a more aggressive and correct projection of the image of agriculture, in general, and agricultural science, in particular. That is the purpose of the U.S. Department of Agriculture's 1986 Yearbook, *Research for Tomorrow,* written by USDA laboratory scientists, university-based scientists, extension leaders, resident instruction leaders, and industrial leaders of agriculture science. It is one of the most popular yearbooks in recent times and could very well go down in history as a hallmark volume. Additionally, the centennial year prompted the publishing of a history book on the state agricultural experiment stations.

But more than looking backward, the centennial provided the basis for a nationwide forum held at the National Academy of Sciences, which focused on where agriculture and agricultural science are going as we close out this century and open a new millennium. Many state agricultural experiment stations are focusing attention on the quality of science during their centennials. The significance of this event has not escaped either the Congress of the United States or the president because the Congress has produced a joint House-Senate resolution recommitting itself to the principles behind the Hatch Act. The president has issued a formal proclamation recommitting this entire nation to principles of applying science to the resolution of real world problems, particularly those related to agriculture. It parallels very well the New York State proclamation.

Perhaps the most exciting aspect of this centennial is the opening of a permanent exhibit in the Smithsonian's National Museum of American History. It was announced at a gala affair on the second day of March, at which sixty-one food and floral exhibits were provided for the enjoyment of the guests, including three outstanding contributions from Cornell University and its two experiment stations. The exhibit, which will open in November, is entitled "The Search for Life." It is about the impact of science on agriculture and on health, and it has four rooms. It tells the story of the time frame 1900–1940, during which agriculture came to full production but also experienced the crisis and problems of the Great Depression and the Dust Bowl years. It chronicles the war years and shortly thereafter, when the initial impact of new knowledge on the quality of life and the quality of food, gained through scientific research, began to be well recognized. It tells about the discovery of the genetic code and the advent of biotechnology as a tool that provides a pivotal point for targeted changes in the flora and fauna to meet the needs of mankind. In that discussion, it shows the problems and concerns of the average citizen and what science can and will do to deal with and delay the fears. It shows in tapestry form the faces of the great Nobel laureates who have made major contributions in agriculture. In the final room one will get a glimpse of the possibilities for the future in the use of science for research on agriculture and health and how these changes may affect mankind. In thirty minutes' time, the average citizen can come to full realization that agriculture, as one of the major areas of human endeavor, is a high-tech, high-intensity, high-impact, high-cost, high competition, and highly significant area. And it is related to health and well-being.

The critical question is whether all of this, particularly more research, is needed for tomorrow. The citizens are the only ones who can decide. Where does agricultural research stack up in the national priorities? Many people look at agricultural research and see only what they perceive as a problem of oversupply. That is, from the researcher's point of view, a marketing issue, and we address it in three ways: focusing on the quality of the product, including its storability and shipability; cutting input costs, so as to make the product more competitive on the international market; and examining alternatives, not only the alternative uses of a particular product but also the use of resources to produce alternative products that will be needed in world trade.

Where will agricultural research come in the nation's priorities? We can be fully supportive of the conducting supercollider costing $4.4 billion; we are enthused about the effort to double the NSF budget by $1.8 billion in five years' time; we think it is highly desirable to map the human genome, which will cost several billions of dollars; and we surely are not against NASA's new surge for a space shuttle, space exploration, and the establishment of a permanent space station, even though it will cost several billions of dollars. But where in that list of priorities does agricultural research stand?

Erich Bloch, NSF director, in a recent editorial in *Science,* said it best when he pointed out that the success of America as a worldwide competitor in international trade is going to be vested in its knowledge base. The continuous production of new knowledge to ensure a competitive advantage is the business of research. If the Hatch centennial has any meaning at all, it is to recommit ourselves to this effort and to assure that adequate resources are provided to assure achievement of our national goals in agriculture.

The Public View of Agriculture

Jerry Perkins

Des Moines Register

This was a very different world one hundred years ago, when Missouri Congressman William H. Hatch sponsored the Hatch Act. Just seven years earlier, in 1880, the Commerce Department had conducted the first agricultural census of the United States, and it found that 44 percent of the American people lived on 4.4 million farms, with an average size of 134 acres. The average age of farmers then was 39.5 years, and the average farm sold $552 of agricultural products a year. That is about the value of what a Central American peasant farmer sells nowadays. The total farm product sales in 1880 were $2.2 billion.

In 1982, 102 years later, the last time the agricultural census was taken by the Commerce Department, it found that there were 2.2 million farms in the United States, with an average size of 440 acres. The average age of farm operators had risen to 50 years, and the average farm sold $58,858 of products annually.

Of course, the concentration of farms into fewer and fewer hands that the recent agricultural census shows is expected to continue into the near future. The Congressional Office of Technology Assessment, in a March 1986 report, has said that by the year 2000 almost half of the 2.2 million farms counted in 1982 will have disappeared. And of the 1.2 million farms that survive, 50,000 "superfarms" will produce 75 percent of the nation's food.

I bring up all these statistics because I believe public support of agricultural research will depend in large measure on the public's perception of the farm sector. And I believe the public's perception of farming will be altered if the character of America's farm system shifts from a family-based system to a corporate one.

During this most recent cycle of farm depression, farming and farmers have benefited greatly, I believe, from public support and generous government farm programs and payments because of the positive image that farmers hold in the public's mind. Farmers, of course, are very aware of the critical role of public opinion, as should be the case for such a tiny minority, which makes up just 3 percent of the U.S. population.

An example of this concern about getting the message out about what is happening on the farm occurred in August 1983, when the Drought '83 Committee of Davis County, Iowa, held a rally on the courthouse steps in Bloomfield, southern Iowa. Temperatures that summer had soared over 100 degrees for months, and it had been one of the driest summers in fifty years in Iowa.

One of the leaders of the Drought '83 Committee was a fifty-year-old farmer named Clyde Knapp, who served as spokesman for the committee throughout much of its short life that year. The cameras liked Clyde's grizzled face, and they zoomed in on him after the rally for an assessment.

"Would you rate this rally a success?" one of the TV reporters asked Clyde after the speeches were done and the politicians had left.

Clyde said he thought the rally definitely was a success. "We had the three major networks and newspapers from three different countries," Clyde said earnestly, not one whit aware of the humor most of the big city reporters found in his words.

Getting the word out about the searing drought was serious business that summer, and Clyde and the other members of Drought '83 knew that if they were to get the aid they would need to continue in farming, the American people would have to be told of their plight.

As a journalist based in Iowa, I have had a front-row seat during the crisis that has gripped the farm sector in recent years. I have fielded calls from journalists from Canada, Europe, and Australia, as well as innumerable inquiries from the media in this country.

I would like to comment on the media's performance because public opinion on farming in this country is molded to a great extent by the way the media reports the story, as Clyde Knapp knew very well. I have found, almost without exception, that the public has been very well served by the media. There has been an occasional slip-up, as when one big city newspaper reported that soybeans were pearly white, or another big-city newspaper listed an Iowa farmer's crops as soybeans and cotton. It is hard to find a cotton gin in Iowa these days.

With those rather puny exceptions—and as a working reporter I assume that those mistakes were added by the copy desk and not written originally by the reporter—I believe the media has accurately portrayed the very real pain and suffering that has gone on in the corn belt and much of the farm sector. Reporters have usually stepped out from behind the statistics to focus on the very real people who have been affected by the crisis.

I do not think any of us should be surprised that the American public supports farming with its tax dollars, nor should we be surprised with the results of two polls I will quote later on that show just how deep that support runs. But as a check on the polls, I asked three people who have a lot more contact with the public outside of Iowa than I do what their perceptions were of public opinion regarding agriculture.

Naioma Benson is from Colorado and is national president of Women Involved in Farm Economics (WIFE). She also chairs the Rural-Urban Action Campaign, which is a coalition of twelve farm, consumer, religious, and labor organizations that claim 70 million members.

"I'm not sure the American public thinks a lot about farming," Benson told me recently, "because most of them think milk comes from the grocery store. But if they don't understand agriculture well, there is still a warm, fuzzy feeling about agriculture and farms. They say things like 'Farmers are the backbone of the country' more than farmers themselves do."

Neil Harl, the distinguished farm economist and agricultural law expert from Iowa State University, told me he has found a high degree of understanding among the American public about what is happening to today's farmers. Indeed, Harl recently returned from a trip to Australia, and he said he found a surprisingly good level of awareness Down Under about farming in the United States today.

But he agrees with Naioma Benson that understanding does not run very deep. There is no universal understanding of the two problems plaguing agriculture—too much debt held by too few hands and overproduction. But the level of awareness that there are very real problems in agriculture today is very, very high, Harl has found.

The third person I would like to quote is the Reverend David Ostendorf, who is director of Prairie Fire in Des Moines, a farm advocate who spoke out early on the farm crisis in Iowa. He says that in some cases people outside the Midwest understand what is happening better than some people within the Midwest. But, he is quick to add, their understanding that the farm crisis of the 1980s can become the food crisis of the 1990s is hampered by the abundance of cheap food that the American public finds on the supermarket shelves.

It is at the supermarket shelf, of course, that most Americans come face to face with their food delivery system. And that might be a good place to begin in discussing the two polls I mentioned earlier about the public's perception of farming.

The first poll was taken in early December 1985 by a marketing research firm for a group called Communicating for Agriculture, a nonprofit, nonpartisan rural association based in Fergus Falls, Minnesota. The poll, which was taken by random telephone calls to two hundred consumers, tested reaction to a special one-year, 1 percent tax on groceries that would raise an estimated $4 billion that would be spent to aid America's farmers.

According to the USDA statistics, Americans spent $363 billion on food in 1983, or about $1,558 per capita for a year. A 1 percent tax would add about $16 to each American's food bill annually to raise that $4 billion in farm support. One-half of those persons polled said they spent $50 to $75 per week on groceries. Here are a few of the results: 94 percent said they had heard of the farmers' plight, and 95 percent said they were very or somewhat concerned about the loss of one-fourth of the nation's farms. Only 5 percent said they were not at all concerned. To 85 percent it was very, or somewhat, important that the food they consumed be raised on family farms rather than corporate farms. Although 13 percent said they felt the quality of food from corporate farms would be better, only 30 percent felt food raised on corporate farms would be cheaper than food from family farms. Asked if they would be willing to pay a 1 percent tax on food to support programs to aid America's family farms, 68 percent said yes, 25 percent said no, and 7 percent were undecided.

The high level of support among the respondents to this poll surprised many of the members of Communicating for Agriculture, most of whom lived in rural America. Those Communicating for Agriculture members felt that just 18 percent of the consumers polled would support such a food tax, rather than the 68 percent that I mentioned did, in fact, support it. That disparity led Rollie Lake, president of Communicating for Agriculture, to conclude that the poll "reveals a communications gap between city and country." Lake also said the survey reaffirms our belief that Americans support family farms.

In 1985 another poll was commissioned by AgFocus and taken by the Gallup organization. AgFocus is a nonprofit organization developed out of the National Governors' Association and was founded to look into the agricultural issues of the 1980s. The organization decided to conduct an extensive survey of the public's understanding of agricultural issues, and the poll was based on 1,507 interviews. What was also interesting was that a group of so-called "thought leaders," including twenty-five U.S. senators and representatives, their aides, journalists, business leaders, academics, and state government leaders, was also polled.

Surprisingly, to me at least, half of those polled said they had friends or relatives who were farmers, although only 33 percent of those from the eastern states had so close a connection with the farm. And yet, even though many of those polled had close connections with farmers, most of them underestimated farm income, and only 29 percent correctly stated that farmers make up less than 5 percent of the population.

Respondents also underestimated the amount of the food dollar that goes to the farmer, and only a small percentage thought farmers were most responsible for food price increases. Of the respondents, 46 percent thought food would be more expensive if raised on a corporate farm, and 30 percent thought corporate farm food would be cheaper; 49 percent said the government has not helped farmers enough; 26 percent thought government help has been about right, and 13 percent thought the government has helped too much.

I think these polls show a broad-based support for family farms, if not a great understanding about what a family farm is, or even, really, what the family farm does.

The section of the Gallup poll that bears the most relevance to discussion on the Hatch Act is the one on modern farming practices. The poll's respondents were split on whether the impacts of modern farming techniques were positive or negative. A majority thought modern farming practices would have a positive effect on the food supply, citing increased production most frequently. In relation to the impact of agriculture on the environment, however, pesticides and insecticides were mentioned most often, and most of those who mentioned them thought they affected the environment in a negative way.

What does the future hold for public support of agriculture and the research that has contributed to its ability to feed America's people so well and so cheaply that overeating in this country is a leading health problem? Public opinion, like mercury, is hard to pin down, but it seems clear to me that the American public will continue using tax dollars to support farmers. There are two wild cards in the deck, however, that may have a large say in just how much the American taxpayer is willing to ante up for agriculture. Those wild cards are biotechnology, which promises or threatens, depending on one's point of view, to revolutionize agriculture in the very near future, and the continued concentration of farms in fewer and fewer hands.

I question whether that warm, fuzzy feeling that Naioma Benson described as the public's opinion about agriculture will continue if we are fed by fifty thousand "superfarms" using computer-guided tractors rolling over synthetic farm fields.

The National Agricultural Research and Extension Users Advisory Board recently made a report to the president and the Congress, calling for new emphasis on profitability and competitiveness. What I found most intriguing in the report was the recommendation that new technology be made available to all farmers, regardless of skill level or size, and that support be given only to those innovations that will be of continuing economic benefit not only to agriculture but also to consumers and taxpayers.

If during the next one hundred years these recommendations are followed, the American public, I believe, will support agricultural research in its vital function of feeding us all.

DISCUSSION

Q. Would you give us your definition of a "family farm"?

A. That's a little bit like asking me to describe "obscene." I know it when I see it, but I'm not sure I can put it into words. A family farm is an economic unit that contains one or more individuals bonded by a familial tie that raises agricultural products in the United States. We can put an acreage limit on it, and the Census Bureau has a different definition than the USDA, but I think I'm trying to give the broadest, most general definition I can. It is true, if I could anticipate a little bit where you're leading me here, that many family farms nowadays are incorporated and so might be called corporate farms. And so then you ask, what is the difference between a family farm and a corporate farm? I can't come up with a clear dividing line that says that one group is family farms and another group is corporate farms. But I think that there is a subjective area where the family is on the farm for reasons other than profit. That brings us into the way-of-life philosophy. Corporate farms in the United States are not extensive, especially not in the Midwest, where we primarily raise livestock, corn, and beans. You find them more in vegetables and other sectors.

Q. In 1980 I attended a World Food and Hunger Conference, sponsored by the Methodist church in Cincinnati. One of the long-lasting impressions that I got from that conference that troubled me immensely was that about one-third of the participants, at least in the workshop sessions that I was involved with (and these participants came from around the world, plus leaders in U.S. agriculture), seemed to have an underlying philosophy that it was immoral to make money producing food. My question is, Do you uncover any feelings like this in the surveys that you studied or among your contacts?

A. Living in a state where eight out of ten jobs depend on agriculture, I don't think you could make the statement that raising food for profit is immoral and remain very popular in Iowa. In fact, in Iowa, given the farm receipts of the last five years, we would love to roll in a little bit of sin. But the question of using food as a foreign policy weapon, or our obligation to feed the poor people of the world, is something about which many Iowans feel very strongly. I believe survey after survey has shown that supporting PL 480 and similar programs has very high support in Iowa, if for no other reason than that it helps use up some of this incredible surplus we have developed. But I think, also, that most Iowans want to support the poor people of the world, and they feel this obligation. I could cite several specific examples, for instance, the drought in the southeastern United States this year. Iowa farmers got together and donated tons and tons of hay for the southeastern U.S. farmers, and hay was sent by the train carload to the Southeast. A group of students at the University of Iowa has been raising money to buy surplus Iowa corn to send to Nicaragua, which I found interesting. I was in Nicaragua in August of 1986 and witnessed people standing in line for corn in a country where, when I was a Peace Corps volunteer in 1972, we ate a lot of corn. Because of pressures of the war and other problems with the economy (mismanagement among them) of the farming sector, there is now a shortage of corn in Nicaragua. And I think that most Iowans would probably favor sending all the corn down there that those people could eat. And then, I guess the contrary evidence, and I am including myself, is that most of us tend to think of this surplus sitting in our grain elevators and piled in huge mountains in the streets in the small towns as a curse. Really, we should probably look on it as a blessing, if we can just manage it a little bit better.

Q. My comment and question have to do with pesticides. I think you mentioned first that the media is partly responsible for the public's shallow conception. You also mentioned that one of the few areas on the minus side is pesticides. I don't think I've seen a positive article in the media in five years on pesticides, and some I have seen have been absolutely wild in their misstatements. The people in academia trying to correct these misconceptions find themselves stonewalled at every turn, including the media in Iowa.

A. My newspaper has not carried an ad from a chemical company since we published *Silent Spring,* about twenty-five years ago, so I'm probably not a very good person to comment on that. We ran a series of articles a year or so ago by another reporter on groundwater contamination by pesticides and insecticides, and in it we did a good job of addressing both sides of the issue of groundwater pollution by insecticides and pesticides. Other than that I don't feel that I can respond to your general comments very well. Your point is well taken. Probably we haven't done all we should to listen to both sides of the story; but when you work for a general interest newspaper, you find that you try to give both sides, and you try to present the argument in a way that my gray-haired mother sitting at home in Des Moines will understand and hope that you do a fairly good job of going right down the middle.

Partnership in Research—Industry

William L. Brown

Pioneer Hi-Bred International, Inc.

We are celebrating the one hundredth anniversary of the Hatch Act and the enormously productive era of agricultural research stimulated and nurtured by that act. Yet we should not forget that agricultural research did not begin with the Hatch Act but was practiced by both industry and public institutions years before 1887. The famous French seed firm of Louis de Vilmorin, established in 1727, was doing some very sophisticated plant breeding by the mid-1850s. The Vilmorin initiative was soon followed by similar activities in England, Germany, and other parts of Europe.

That bit of history may serve as an appropriate introduction to my comments on private research in agriculture and its relationship to similar areas of public research.

Rather than attempt to cover a large number of agricultural research disciplines, I shall limit my comments to genetics and plant breeding. I make this choice because it is in this area that I have the greatest amount of knowledge and experience. Also, I believe that with respect to both private and public sector involvement and cooperation, it is an area that is fairly typical of other segments of agricultural research.

Again, from the historical standpoint, those young researchers who are now enjoying the opportunities, the prestige, and the perquisites that go with employment in industry today should be aware of the attitude toward industrial researchers in genetics and plant breeding, at least, the attitude that prevailed as recently as forty years ago. At that time, positions were not easy to come by, and competition was keen for any opportunities that did develop. It was generally assumed, then, that the most able and the best-prepared individuals were rewarded with positions in academia and the experiment stations, whereas the less able took positions in industry.

I still recall with considerable amusement the reaction to my own choice of a career in the early 1940s. After a relatively short "educational experience" in the USDA, I deliberately chose a research career in the private sector. Several public institutions offered me positions at that time, and none of the department heads or administrators with whom I was in contact could understand why one would take a position in industry when more prestigious and secure positions were available in public institutions. Fortunately, those attitudes have now changed.

Notwithstanding the early gap between agricultural researchers in public institutions and private organizations, in more recent years the two groups have shown a high degree of cooperation, and in many instances they have developed true partnerships that have proven to be mutually advantageous and productive. This tendency seemingly is continuing to increase.

Perhaps one of the oldest and still best examples of cooperation between the public and private sectors has been in the development of hybrid maize. This is a unique example that, I believe, is not duplicated anywhere else in the world.

In the early days of hybrid maize, most of the research was done by the land-grant universities, the USDA, and the state experiment stations. This included almost all of the plant breeding, as well as some of the practical agronomic research applicable to seed production. There also emerged early in this business a few private enterprises engaged in seed production and marketing. Without exception, these enterprises were started as very small operations. Most were inadequately financed, and as a result their future was far from assured. A very few of them grew out of small, private breeding programs. Others, recognizing the competitiveness of the business, added breeding to their operations at a very early date.

Hybrid seed maize was, of course, a completely new phenomenon with no knowledge base or research data from which to draw. No one knew whether this new product would be accepted by the farmer or, if accepted, what organizations would be required to produce and market the seed. Some experiment station administrators felt that the experiment station's role in developing hybrid seed corn was not only to breed but to produce seed. Those who took this position looked upon the production and sale of seed not only as a service to agriculture but, perhaps more important, as a source of additional income for the station. Other, and I think perhaps wiser, heads viewed seed production and marketing as strictly a private sector enterprise. Fortunately, the latter idea prevailed, a potentially competitive situation between public and private sectors was avoided, and, instead, a remarkably successful partnership was adopted, which has survived to this day.

In addition to seed production, much of plant breeding and genetic research related to hybrid maize has been absorbed by industry. Yet the public sector continues a reduced, but nonetheless significant, role in these areas. There is close cooperation between the two groups, which involves not only the exchange of ideas and information but also breeding materials in various stages of development.

The question is sometimes asked, in both industrial and academic circles, why it is necessary or even desirable for public breeders to continue working with crops in which industry is highly involved and seems to be perfectly capable of providing the farmer with new varieties and hybrids adequate to meet current and future needs. Among those who raise this question, most seem to feel that duplication in breeding is inefficient, expensive, unnecessary, and to be avoided.

I personally take a different view of these activities, although I recognize that my opinions probably do not represent the majority. I believe there is merit in simultaneously having both public and private groups engaged in development of new varieties, even though either group could, if need be, meet the growers' needs independently. I take this position for several reasons. Even though two equally productive breeders may use similar breeding materials from which to develop varieties to meet similar environmental and maturity conditions, the chances are that the varieties developed by each will be sufficiently different to be viewed as being distinct. Although all breeders recognize a common group of traits for which each selects, individual preferences will result in recognizable differences in the two sets of varieties reaching commerce. As a result of these differences, the germplasm base is somewhat expanded beyond what it might otherwise be, and that is a real advantage.

Many breeders in the public institutions are also engaged in training graduate students. Some hands-on experience during this training period is, it seems to me, of considerable value to the student. In the absence of an active plant breeding program, teachers are unable to provide that extra bit of practical training which could very well mean the difference between a mediocre and an excellent program.

Most breeders today have a sense of responsibility and, consequently, release to the public only varieties of merit. Yet there are advantages to competition even in plant breeding and, not surprisingly, one occasionally encounters a breeder who seems to be a bit biased in favor of his or her own creations. It is helpful, therefore, to the ultimate user of new cultivars to have all new introductions compete with the best the public and private organizations have to offer. I have observed that when this happens the farmer will almost invariably choose those varieties best for him. Modern advertising may bring new varieties to the attention of the farmer, but, in my opinion, has little to do with his final choice.

Many references were made in earlier papers to the outstanding record of contributions to our system of agricultural experiment stations to agricultural production in this country. That record has been outstanding, everyone agrees, and the nation should be grateful for it. Yet our system of joint federal-state agricultural research cannot rest on its laurels or continue to bask in the glory of the past. We all know that the needs of agricultural research today are vastly different from those of twenty-five years ago. If the future contributions of molecular and cellular biology to agriculture are to be realized to their full potential, the research direction of the agricultural experiment station is going to have to change markedly. Yet among those institutions, some are following the same pattern of research as practiced a quarter of a century ago and are either unaware or unconcerned about what is happening in the new fields of molecular and cellular genetics.

That attitude is going to have to change if the future of agricultural research is to continue at the same level we have enjoyed in the past, and certainly those attitudes are going to have to change if we are to take full advantage of these new technologies. In these times of budget constraints there is no excuse for this ignorance or neglect, which, incidentally, should not and, we may hope, will not be tolerated by the taxpayer.

Both groups will not be extensively cooperating in the basic or fundamental research areas. Notwithstanding the changes that are taking place in agricultural technology, which have led to some increase in basic research within industry, particularly in molecular biology, most private research organizations will not become deeply immersed in those areas in the future. Industrial organizations support their research with income derived from product sales. That is their only source of support. The high risk associated with basic research, therefore, essentially eliminates this activity from interest within industry. Consequently, the public institutions will continue to be expected to meet this need. It is one area of research need in agriculture about which I worry a great deal.

It seems to me that although the need for new knowledge is widely recognized by scientists and research administrators, the increase in constant dollars for support of fundamental research is minimal. Should this trend continue much longer, we could soon face a situation in which the well of new knowledge has dried up and the sources of developing technology are depleted. Such a situation could lead to a wide gap in the available versus the needed knowledge base. Playing "catch up" in this game is a long and very expensive process. I hope, for these reasons, that the public sector is fully cognizant of this problem and is prepared to meet our fundamental research needs adequately now and in the future. Again, I am confident this will not be done by industry—either independently or cooperatively.

DISCUSSION

Q: I applaud your position on the merit of private and public sector research in varietal results. I think you have made a very important statement. I would like to ask if you think there is potential for work in maize, first with open-pollinated varieties, and second then with apomictic hybrids, and where it should or not occur, in your view.

A: There certainly are needs for what you refer to as open-pollinated varieties in maize in some parts of the world. I would refer to them as "improved populations," which can be reproduced without bringing in the techniques of annual hybridization and could bring to parts of the developing world improved maize productivity at a lower cost than could be made going the hybrid route. There is a place for that. There is no place for that in the developed world, in my opinion. There are no improved populations that are comparable in performance to the best hybrids that can be developed from those populations, and therefore, there is no reason for the developed world to be interested in that approach.

On the second question, referring to apomictic hybrids, yes, there would be a place for those, should the techniques and the biology that makes them possible be developed. The questioner is asking whether or not a process of apomixis, which is vegetative reproduction through seeds, could have a role in the perpetuation of hybrid varieties without going through the process of making those hybrids each year. Should that become possible, it would be used. It is not possible to do that now. We do not have apomixis in most of the species in which hybrids are being used. But if those techniques should be developed, I am sure that advantage would be taken of that phenomenon.

Q: You stressed the importance of attitudes and attitude adjustments. From your position in industry I'd like to hear your comments on whether you see a potential for sabbatical leaves in industry somewhat similar to those in academia, and whether there might be opportunities for some exchanges on sabbatical leave between the two groups so as to enhance attitude adjustment and cooperative and understanding attitudes.

A: Thank you for a very interesting question and one that I have been concerned about for a long, long time. Those opportunities are not available now, to any general extent, to my knowledge. In the company that I was with for many, many years we have attempted to provide sabbaticals for our people who we felt could use them to advantage, and they have been used to some extent, but not to the extent I had hoped they might be once they became available. We do provide, in our own organization, the opportunity, not frequently, but occasionally, for research people from the universities and from the public groups to spend time with us, either on an annual basis for several months, or whatever. But I do not think those opportunities are generally available. Why, I don't know. I think it would be mutually advantageous if they were, and I would like to see the idea promoted.

Q: You have indicated that the experiment stations (at least I interpreted you to say this) should perhaps reinvestigate their priorities, reorder their priorities, and you emphasized more basic biotechnology research. Which of the historic roles that we have played or activities we have engaged in do you think we should move away from to free up the resources to do those things?

A: In my opinion, one of the constraints on agricultural science today is a lack of knowledge of some basic biological processes which operate in all organisms. Research to elucidate these processes should have high priority. When I said earlier what I did about those institutions continuing in varietal development, I recognized that was going to be difficult to do if these institutions moved into new areas. But I think the research administrators of the experiment stations today need to think hard and long and seriously about the real needs in agricultural research, and I think you can't do that very long or very seriously without coming up with a need for greater emphasis on basic work. That work is going to have to be done by the public institutions; and if it means curtailing some of the more practical agronomic research that is being done, I think it would be a good move to go in that direction. I think some of the experiment stations are still doing what they were doing twenty-five years ago because they haven't thought about what they are doing, and I think there is some so-called very practical research whose value I question, particularly when one compares those needs with the needs in the more fundamental, basic areas.

I recognize that not everyone can do everything. Individuals have limitations, and the people who are doing practical research in field crops or agronomy are not going to be able to do very much, probably, in molecular biology. But it seems to me that these changes need to be recognized and as personnel are replaced through retirement and what not, the move should be at least to some degree more toward supporting the basic areas than has been true in the past. I think the needs are greater there, and I think the stations need to recognize those needs.

Q: Along those same lines, I take it you would, however, think that we should continue to do germplasm maintenance and germplasm enrichment, which has been a public function right along; but unfortunately, the public sector does not want to support that research as handsomely as it did once in the past. Out of this are growing requests for us for user fees from the Office of Management and Budget; and they have gone one step further to support plant breeders in some institutions (this, fortunately, is not one of them) because the trustees are insisting that any varieties that do come out be patented and then all sorts of bad things go from that point on, including selling proprietary seeds with variety unspecified. How do we support the basic old-fashioned germplasm maintenance and enrichment?

A: That's a very difficult question, as you well know. Philosophically, I am opposed to patenting. Philosophically, I am opposed to charging for germplasm. I think the system that has worked so well in the world up to the present time has so many advantages that if we lose it we lose something fundamental. At the same time, I think we are sticking our heads in the sand if we feel we are not going to change. I think we are going to see more and more plant patenting. We are going to see more and more sale of germplasm, which, I suppose, may be necessary; but if it happens, it will deter the free exchange we have had in the past, which had many advantages, and it will deter not only the exchange of material but the exchange of ideas and information as well. I think we have to face that. It's here, and it's going to grow, and I don't believe there is anything we can do to stop it, although I wish we could.

Q: A little bit along the same line—the changing in support of your suggestions that universities work in more basic areas—do you, in that sense, see a company such as you have been with and other companies being willing to support that basic area, and to what extent do you see them doing so?

A: I can only speak for the company that I have been associated with for some time. We have supported basic research in some of the public institutions, we have felt, for us, rather liberally, and I think we are continuing to do it. One reason we have done it is that we felt it might encourage others in our position to do it. That has not happened to the extent I had hoped it might, but that doesn't mean we should quit trying. I think the private organizations do have some obligation to support that kind of work in the universities, and I'm all in favor of it. I think it's not only an opportunity, I think it's an obligation, especially in times like these, when the usual sources of funds are not as available as they once were.

Q: There is considerable competition among private breeders in some parts of the country, and I suspect that competition is going to increase. Do you have any suggestions for dealing with that competition?

A: I think it's good. I think the more competition we can have in breeding the more the consumer is going to profit. I think I pointed out that there is competition in plant breeding, and I would hope to see it increase. The more competition there is, the more and better the work that will be done; so I welcome it, from wherever it comes.

Partnership in Research—Extension

James H. Anderson

Michigan State University

During the years from 1820 to 1850, the new phenomenon called Jacksonian Democracy brought a new social, political, and geographical mobility that greatly altered American life. With the development of this new open society, people began to question the inherited educational system. American society was too democratic to accept the idea of a gentleman's education. It was too dynamic to accept its fixed character; and it was, perhaps, too practical to accept its classical content. As the nation pushed toward the frontier, so did higher education. New colleges of science and mechanics were set up, and they were in tune with the needs of an expanding society and the booming industrial revolution. Expanding industry was creating a need for technically able workers, and many of these new colleges found benefactors in the nation's railroad men, investors, and industrialists.

Although education made great strides in the years from 1820 to 1850, most Americans felt there was still much to be done. For example, there was a need for improved practices in agriculture, specifically in the areas of cultivation and husbandry. Many farmers at this time had a high suspicion of "book learning." But there was a small group of visionary agriculturists who felt that technical education had value for agriculture as well as industry. Even though farmers could obtain information from such sources as the Patent Office, farm journals, and books on agriculture, there was a growing interest in the establishment of agricultural schools and experimental farms. In 1855, agricultural schools were established in Iowa, Pennsylvania, Massachusetts, and Michigan.

In 1862, the Morrill Act formally ushered in the most revolutionary form of education in the history of mankind. It was the beginning of the development of what we have come to call the land-grant mandate—to promote the liberal and practical education of the agricultural and industrial classes in the several pursuits and professions of life. That mandate called not only for a liberal education but for a practical education in applied professions and vocations. Furthermore, such education was to be offered to the agricultural and industrial classes—it was dedicated to the education of the disadvantaged, or those who, in the biblical sense, worked by the sweat of their brow to earn their bread. The trademark of the system is the tripartite division of functions into instruction, research, and public service. Obviously, instruction and research were not new activities for colleges and universities. Instruction was a universal priority in both the United States and the European systems. Furthermore, most universities tended to develop into centers for the generation of new knowledge. The idea that an institution of higher learning should become engaged in public service was a radical departure but certainly not radical enough to explain the success of the land-grant experiment. The genius of the land-grant system was not any one of these activities alone, but the integration of all three into an interacting, reinforcing, and responsive approach to education.

The modern land-grant university is a unique institution and unlike any other in the state. With a variety of comprehensive programs in teaching, research, public service, and international activities, the university has an opportunity to identify and solve problems facing society on a broad front. The collective energies of the university must be focused on carrying out the mandate for which the university was created; however, that mandate is much more comprehensive today than it was in 1862 when the Morrill Act was passed. In 1862 most of the population was rural and engaged in agriculture—farmers who lived on the land. Today's "agricultural and industrial classes" include both rural and urban dwellers, and for the most part they are employed in education, science, manufacturing, skilled and unskilled trades, service, management, and the arts and humanities, as well as farming and agribusiness. Clearly, the programmatic commitment of a modern land-grant university encompasses much more than what the founding fathers envisioned. The modern mandate is to develop programmatic excellence in all activities and to embrace a philosophy that moves the university beyond the ivory towers of academia. To do less is to forfeit the confidence and trust of the people who support the university and its various educational, research and outreach programs.

The Present Situation

Historically, the roots of the land-grant system have been deeply embedded in agriculture.The future, however, demands that the tripartite function of instruction, research, and public service be extended and broadened to other segments of the university. The university is a tremendous resource that belongs to the people, and ways must be found to extend that resource to other segments of society. Obviously, the university cannot be all things to all people. Therefore, procedures must be developed whereby the special strengths and skills of the university can be brought to bear on critical societal problems. Tremendous changes are taking place in society, and it is imperative that the university address problems inherent in these sweeping changes.

Society is feeling the pressure of a shift from an agricultural- and industrial-based economy to an information era in which high technology, communication sciences, and service industries will become much more prominent. Our population patterns are changing. Growth has slowed. The population is aging, and urban migration is being reversed in many sections of the country, with smaller rural areas attracting new residents. A period of economic recession has left families and businesses with minimal reserves and strained finances. Likewise, public institutions have lost much of their programming flexibility and faced increased demands with reduced resources. The quality of our environment is threatened, not only by past abuses but by continuing contamination and degradation. Communities are rapidly changing—some declining and some exploding. Because of these changes, coupled with state and federal policy shifts, many local government units now face a severe revenue service squeeze. The passage of the Gramm-Rudman-Hollings legislation further exacerbates this problem, not only for communities and state government but also for institutions of higher education.

The Years Ahead

The years ahead hold great promise for the land-grant system. Fulfillment of that promise depends upon how well we provide leadership in defining and addressing emerging issues and challenges. Since the future will be characterized by many changes, it is essential that we make the right choices. Success in making the right choices will be largely determined by our willingness critically to analyze every facet of our activities and our collective vision of the future.

John Naisbitt, author of *Megatrends,* is probably one of the most quoted futurists in recent times. I believe Naisbitt's words (paraphrased from the last chapter of *Megatrends)* are particularly appropriate as we try to catch some vision of that future and some idea of the changes, challenges, and choices that will inevitably be ours.

> We are living in the time of the parenthesis, the time between eras. It is as though we have bracketed off the present from both the past and the future . . . we have not quite left behind the past . . . but we have not embraced the future, either. We have done the human things: we are clinging to the known past in fear of the unknown future . . . those who are willing to handle the ambiguity of this in-between period and to anticipate the new era will be a quantum leap ahead of those who hold on to the past. The time of the parenthesis is a time of change and questioning . . . although the time between eras is uncertain, it is a great and yeasty time, filled with opportunity. If we can only learn to make uncertainty our friend, we can achieve much more than in stable eras. In stable eras, everything has a name and everything knows its place, and we can leverage very little. But in the time of the parenthesis we have extraordinary leverage and influence—individually, professionally, and institutionally—if we can only get a clear vision of the road ahead. My God, what a fantastic time to be alive!

I believe Naisbitt is accurate in characterizing our time. It is a time of change and questioning, but it is also a time of choice. If we are to make the right choice, we must catch some glimpse of the future and some idea of the road ahead. As we contemplate the future, we must remember that history is replete with examples of predictions that turned out to be wrong. Lord Kelvin, the great physicist, expressed his belief in 1895 that "heavier than air flying machines are impossible." Lee DeForest, inventor of the vacuum tube, argued in 1926 that commercial television was "a development of which we need waste little time dreaming." And Admiral William Leahy, President Harry Truman's chief of staff, warned in 1945 that "the atomic bomb will never go off, and I speak as an expert on explosives." Small wonder then, as Winston Churchill sarcastically observed, "It is much safer to wait until an event has taken place before prophesying its outcome." As a university community, though, we do not have the luxury of waiting for the outcome if we expect to have a hand in shaping the world of tomorrow.

Let us now focus our attention on several items that will be essential for us to consider as we plan for the future.

- The changing technology, structure, and environment of agriculture and natural resources and the consequent obsolescence of many of the institutions that serve agriculture require us to devote more effort to adapting our institutions, developing new institutions to serve agriculture, and understanding the structure of agriculture as it evolves. The breakdown of family structure, the apparent erosion of the infrastructure in rural communities, and the out-of-school developmental needs of youth are all areas that leaders have a special responsibility to address.

- Budget restraint will probably continue at the state and national levels, and careful attention must be given to redirecting efforts as well as to outlining additional resource requirements as priorities are established and new challenges are outlined. Planning and the establishment of priorities must be viewed as mechanisms for redirecting existing resources, as well as for obligating new resources. This will require leadership of all levels within the faculty and administration of the university.
- Environmental concerns necessitate that more attention be paid to the externalities of developments in scientific research. The adverse impacts, as well as the benefits of new developments, must be determined and evaluated. This places a new dimension on our research activities and means that research in the future will become more costly. This dimension must be incorporated into research planning, and it is imperative that we lead rather than react.
- The development of microelectronics/computers/robotics has greatly expanded our capacity for data acquisition, analysis, and information transfer. This is revolutionizing our life in many ways; however, the development of rapid information transfer systems will continue to affect the total educational enterprise. It is just a matter of time before uplinks and downlinks are established with every county and with other universities throughout the nation. Increasingly, we will be able to tap larger and larger data banks and deliver information with a great deal more specificity and with a timeliness that has heretofore been impossible. Timely information is a valuable commodity, and the university must continually upgrade not only the information transfer systems but also the professional skills of the faculty so that they can take full advantage of new developments. This new technology has particular relevance for Cooperative Extension and lifelong education programs.

- The rapid expansion of knowledge in the biological sciences offers great promise for the development of a new generation of agricultural technology and one that is more science-based and less resource-based. Developments in the basic biological sciences will bring about technological developments that are impossible for us to conceive at the present time. Until mechanization proliferated in the nineteenth century, farming had changed so slowly through the ages, the story goes, that if a farmer from the time of the Pharoahs in ancient Egypt had appeared on George Washington's farm, he would have been able to recognize the tools and pitch in with the work without instruction.
- Scientific developments in the last fifty years have revolutionized all facets of agriculture, and a person from the turn of the century would be completely confused if he or she were to appear on a modern farm today. I believe the next thirty years will bring about an even more drastic revolution as science spawns a new generation of technology. For the first time in the history of mankind, we are learning enough about the basic processes that take place in living systems, both plants and animals, to be able to manipulate them in a controlled or planned way. This is a tremendous challenge, and the university must take the lead in the application of the new developments taking place in basic biology. This is a major challenge but one that will pay great dividends.

The modern farm tractor is a symbol of the rapid changes that have taken place in agriculture, signifying the switch to mechanical power from the millennia of animal power. Furthermore, the ammonia tank and the sprayer symbolize the adoption of chemicals for fertilization and pest control after centuries of dependence on less effective methods. Will a gene or a chromosome or something that stands for molecular manipulation of plant and animal cells be the symbol for the agriculture of tomorrow? I believe it will because the emerging science of biotechnology seems poised to revolutionize the ancient calling of farming. The engine of change, begun less than fifteen years ago with the first successful directed implant of foreign genetic material into a host microorganism, has built up a head of steam. It is chugging along now from the laboratory to the farm, still relatively slowly, but getting faster every day. When it reaches full speed, perhaps early in the twenty-first century, watch out. Farming practices are likely to be as different from today's as today's are from the pretractor, prechemical era.

As we gear up to capitalize on biotechnology, we must continue to strengthen the mission-oriented basic research and also greatly expand basic research in biology. Consequently, it will be necessary for the agricultural experiment stations to redirect existing resources into long-range, mission-oriented basic research. Since we will not have sufficient resources to finance this thrust completely, the interface between research and extension will shift and many of the developmental activities now being done by the experiment station will more appropriately be done by extension in the future. The more powerful information transfer techniques such as computer networks, interactive video, and video cassettes will enable extension to serve present clientele and expand into additional areas as societal needs change. It will also be necessary for extension to eliminate some of the more routine services it has performed in the past. Extension will be increasingly called upon to serve the nonagricultural public and, in my judgment, this will add a great deal of support to both the university and the college of agriculture.

Many retirements will occur in the next few years, and we will have an opportunity to redirect the activities of the entire college in a way that has not been possible in the last thirty years. Strategic staffing plans must be developed by all departments and units within the college. These plans will be invaluable as vacancies are filled because we cannot afford to make new staffing commitments from a short-range perspective. If we do, we are apt to recreate a staff with similar characteristics to that of the last thirty years. This is one of our greatest challenges because of pressures from clientele.

It is obvious that the university will not be doing business as usual in the future. I am confident that we will be able to respond to the many challenges implicit in the foregoing discussion. We will chart new frontiers in research, develop new and innovative information transfer systems that will allow our outreach programs to be more effective, and design new curricula that effectively integrate subject matter from a holistic point of view, rather than from the perspective of a single discipline, incorporating more information on other cultures, languages, economics, and biological sciences. Further, we will maintain leadership in our international programs because we are a part of the international community. To do all these things it will be absolutely necessary that teaching, research, extension, and international activities continue to be integrated in such a way that they reinforce each other. Further, it is essential to use the interface between research and extension if we are to minimize the time between the development and application of knowledge. Universities cannot afford obsolescence among faculty and staff, and it is imperative that they be provided with continual opportunities to update and expand their knowledge base through sabbaticals, short-term leaves, and participation in a wide array of professional activities.

I look to the future with a great deal of confidence and enthusiasm, and I believe the partnership between research and extension will remain strong and viable. The land-grant system has responded to changes and challenges in the past, and I am sure it will continue to do so in the future.

DISCUSSION

Q: You said extension and the land-grant system must broaden their mission. You have also said that they cannot be all things to all people. How do we decide where, between those two, we build on strength rather than stretch ourselves too thin?

A: That's a good question. Also, you missed one point. I also said that we must establish our priorities. I think that each institution must look at its own special strengths and skills and then chart out both its research and extension programs to fit them. I can contrast the state I came from, Mississippi, to the situation at Michigan State. The research program is entirely different at Mississippi State than it is at Michigan State. The program at Mississippi State is directed much more toward applied research. I do not expect that Mississippi State could accomplish what Michigan State or Cornell could in biotechnology. And so that is what each of us must chart out—the priorities, built on the strength that exists at any one institution.

It seems to me as I interact with leaders across the state that there is a recognition that knowledge is power. In other segments of society we have many institutes and centers springing up, not only in the college of agriculture but in other segments of agriculture. They are all concerned with extending knowledge. I think extension is going to become a facilitator of information transfer in many cases. Much of the new high biotech is not going out through traditional extension channels. It may be going out through a connection in which the university is partially involved in a private enterprise because simply to put it out in a publication or a bulletin will not be adequate. There is no question, though, that the service responsibilities of extension, with all the changes that I referred to taking place in communities, will be important. I think we have to get much more involved with social scientists. We have been almost derelict in failing to call on the social sciences to help us respond to some of the needs across the land.

Q: Since we need the city legislators to help with the budgetary aspects, what are the major programs you found that are practical for 4-H and agriculture? Human ecology has done a great job in moving in to the city folks, but how could 4-H and agriculture be adapted to their use?

A: Of course the inner-city 4-H program is a very large operation. The only difference between an urban and a rural 4-H program is largely the size of the animals that are involved. The ETHNET programs have gone very well. You have urban forestry and the whole area of turfgrass. I just got a check the other day for $250,000 from a guy wanting to support a program. He services fifty-five thousand lawns in the city of Detroit, and yet he says that nowhere in the state are people being adequately trained to understand the potential health hazards of the chemicals they are using, and so he is willing to invest in such a program. In Michigan the House is controlled by Democrats in the city of Detroit, and there is no money unless they approve it. If they see there is a payoff on what we are doing, then they are quite willing to support the agriculture programs. That is what I'm talking about.

Q: Should extension specialists become more involved in the actual conduct of research? Do you see this as one of the directions of the future?

A: I see two things involving extension as I look to the future. I mentioned that I think applied developmental activities may more appropriately be the domain of the extension service. We have moved all of our research stations to research and extension centers, in which they are significantly involved in developmental application. If someone has always been involved in development, it doesn't mean he or she will immediately go into basic research. As we have opportunity to bring in new people we can shift the balance, and extension can move in and fill that void. The second idea I have about extension is the question, What kind of extension agent do you really need out in Podunk, Michigan, ten years from now? Do you need someone trained in agriculture? Or do you need a person who is an absolute master of information transfer, who knows how to tap into systems, because ten years down the road communities that are concerned with environmental problems may need service out of the College of Engineering? As we think of tapping that system, that knowledge base, do we need somebody who is agriculturally trained to a minimum amount but has most of his or her training in information transfer techniques and how to get in with the system and how to tap the data bases? I think there is going to be a lot of debate on what characteristics the extension person of the future should have.

Partnership in Research—Foundations

Theodore Smith

Consultant to the Rockefeller Foundation

In 1903 the newly organized General Education Board, a trust created by John D. Rockefeller, Sr., undertook a survey of educational needs in the American South. It had no thought of an agricultural program, but it was interested in schools. The officers of that trust had not gotten very far in their explorations before they realized that the quality of the schools depended on the size of the tax base; and the tax base, in turn, depended on agriculture. In short, little could be done to improve education until something was done to improve agriculture.

At that time the boll weevil, a pest that had immigrated from Mexico, was riding high in Texas. Seaman Knapp of the USDA established a demonstration farm in the infested region to show farmers ways to cope with the boll weevil. By such measures as careful seed selection, deep plowing in the autumn, wide spacing of plants, intensive cultivation, systematic fertilization, and the rotation of crops, Knapp had increased yields on his demonstration farm, and before long farmers were applying similar methods on their own land.

In a short span of time from that beginning in 1903, the General Education Board and the USDA (an interesting partnership at a very early stage between the U.S. government and the foundation) worked out a cooperative agreement to extend the demonstrations to other states. By 1906 they began this work, and apparently before they were through there were some one hundred thousand demonstration farms flowing from this kernel of an idea. That program, as we know, moved from cotton to include corn and other crops. Without overstating the case, it seemed clear that this particular episode of government-foundation cooperation facilitated the development and emergence of agricultural extension nationwide.

In 1923 another Rockefeller-funded trust was established, the International Education Board set up by John D. Rockefeller, Jr., and it immediately made the farm demonstration idea its first agricultural program. This board's first agricultural program director was Cornell's Albert Mann. Although I do not know the historical record in detail, it seems reasonable to credit Cornell with keying this program directly to the challenge of seeking out the most promising young scientists and assisting their development. The record shows that 233 young people from thirty-one nations were given fellowships in agriculture to prepare them for teaching, research, and administrative roles.

It was under this board's agricultural program that Cornell began its work at Nanking in China, which became the precursor to the Rockefeller Foundation's own agricultural program in China, initiated in 1935.

The extraordinary record in Mexico begun in 1943 once again benefited from Cornell's support: Richard Bradfield of Cornell served as one of a three-member advisory panel, which recommended to the Rockefeller Foundation that it establish a maize-breeding program in Mexico. One could cite the Philippines and many, many other places where Cornell and Rockefeller collaboration has been valuable.

Let me now set history aside and move to the present, focusing on international agriculture. I would like to do this more in the role of an observer than as a foundation professional. There is a set of developments in international agriculture which I find troublesome, even alarming. As I see it, a series of forces has conspired for more than a decade to depreciate the role of American universities in international development. The policies contributing to this are wrong-headed, shortsighted, and not cost-effective in the long term. These policies, which are diminishing university capabilities, are not the product of an identifiable conspiracy but rather of patterns that have become embedded in formulas for international assistance over the last twenty years.

Here is what I think are the main elements of what is wrong.

First, the mode for funding international agricultural research is increasingly restrictive. It has become almost total prisoner to the project format. Project funding is narrow and tends to be technically very specific. Paradoxically, this is happening when many of the most significant development problems appear to center on weaknesses in human institutions and shortages in scientific manpower (human resources). Many of us remember when funding supported programs, not projects, and we could much more easily move ideas and concepts across scientific boundaries and across bureaucratic jurisdictions in the developing countries. It is not that there is less money for technological development today internationally (in many respects

I think there may be more), but rather that the pie is cut very differently today. Universities are now asked to deliver technicians, not scientists or technologists.

Second, as a corollary, international technical assistance is decreasingly people-oriented. One reason is the decreased willingness of project funders to include graduate students in field projects. This policy is shortsighted from at least three standpoints: future American competence in international agriculture is being compromised; the cost of projects is being run up by the rejection of lower-priced professionals—and I include graduate students with field competence in the ranks of professionals; and finally, the recruiting pool for this country's international assistance bodies is being diminished. If I recall correctly, less than half of AID's program officers concerned with agriculture have any training in agriculture. Policies that concentrate so heavily on using rather than creating capital—especially in a rapidly changing and increasingly international world—are mindless, to a large degree.

Third, too many people assume that development assistance that is used to support or strengthen U.S.-based institutions (that is, our resource base and our historical comparative advantage) is not cost-effective. Phrased differently, their view holds that this money is better spent in Burkina Faso than at Cornell. The problems with this argument are that it is based on ideology, not on empirical findings, and that it assumes that the money sent to Burkina Faso knows what to do with itself—that it will be used well. One has only to look at the last twenty years of development assistance in Africa to know that is not true. The record of "failed" or, to put it more diplomatically, "low rate-of-return" projects, ceased to be a secret long before the recent famine stories.

Finally, there is a tendency for government and international lenders to avoid some extremely important issues because of their sensitivity—mainly issues having to do with people, not technology. These are issues which universities are often well prepared to tackle. Further, donors very often appear to be driven by immediate problems and not by longer-term interests. The first of these points is self-evident; the second simply neglects the fact that institution-building (a necessity for development) requires time periods of at least ten years and commitments to match. Unless planning and commitment horizons are lengthened, reality will continue to be treated in unrealistic ways.

I have a sense that present international development funding policies are running down or eating into the capital of America's greatest asset in international agriculture—the research university. It is my impression that the states are pulling their weight on this front to an extent that would surprise many taxpayers. I do not think that the federal government, and, to a lesser extent the major foundations, fully realize what is happening. In the years ahead Washington must recognize that international agriculture is both an international and a domestic issue for us. And I might parenthetically add here that area studies, those components of university life which bring Asia, Latin America, and Africa onto our campuses and embellish and advance our knowledge and understanding of different cultures, are under siege and have been for some time. Of the $30 million allocated in Title VI funding for area studies, $3 million goes to African studies, and that funding is split among ten campuses, of which Cornell is not one. The U.S. government is currently spending $3 million to support its premier African study centers, and I have to wonder if that isn't totally out of proportion, compared to the need.

Nor are our research universities in perfect shape, ready to deliver on every front if only additional untied funding were available. Most major universities have some peculiar struggles of their own to face. For example, important elements of modern agricultural science are now found in molecular biology, and many agricultural schools have yet to establish diplomatic relations with molecular biologists on what is often called the "other campus." The historian has not yet been connected to the plant breeder—a strange connection perhaps, but the colonial records of agricultural technology intervention in Africa are very good in some cases and it would not be a bad idea to see where others stubbed their toes decades ago.

These examples and many more feed the thought that the institutional challenge of the twenty-first century will be that of designing innovations that will allow increasingly specialized scientists to cross scientific boundaries. We learned some time ago that it is the combining of specialized knowledge that speaks most effectively to the human condition.

If we summarize the broad patterns I have just described, we find, first, that international development funding is misdirected in that it is running down agricultural research university capital and is failing to capture the strengths of these universities; and second, that the research universities need to find new ways of combining knowledge from multiple scientific domains. Then the question arises as to what foundations can do about this situation, if anything. Leaving aside the matter of funding for a moment, foundations have some attractive operational assets or, as the economists would say, comparative advantages. One is their convening power, the ability to bring people together. The ability to reach out for new agendas and to begin to put them on the map through conferences or seminars organized by those who are pushing the new ideas has been a part of the foundation portfolio for some time. Foundations can be selective, they can fund reasonably quickly, and they can accommodate sensitive, even volatile agendas far better than public institutions can. Further, their convening power is, or should be, a public resource. Looking forward to the next century, I think foundations should increasingly be used as instruments to facilitate the arrival and exposure of new agendas and to facilitate boundary crossings between disciplines, schools, institutions, and countries. I think there is a connecting role to be played, but the foundations have to be reached for if they are to play that role effectively.

Second, foundations should be able to take risks on institutional innovations. Somehow, stuck in my craw is the thought that institutional innovations may be more important than technological innovations for the period ahead. It may be, today, that foundations take fewer risks than they did a decade ago, but I would never hesitate to promote high-risk, high-gain ideas in foundation circles. Foundations need more such opportunities to respond to if they are to live up to their own rhetoric—and there are few, if any, alternative sources for risk or "venture capital" funding around.

Third, foundations can use their money to generate other resources. With declining resources, either in real or in comparative terms, foundations are increasingly interested in seeing their money go farther. Foundation support is thus more likely if research proposals include, at the design stage, strategies to expand both resources and scientific linkages.

Fourth, sometimes foundations engage in activities that represent major contributions to the agricultural research community but appear somewhat remote to the campus, at least at the outset. For example, an effort is now beginning to establish an organizational framework for biological diversity conservation. No formal international organization currently provides such a framework, and some foundations have been invited to consider backing an informal consultative group that would focus on the exchange of information related to needs and priorities of developing countries. It is too early to say where this effort may go, but it is of the genre that foundations can respond to.

Let me now, in conclusion, turn to some possible directions in international agriculture which may be emerging as we move toward the twenty-first century:

1. An increasing amount of the world's agricultural research will be carried out in what we have been calling the "developing countries." The signs of the future are already quite clear in Brazil, India, Mexico, and China.
2. A by-product of this development is likely to be substantial increases in reverse technology flow. That may seem quite remote at this time, but looking ahead, it may be true. That is, the industrialized world should increasingly benefit from research done in developing countries.
3. There will be a growing need to find new institutional mechanisms for research collaboration between industrial and developing country states—and, perhaps more important, between American and developing country universities or research systems. Foundations should be asked to play a role in helping to establish new and more productive models for such collaboration.
4. There currently appears to be a fundamental public/private dilemma to be resolved in the biotechnology realm—one involving patents and intellectual property. Although these challenges are new and appear formidable, that is, how the fruits of private sector biotechnology research developed in this country can be made available to the public sector of developing countries, I see these problems being resolved in the next decade or two through the use of markets. I may be overly optimistic. The problem is that areas of technology that have traditionally been in the public domain are moving somewhat more strongly into the private domain. How can poor countries afford, or even find mechanisms to secure, emerging advanced technology?

Finally, foundations are public utilities—peculiar ones, to be sure—but public utilities, nonetheless. They should play to their own strengths, they should look for niches because they cannot be universal, and they should act before consensus emerges. There should be an element of risk in what they do, and they should identify other potential funding sources for their ventures at the outset, lest they fall on their faces too often.

DISCUSSION

Q. Do you see any easy way out of the project orientation of international development funding, given AID's two-year, four-year staffing patterns?

A. I wish I did. I don't see it right now, although sometimes I draw a little bit of comfort from the thought that things go in cycles and that we may be at a low point in the cycle, where the pattern of AID, in particular, is to draw up proposals for projects that really are closer to the private business sector in this country and using or squeezing whatever resources can be brought to bear on the problem, rather than considering the investment that, in my judgment, should go along with overseas development assistance efforts. The machine that is moving that process seems to be very powerful, and I just wait for the turn-around.

Q. I was struck by your early statement about how ahistorical we are. I don't have a question, but I have a comment. First, I would like to commend the Planning Committee for a truly thrilling program. I commend the faculty members and the graduate students that I see here. Several speakers throughout the two-day program have stressed the importance of institutional changes and attitudinal changes. My point is that I wish every graduate student in the College of Agriculture could have been here, and as many faculty members as could have, because I think this is where attitudes are going to have to start to be adjusted to see and sense the excitement, the accomplishments of the past, and the opportunities and challenges that we face in the future; and I think this program would have been of tremendous benefit, particularly to the graduate students in training on this campus at the present time.

Q. We have a former Cornellian who has been working in Bangladesh for the last six years, sponsored by World Relief. Is there any way of funding him? I know a while back we tried to get some funds to him for seeds, and there was a major problem getting them to him because of the rules and regulations. Is there any way we can get information about helping those individuals who are doing work on starting plants under protective materials so they can get away from the rainy season, and so on?

A. That's a tough question to answer. I would like to be responsive. Let me give you two or three shots at it. First, major foundations, and I would include Ford, McArthur, Rockefeller, and Kellogg, tend to be oriented toward the longer term, toward building capacities for the future, and not too interested in relief efforts. There are many monies flowing from a variety of sources for relief efforts. But your question seems to mix up a long-term and a relief dimension. The second answer is that there are resources to track foundations—there is a book you can get in the library called *The Foundation Directory,* and it can be organized by state, by foundation, by agriculture, by whatever it happens to be; and there are ways to begin to sort that information out. I think historically, if you're talking about a very small activity involving one key individual, that individual's links back to the research university sometimes are the most direct and the most effective way to create a bridge.

Q. Would you elaborate on historical successes, perhaps chained to the future, in the implementation of foundation-funded research? When the research is conducted, is it expected that it will be implemented, what percentage of it, and in the future is there going to be a stronger linkage between the research that is being conducted internationally and the efforts to have that research implemented? Will technology be transferred for that knowledge to work?

A. It depends upon where you cut in. The Rockefeller Foundation's work today in rice biotechnology involves basic tools, and there are some ten to fifteen grants that are supporting work at the very preliminary stages. A second stage of that effort might well be to move the fruits of that research out to the International Rice Research Institute as we begin to get closer to the applied side. Even then you have another step on to country research programs from IRRI, and so the question as to whether you are actually getting to the ground with your research depends on the situation.

A second response is that the Rockefeller Foundation, in what, for it, is a significant change over the last two years, is raising questions that it did not face as squarely, at least in the last decade or two, that is, questions as to whether technology works on the ground. For the last couple of decades the foundation has been deeply into supporting laboratories with basic research, not only in agriculture but in contraceptive research, biomedical research on the health side. Now the foundation has announced goals that say it will stay in basic research but will also take a deep interest in how the fruits of that research are applied in a village in Africa, where tribal customs may have more to say about the importance and the relevance of that technology than do its inherent technical qualities. So, Rockefeller is now moving toward a concern for the application of the research. There is an attempt to begin to marry some of the social sciences that deal with people and how people behave with some of Rockefeller's traditional strengths in the biological sciences.

I would like to make one more point. It is unlikely that a large foundation would deploy itself, at least at this time, to ground-level working on experiment stations in developing countries to get out on farmers' fields. I think that era is probably gone for cost reasons and others. Second, perhaps more important, some of your students are now in the research stations in developing countries, and the principal challenge is to support and bolster the work they are doing.

I

Partnership in Research—Users' View

Jeanne W. Edwards, Member

National Agricultural Research and Extension Users Advisory Board

They are gone now—my great-grandfather, my grandfather, and my father—that band of superlative farmers. Traveling in their footsteps, I have seen them at their best and, perhaps, their worst. I have read one hundred years of their records and their daily ledgers and relived their hopes, joys, and disappointments. In searching for the secrets of their success, I developed a deeper commitment to the food system they helped to build. Also, I share their faith in that system.

It has been said that faith is "merely letting one's mind rest in the sufficiency of the evidence." I suspect that for each of us the sufficiency of evidence is different. Four generations of successful farming, using the tools provided by our experiment stations, is sufficient evidence for me to have faith in our state agricultural experiment station system.

The experiment stations must take enormous pride in their one hundred years of service, pride not that they have been called upon for so many years but that, when called upon, they have not been found wanting. I speak for four generations of farmers when I say our partnership has been good and we are thankful for it.

The visions of the future that I extend here are my own. They are based on my life as a farmer and a rancher and as a self-taught agricultural economist.

Forthcoming Issues

Issue 1. I see a system stressed because we must live in two places at once—the present and the future—and the commute is very difficult. It is a paradox that, if we wait until dangers become realities, we lose the chance to do anything about them. We still have a great scope of creativity, but the facts are often unclear. When we know all the facts, it is often too late to act. This is the dilemma of farming and the reason I believe leadership of vision is the most important issue we must address.

Leadership of vision is not an easy assignment, and I do not mean to say that experiment station directors are exclusively responsible for it. Federal policy makers and private industry must be visionary too. Nonetheless, I am totally confident of the capability of experiment stations. For example, we farmers and ranchers can adjust to adverse situations such as weather, pests, or disease because of the tools research has provided. But we did not know how to adjust in 1983 when we took millions of acres out of production and the rest of the world responded by planting more. And I wonder if we know what the impact will be on agriculture when a 100 percent tariff is imposed on $300 million worth of Japanese electronics products sold in the United States.

Yesterday's survival depended upon efficient, increased production, but tomorrow's successful farmer must adjust quickly to unforeseen factors. The agricultural experiment stations will give us the research tools necessary to be efficient and resilient against these unknown disadvantages. We must be the best competitor in the marketplace, and it is research plus rapid development that will keep us competitive. My crystal ball shows the following tools to be crucial for successful agriculture in the future: new products with export potential, new uses for old products, lower production costs using fewer inputs and better environmental protection, better-quality products, and more value-added products.

It has been said that a man with only a hammer in his tool kit sees the rest of the world as a nail. That seems to fit the farmer. Agricultural research is our hammer. Like no other American industry, private sector agriculture has a very close tie, almost an intimacy, with public sector agriculture. The steel industry is supported by its own research. The automobile industry supports its own marketing. The textile industry relies heavily on on-the-job training. We in private sector agriculture have the public sector as our research, marketing, and teaching arm.

Issue 2. I see a system stressed because our commute between today and tomorrow takes place on a road that is potholed by factors beyond our control. We do not see them before we pass over them, or through them, or even fall into them. Farming today is not flexible enough to handle surprises.

The unfavorable conditions that surprised us in the early 1980s gave several other nations the opportunity to gain export market shares. The United States has gone from being the world's dominant food exporter to the world's second largest food importer. The Office of Technology Assessment (OTA) reports in *A Review of U.S. Competitiveness in Agricultural Trade* that these other nations will give up their new share "only reluctantly." In the case of the European Economic Community, for example, expanded exports are a part of a larger strategy to protect European agriculture. Other nations have borrowed funds to make significant investments in such areas as land preparation, purchases of agricultural equipment, and construction of port facilities and roads. These activities encourage exports—which will likely be increased, by whatever means—to repay the initial loans. The bottom line is that our world trading competitors will not be politically outsmarted. They have too much at stake. It is equally important that the measure of U.S. agriculture's international competitiveness, according to the OTA's report, "may not necessarily be whether the peak market shares of the late 1970s can be regained. Rather, the focus for the future may revolve around whether U.S. producers can profit from their exports. If this does not occur, trade may actually decrease the total income available to U.S. farmers."

The guillotine powerfully focuses the mind. Our minds must now focus on strategies and systems that produce real profits in the real marketplace. We cannot shape the world to fit our products. We have to shape our products to meet the demands of the world market. One good example comes to mind to illustrate this point. After a phenomenal success in the United States, the "Barbie Doll" company decided to market its dolls in Japan. The project was a total disaster. Why? Because Japanese mothers are not tall, tan, shapely, or blond, so why should they buy their daughters dolls that are? When the company molded its Barbie dolls after the women in Japan, the product was a success.

There is a good chance that the real profits of future American farmers will no longer depend on subsidy payments. We all see editorials that say "never have so few been subsidized by so much." We would be remiss if we ignore the writing on the wall. Maybe not in this Congress, but soon, legislators from growing urban communities will find that the line between the real and the perceived, the necessary compromise and the cheap expedient, is exceedingly fine.

Real profits (without subsidies) in the real world market for American farmers will come when attention is focused on developing products that can compete regardless of the worst possible scenario of national or international politics. Only when American farmers can offer the best-quality products at a reasonable cost of production will we be assured of real profits.

When I spend hour after hour listening to and reviewing testimonies about national economic policy, Third World policy development, trade legislation, bank debt on the international scale—all factors that affect American farmers—I feel like the little boy standing on the parade ground screaming, "But the king is stark naked." We cannot politically outsmart these other competitors. "We, the people" will not allow what is required to outcompete them because it would mean raising taxes, cutting wages, lowering our standard of living, or subsidizing food exports against human need. We can and we must outresearch and outdevelop our competitors with new and better products using fewer inputs. Am I the only one at the parade who sees research, extension, and education as the sound ensurer of the vision we need?

If I am not the only one blessed with this supreme wisdom, then I suggest we make haste to establish a sturdy vehicle to get us there. The future of U.S. agriculture is limited only by our imagination.

You, at Cornell, are a "flagship." Your track record is superb. Thus we start with faith in the system. Cornell must take the leadership in instigating regional think tanks. It must provide leadership in establishing "a quality of habitat" for our researchers to brainstorm with each other and with farmers and ranchers. I believe that ours is the only nation that honestly believes a researcher is contributing only as long as he is breaking test tubes in the laboratory. New ideas happen—not in one arena—but when two or three disciplines come together. We need to build strong bridges between our basic science departments, including Cooperative Extension, economics and business, veterinary medicine, agricultural engineering schools, and the applied research departments in the college of agriculture. As new initiatives spring from our think tanks, our public sector research should bring economists and researchers together to discuss, in practical terms, what the impact of the researcher's work will be if it is successful. In this habitat for researchers' thinking, include the nonscientific, dirt-on-the-boots farmer and rancher. We really have ideas, but we lack the platform from which to voice them. Farmers, by and large, are ready and willing to share their visions. We are usually timid, however, about getting involved with the highly educated scientist in public meetings. It is an understandable hesitation. Being vocal in public scientific meetings as a farmer is probably the cruelest form of activity known to man, short of war and cannibalism.

Even though farmers and researchers often do not have a common language, we do or should have common goals: success in selling agricultural products at a profit in whatever market exists at the time.

As a rancher, I am extremely sensitive to the fact that the United States is the top importer of range-fed beef. In 1986, we imported $1.3 billion worth of foreign beef. This is three times the value of U.S. beef exports. Burger King restaurants consume 6 million pounds of beef grown annually in Costa Rica. Almost all the beef in Campbell Chunky soups now comes from its beef processing plant in Argentina. For me to compete successfully, I must be able to offer a better product using fewer inputs. Producing more of the same quality meat, while increasing my inputs, will not make me successful.

If it rains for forty days and forty nights, northeast Nevada will get one-eighth of an inch. I cannot count the number of times I have ridden out on the range to agonize over the drought conditions on the range only to see the bane of a cattleman's existence—rabbitbrush (Chrysothamnus nauseosus)—growing a mile a minute, while the backbone of our operation—Crested wheatgrass (Agropyron cristatum)—is dry, brown, and useless other than as filler. I know without any science background that there is some communication system within that rabbitbrush. There is a little voice that says, "Okay, you little sucker, you haven't had rain in sixty days, so grow." And it does. It grows. What would happen to the range-fed cattle industry if someone took that communication system out of that rabbitbrush and put it into my Crested wheatgrass? And while you're at it, you could add a little more protein. We are limited only by our visions. Using the words of the immortal bard Pogo, we must not fail when we meet our "insurmountable opportunities."

Issue 3. One cannot think of new, better, or cheaper products without highlighting the promises of biotechnology. It impresses me, however, as being a bit premature to rest on this wonderful hope alone. Our eagerness to target biotechnology as a panacea so early in the process reminds me of a bulletin once put out by the Lands and Forest Department of Ontario, Canada. It offered helpful tips for catching a porcupine, reading in part: "The best way to effect his capture is to wait until he is out in the open. Then, watching for his slapping tail, rush in and pop a large washtub over him. You then have something to sit on while you figure out the next move."

Common sense tells me several things about the possible success of future biotechnological tools for the farmer:

1. We must be aware of the economic feasibility of new technologies. The research agenda must be adjusted to place higher

priority on finding new inexpensive technologies to support inexpensive commodities.

2. Before being implemented on a wide scale, potential biotechnological tools must be analyzed carefully to determine whether they can contribute to increased profitability on a long-term basis regardless of the nature of federal programs.
3. Once economic feasibility is established, the technology must be transferred to the user in very short order. We cannot afford to sit on that washtub very long. We have to become faster at commercializing our technologies, for the "window of time advantage" is growing smaller for American farmers.

Issue 4. Our future holds a newly discovered reality, which is the environment. We suffer from glutted soils, heavy silting, increased flooding, alarming depletion of aquifers, pervasiveness of chemicals, run-off pollution, destruction of forests, wholesale resistance to chemicals by insects and weeds, and scarce water.

Disagreeable as these facts are, basic and applied scientists must provide scientific data so our society can make knowledgeable choices. The choices will be made—have no doubt about that—with or without the input of scientists. "We, the people" will have a better chance for tomorrow if our choices are based on fact rather than on wishful thinking or political clout.

My crystal ball reports many more issues in the future, but I will mention only a few.

- Size of future farming operations. Is the growing trend of "bigger is better" a potential disaster to U.S. food security? This is not from the Users Advisory Board. This is from me. I have grave concern. When Coca Cola bought out Minute Maid and moved all of its orange production to South America, the *Wall Street Journal* and the *New York Times* said it was un-American. It is not un-American. The moral and legal responsibility of corporate agriculture is to its shareholders. I know it is chic to say that to be effective you have to be big. I believe we desperately need scale-neutral research. Let's not always assume that bigger is better. That may not be too academically sound, but I think we need to think about it.
- Importance of agriculture to the future stability of the United States. It is important compared to what?
- Structure of controls of biotechnology in the future. Is our act together?

- Role of the state experiment stations. Will they celebrate two hundred years of research?
- Agribusiness in the college of agriculture or business schools.
- Research responding to changing demands of diets. Is it responding to fact, or is it responding to whim?
- Where and how will we deal with funding? Who will fund and for what?

These issues are of immense importance to the future success of American farmers. We must, as a family of agriculture, address them.

Relationship between Users and Researchers

In our courting days my husband-to-be was a Fellow at Columbia Presbyterian Hospital. We were chronically below the poverty level and certainly could not afford any elaborate entertainment. We found, however, that for five cents each we could ride the Staten Island Ferry from Manhattan out past the Statue of Liberty to Staten Island. Then, for another five cents we could ride it back. I suspect that today a ride in the space shuttle would probably not provide more joy for me than those rides on that ferry did.

Probably the highlight of those ferry rides was watching a giant steamship being brought to port by tugs. It was hard to believe that so many different skills, at so many different levels, could work so closely and accomplish such a successful choreography.

The relationship between users and researchers requires a similar commitment.

Besides the mutual commitment, there are several things worth noting in the successful ship-tug relationship.

1. The ship and the tugs must understand and agree upon the docking pier.
2. The captain of the ship identifies the pier; the captain of the lead tug selects the course of how to get there.

In our line of work, private agriculture selects the objective, and public sector agriculture selects the strategy for getting there.

The docking place for the farmer's products has changed over these past few years. My grandfather sold to a hungry, growing-in-population town and county. My father's generation sold to a nation of growing and hungry people. I must seek a competitive position in a world market that is today producing more calories than there is money to buy. We are out of the pattern of history. I do not have to tell you what would happen if the tug and ship tried to go to different piers.

After understanding and agreeing upon where we must go, we must understand our respective roles in the effort. Research, extension, and education must be aware of the possible "floating debris" such as trade policy, international politics, national economic policy, and noncompetitive, high-quality products. Also, we cannot afford—either one of us—to waste time fighting "turf" battles, or bickering about whose responsibility it is to relay information, or whose dollar is being spent in whose budget. Public research, extension, and education must share facilities and expertise. Today is not one day too soon to begin regional centers of excellence.

To get to the dock, we must establish a clear vision, a vision of where we are going and how we will get there. We must establish havens where the bright minds of farmers, ranchers, researchers, extension agents, agricultural engineers, teachers, and students have an opportunity to enlarge our scope for creativity. From the agricultural experiment stations we must have the leadership to prepare for the future and the courage to initiate the changes.

The bibliography for this paper is embarrassingly short.

The first item is one hundred years of ledgers from a five-hundred-acre farm in Illinois. The second is a single OTA report. The last is an older book, and for me probably the most important: Proverbs 29:18: "Where there is no vision, the people perish."

The Twenty-first-Century Farm: Impacts of Technology

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Throughout history the most basic problem has been simply getting enough food. Now the reverse is true. Today, the farming world faces a crisis of worldwide overproduction. I have suggested on one occasion that what may be needed is a summit meeting to deal with agricultural surpluses on a global scale. The world has learned to produce food, and now one-third of the world, 165 nations, offers farm subsidies, often paying farmers prices far above world market prices. World spending for farm subsidies has risen from $25 billion in 1970 to an estimated $150 billion in 1987, of which $26 billion came from the United States. The world is not only plagued with excess corn, wheat, and soybeans in the United States but with beef, wheat, and corn in Argentina; soybeans in Brazil; dairy products, wheat, and corn in the European Economic Community; rice in Japan, Taiwan, and Indonesia (both Taiwan and Japan have 2 million metric tons of surplus rice, and rice is not fed to livestock); and wheat in Canada and Australia. Even in Africa, this past year agricultural output grew by 3 percent, exceeding the population increase for the first time in fifteen years. Yes, the world has learned how to produce food, and that is not going to change significantly in the years ahead.

The problem is that there is tremendous waste involved in overproduction. The Conservation Foundation published a booklet recently on this issue. About one-third of the pesticides and fertilizers used in agricultural production in the United States is used to produce commodities that nobody wants. This has enormous implications with respect to the use of resources—human, land, water, fertilizers, and pesticides—being poured into producing commodities no one wants, for which there is no market, and which have very adverse effects on the environment (Vietmeyer, 1986). It is a very costly practice with respect to human health and food safety.

As long as prices offer farmers profitable production opportunities, they will keep buying inputs off the shelf to produce all that consumers want and more too—plus whatever surplus governments are willing to pay for.

We are not alone in this world of agricultural subsidies. About twenty years ago, in December 1968, I gave a presentation at the annual AAAS meetings in Boston, Massachusetts. It had to do with the food supply and the fruits of research. That was in the period when people were talking about a starving world, population bombs (Paul Ehrlich), and the triage philosophy (Garrett Harden). At that time I stated in an article published in *Technology Review* that we had already witnessed the last great famine on earth. I was criticized publicly and chastised for making such a comment. But after two decades, my view has essentially proven to be correct. No longer are we "one bad year away from food security" (Abelson and Rowe, 1987; Avery, 1985).

Grave concerns have been expressed, and in my opinion grossly overemphasized, with respect to environmental problems such as sustainable agriculture and soil erosion. We tend to forget about the good things that are happening in this area. Land has also been improved. We ought to look at the writings of Theodore Schultz, the Nobel Laureate in Economics, University of Chicago, who points out that in the transition from cotton to soybeans in the South, soils have actually been improved. Even if there is a reduction of 5 percent in inherent productivity because of soil erosion during the next century, such losses in yield will surely be overcome and compensated by new soil and water management technologies.

A new wave of pessimism is coming across the land that relates to an idea I picked up in China just about two weeks ago, which is also advocated here in this country. A new set of prophets of doom has arisen among spokespeople representing a very respectable part of our scientific community. Their concern is the rising level of carbon dioxide and other atmospheric gases (Schneider, 1987). This is supposed to bring about dramatic climate changes and dislocations of agriculture so that eventually the corn belt will turn into a desert. The prediction is that the polar ice caps will melt, sea levels will rise, and vast coastal areas will be flooded. We forget some of the good things that could be said about the rising level of carbon dioxide in the atmosphere. It has already risen from 260 ppm up to 350 ppm with no detectable climate change, at least any that can be detected by climatologists. We also must remember that with increasing levels of carbon dioxide, if there is a warming, then growing seasons will increase and the productivity of agriculture in temperate zone areas will rise. Also, with rising levels of atmospheric carbon dioxide, photosynthetic as well as water use efficiencies can be greatly increased.

Moreover, agriculture has repeatedly demonstrated its ability to cope with climate change. An example is the heat wave and drought throughout the United States in 1983. In other words, the points that are mentioned with respect to climate change, as a result of rising levels of carbon dioxide, occur about every decade with interannual variations, and agriculture has demonstrated its ability to cope (Wittwer, 1987b).

Agriculture is a very dynamic industry. More and more technology will be the major force shaping the structure of U.S. agriculture and what happens out on the farm. With the above setting what will be the impacts of technology on the farms of the twenty-first century?

Food Crops

We will see developments on the farm comparable to and even greater than those triggered twenty years ago by what William S. Gaud, then director of the U.S. Agency for International Development, called the Green Revolution (Vietmeyer, 1986). We recognize that there are some twenty crops that literally stand between people and starvation. They include the cereal grains, the legumes, the tuber crops, the sugar crops, and some of the tropical crops—coconuts and bananas (Johnson and Wittwer, 1984).

The striking difference that will occur will be that sugar crops will decrease in importance. In this nation 51 percent of the sweeteners used by the consuming public were something other than sucrose in 1986. In other words, we are entering a new dimension with respect to at least two of the major food crops—they are going to disappear and be in large part replaced by artificial sweeteners and high-fructose corn syrup.

The most important drink in the United States at the present time is soft drinks; their use exceeds that of water. The primary ingredient of these drinks is something sweet, yet less and less sucrose is being used. At least twenty nations produce or want to produce sugar for export, and there is no market for it. The future looks bleak for this commodity.

New Crops

I would project that the farm of the twenty-first century will be growing many more commodities that will not be classified as traditional food, feed, or fiber crops (Molitor, 1987b; Vietmeyer, 1986). In the words of one writer, there will be an "industrial harvest" from what is now America's corn mountain, of which we produce half the world's supply, and of which we now have 5.3 billion excess bushels in storage. Within perhaps a decade there will be oil-based products ranging from detergents to coal desulfurizing agents. There will be urethane foam, maize-based surfactants, and biodegradable plastics derived from corn starch. Corn will be used for something other than food, feed, or fiber.

New crops of potential use in agriculture and forestry will be introduced (Molitor, 1987b; Vietmeyer, 1986). There will be food crops, those adapted for arid lands, and shrubs and trees, some of which are nitrogen fixers. Agriforestry will find a niche on the farm of the twenty-first century.

Pesticides

In the twenty-first century there will be much less use of chemical pesticides. There will be electrostatic spraying. We will be concerned about costs of materials, increasing environmental constraints, destruction of nontarget organisms, including natural parasites, food safety and human health, and increasing numbers of biotypes gaining resistance. All will mandate less chemical usage (Gibbs and Carlson, 1985). Here the Chinese are already far ahead of us. They have reduced the use of chemical pesticides to one-half the amount used three years ago. They are relying more on management and natural parasites and on living insecticides—ducks, frogs, and spiders—and resistant varieties. According to a recent National Research Council report, insect resistance to mites in the United States has risen from 7 species resistant in 1938 to 774 species resistant to chemical pesticides at present. Resistance management will become an important issue for crop production in the twenty-first century.

Resource Conservation in Crop Production

Conservation tillage (no-till, ridge, living mulches) is a wave of the future. The combination of allelopathetic properties of plant residues will be combined with conservation tillage technologies providing "natural herbicides" and continuous cultivation of tropical soils

(Gibbs and Carlson, 1985). Continuous cultivation of tropical soils presents a problem. It represents a significant departure from that of temperate zone agriculture. Yet production output from such soils in the tropics will be vital for optimizing food supplies on a global scale and where they are most needed in the twenty-first century.

Water

Agriculture needs water more than anything else, including soil and energy. Management of water resources, both availability and quality, will be particularly critical for sustainability, productivity, and dependability of food production. In the United States 80 to 85 percent of the freshwater resources are consumed in agriculture, mostly through irrigation. This is a far greater percentage than the national budget of energy for agriculture. The current overdraft of groundwater in the United States—approximating 20 to 25 million acre feet a year—should be of concern to us. It is irreversible use, in large part, of a nonrenewable resource. It is recognized that water is the most critical natural resource for future agricultural development not only in the United States but in most of Africa, Egypt and the Sudan, the Soviet Union, Indonesia, Taiwan, Pakistan, Australia, Argentina, and Brazil. In fact, almost all countries have the problem. One-third of the world's food supply is now grown on 18 percent of the cropland that is irrigated.

Energy

There will be greater efficiency in the use of energy for the agriculture of the twenty-first century. Most of the energy (at least 50 percent) applied in agriculture comes from fertilizers and pesticides. Technologies will emerge that will increase the efficiency of energy use through the control of nitrification and denitrification, increased biological nitrogen fixation, and integrated management technologies for pest control.

Protected Cultivation—Agricultural Plastics

During mid-April of 1987 I was in China. Protected cultivation is something to behold. I call it the "plastic revolution." The first developments in this area occurred in the United States following World War II but have now been extended worldwide. Plastics are being used not only for covering greenhouses and as row covers and tunnels but as soil mulches. They extend the areas of production, control weeds, conserve soil moisture, repel insects, protect crops from cold and freezing temperatures, hail, and wind, and greatly improve yields and quality. For vertical expansion of production, improved quality, control of soil erosion, weed control, and water conservation, the use of agricultural plastics will expand on farms of the twenty-first century. Already in China plastic soil mulches or covers are used on over a million hectares of cotton, corn, and peanuts and on 70 percent of the 850,000 hectares devoted to production of watermelons. Biodegradable plastic derived from corn starch will likely be the next breakthrough.

The Resource Base

The resource base will change with time and technology. History has taught us the power of technology to expand the resource base (White, 1987). The problem of projections of the past is that they have all been based on a static resource base. There are many examples of time and technology changing the resource base. High-fructose corn syrup is one example. This long-ignored principle has completely invalidated the projections of the Club of Rome, the Global 2000 Report, the Presidential Commission on World Hunger, and the Report of the White House Panel on the World Food Supply of twenty years ago and now offer little credibility to some of the reports that are still coming out projecting global starvation and worldwide hunger.

The current technology revolution singles out information or communication technology and biotechnology (Brill, 1986; Farm and Industrial Equipment Institute, 1986). As an example, in the plant sciences I see computer-programmed, automated tissue culture production units to provide super plants and trees for the farms of the twenty-first century.

Spring is the annual transplant season. There are vegetable and flower transplants or bedding plants in abundance. Now it's "plug culture," and all plugs are transplants but not all transplants are plugs. It is becoming a science of high order. Some operators of greenhouses produce plugs 24 hours a day nearly 365 days a year on cycles as short as 10 days. Vegetable and flower plants are being produced on an assembly-line basis, and the technology is being extended to forest tree seedlings and tobacco transplants. The Chinese are transplanting corn and cotton.

Animal Agriculture

Dairy

Dairying is and will remain the most stable and value-added agricultural industry of the world. It is adapted to and will largely remain in temperate zone agriculture. The impacts on grain and forage production are significant, as well as on the beef industry, to which it contributes 20 percent. Dairy products have an inelastic supply and demand, and surpluses are inevitable because of interannual variations in production.

Dairying during the past three years has witnessed the greatest growth in sales since World War II. A remarkable sales promotion effort, with 89 percent industry participation, advertising milk as the perfect food and as an excellent source of vitamin A and calcium, has paid off.

Yogurt is the most rapidly growing product in grocery store sales, with a growth of 10 percent in 1986 and sales of $1.9 billion in 1985. This meteoric growth in consumption of yogurt will continue. The forms in which yogurt is being offered can even now hardly be numbered, and innovations in its preparation will continue. It will help meet a need when 20 million Americans, mostly women, have calcium deficiencies and are developing symptoms of osteoporosis.

Remarkable production increases and new developments in dairy products have occurred during the last forty years. Milk production in pounds per cow in the United States was then 5,882. It rose to over 13,000 in 1985, with cow numbers reduced from 21 to about 11 million. Between 1983 and the year 2000 milk production per cow will likely double again and there will be only 7 to 8 million cows. Dairy cows will be the first major recipients of the rewards of biotechnology (Kiddy and Jorgensen, 1986).

We will see expansion of dairying in many nations. India, for example, is the third most important dairy producing country in the world. Milk production in China has doubled in the last three years (Wittwer et al., 1987).

Beef Cattle and Pork

In this symposium much emphasis has been given to the growth hormones and biotechnology and the production of more lean and less fat meat. Industrialization of hog production in the United States will continue. Environmental problems will mount, especially with odors and waste disposal. Programmed feeders, improvements in housing, environmental controls, improved waste management, and sensors for farrowing facilities will be further developed and adopted by pork producers.

Broilers, Turkeys, and Eggs

In the United States the per capita consumption of turkeys is between eleven and twelve pounds per year. We are the largest turkey-consuming country in the world. France is our nearest competitor, and it is not even close. Turkeys are still a rarity in most parts of the world, certainly in China and India. Probably within a decade the production of broilers and turkeys will outstrip that of red meat. The driving force is, and will likely remain, economics. Poultry is cheaper. Per capita egg consumption in the United States will continue its downward trend but in some countries, such as China, it will rise.

Horses

Aside from food animals, an area of animal agriculture that has grown enormously in recent years is recreational horses. It will continue to grow. More college students in the United States are probably interested in horses than in all other species combined. There is a recreational and a romance component associated with horses. This area of animal agriculture involves complex sociological factors, and classical laws of economics do not apply, nor will they in the year 2000 (Siedel, 1986).

Overview of Animal Agriculture

Overall the productivity and size of farm animals will greatly increase by the year 2000. Technology will raise world farm output, and agricultural research will advance more rapidly and broadly than ever before. An increasing premium will be paid for keeping up with the latest technology and being flexible enough to adopt it.

The use of growth hormones for dairy, beef, and swine will become a reality by 1990 (Etherton et al., 1986; Hohman, 1986; Kiddy and Jorgensen, 1986; Smith et al., 1987). It could be a scale- or size-neutral technology that provides rewards to the small producer, if coupled with appropriate management, equal to those of the large producer.

Embryo transfer is a reality, and success with frozen embryos is almost equal to that with fresh (Kuzan and Siedel, 1986). Sexing of embryos as well as sperm will be an accomplishment for the farm of the twenty-first century. The multiplication of embryos by surgical bisection is now limited to two and to four. Multiplication of embryos by nuclear transplantation, however, offers the potential of producing an unlimited number of identical offspring. Reproductive interventions will become commonplace. Sensors will be developed that will detect animal stress by measuring the pulse, blood pressure, and respiratory rates.

There will be electric automated milking machines by 2000—perhaps earlier. Dedicated microcomputers will be affixed to cows to serve nutritional and veterinary needs, release the feed, move attachments into place, milk the cow, and clean up for the next use. They will be called "cow-robots" or "cobots" and will work around the clock, day in and day out. Currently, there is far more capacity to milk cows than there are cows. More frequency in milking—three times a day, now practiced in some West Coast dairies, will expand to other areas.

Environmental Control

The current widespread use of feed additives, growth hormones, steroids, antibiotics, and chemotherapy and pesticides will reach a crisis within the next two decades as the public becomes more vocally concerned about environmental issues, food safety, human health, and animal welfare. Evidence is mounting that bacteria become immune to penicillin and tetracyclines because of their continued presence in cattle, hogs, broilers, and turkeys. An alternative to the use of the many biologicals and pharmaceuticals that are being used for pigs, chickens, and cattle will be an emphasis on built-in, permanent genetic resistance to diseases and improved management in housing through automated environmental controls activated by special sensors of critical environmental factors. Genetic vulnerability to harsh environments will be reduced through design of controlled environments for livestock. The environmental area and animal behavior is a frontier that will be explored extensively.

In summary, some of the most remarkable changes in animal agriculture will likely occur during the next fifteen years (Etherton et al., 1986; Hohman, 1986; Kiddy and Jorgensen, 1986; Kuzan and Siedel, 1986; Molitor, 1987a; Pearson, 1987; Siedel, 1986; Smith et al., 1987). These changes will be augured by uncertainties of markets and consumer preferences, new products, human health, and food safety issues related to residues in milk, meat, and eggs and the use of antibiotics and other pharmaceuticals in livestock and poultry feeds.

Automation

Computers will be used for many purposes including immediate access to worldwide market information. Automation in agriculture will come from computer programming and development of sensors for improved automation of each essential biological and physical farm operation or process. It will involve the entire food system from production through harvesting, processing, packaging, and marketing (Farm and Industrial Equipment Institute, 1986).

Marketing

In marketing agricultural commodities more emphasis will be placed on packaging. Currently $25 billion is expended in the United States annually in food packaging, which is approximately equivalent to the net farm income and the appropriation of resources in the nation's farm commodity and price support payments. Packaging for consumer goods and microwave cookery will expand.

Farm Technology from Abroad

We need to create mechanisms to use technologies developed in other countries more effectively. We can learn from other people. There are many notable examples of commodity-oriented food-producing systems in which examples of unique agricultural production and marketing systems have occurred, and many more are in progress (Nickell, 1986; Wittwer, 1987a). I refer specifically to grain production in India's Punjab, corn production in Zimbabwe, the white revolution or "operation flood" in India's Gugarat, hybrid rice in China, palm oil in Malaysia, asparagus in Taiwan, and hybrid corn in the United States.

The account of how China, through its blending of traditional with modern technologies, is feeding over 22 percent of the world's population on 7 percent of the arable land is worthy of attention by all interested in the farm of the twenty-first century (Wittwer et al., 1987).

Much of what we in the United States and the Western world have taken credit for was developed in China. Even today the Chinese lead the world in many water management technologies, haploid culture for new crops, hybrid rice production, polyculture of fish, and soybean genetics. The past and present achievements of the Chinese in food and agriculture are critical for shaping the economy and welfare of farms for the future.

Conclusions

What a marvelous opportunity we have in the world today, with our agricultural and food abundance, to take positive actions in resource conservation—soil, water, fertilizers, pesticides, energy—to improve human diets and for better nutrition and food safety. Now is an occasion to open up new frontiers in science and technology, to use technologies developed abroad, and to conserve our resources instead of pouring them wastefully into overproduction.

There is a great need for articulate and knowledgeable spokesmen to stand up and be heard among the advocates against further progress in science and technology. Two classical examples are just now attracting nationwide attention and capturing headlines: frost-preventing bacteria in a strawberry field in California and the use of the bovine growth hormone to increase milk production in dairy cows.

Can United States crop and livestock producers compete in a world of cheap Chinese labor, Brazilian and Argentinean farm land, and Indonesian fertilizer with countries needing our technical assistance and other countries receiving our technical help? The answer is yes! Foreign technical assistance, thus far, has been more a credit than a debit. American agriculture is still a world-class industry. We have a farm infrastructure and private sector in place that are second to none—roads, telephones, superhighways, rail and barge lines, storage and processing facilities, and feed, food, fertilizer, pesticide, and implement companies and institutions. Such infrastructure for nations abroad that do not have them (and most of them do not) are not getting cheaper. If American agriculture is to remain truly competitive for the twenty-first century and beyond, we must first be willing to invest to retain our edge in agricultural science and technology; and second, we must create a mechanism to use new technologies developed in other countries.

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William L. Brown is the former chairman and president of Pioneer Hi-Bred International, and he currently serves as the chairman of the Board on Agriculture, National Research Council–National Academy of Sciences. In his many years of involvement in agriculture, he has made valuable research contributions in the areas of maize breeding, genetics and cytogenics, and evolutionary development and introgression and has received numerous awards and honors.

Lawrence Busch received his Ph.D. from Cornell and accepted a position on the faculty of the University of Kentucky. He is currently a professor in the Department of Sociology at the University of Kentucky. He was born and reared in New York City. He is co-director of the Committee on Agricultural Research Policy. His major publications include a book, *Science, Agriculture, and the Politics of Research,* and three other books of which he is a co-editor: *Science and Agricultural Development, Food Security in the United States,* and *The Agricultural Scientific Enterprise.*

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STAN LUNDINE was elected lieutenant governor of the state of New York in November 1986. Before his current office, he was a member of the U.S. House of Representatives from the 34th Congressional District. While in Congress, he served on the Banking, Finance, and Urban Affairs Committee, the Science and Technology Committee, the Select Aging Committee, and, in 1985, was the chairman of the Subcommittee on International Development Institutions and Finance. He has authored groundbreaking environmental legislation and developed many programs for the community and housing fields. Throughout his public life as mayor of Jamestown, New York, congressman, and lieutenant governor, Lundine has concentrated on fostering jobs and economic development, while improving our nation's industrial competitiveness.

JERRY PERKINS was born and raised a city boy, but his roots are in rural Iowa. Four uncles farmed until they retired recently, and frequent visits to their farms gave him an appreciation for farming. A two-year stint in the Peace Corps was spent working with rural peasants in agricultural development in Panama and Nicaragua. On returning to the United States, Perkins managed a small farm at a group foster home for teenaged boys in New Mexico. In 1976, he returned to Iowa to start his journalism career. Perkins has been reporting on farming since October 1982 and won the best news story award from the Newspaper Farm Editors of America in 1984. He was also one of the lead writers on the series that won the John Hancock Life Insurance Company business journalism award during the same year. He has been associated with the Des Moines Register since September 1982 and is its business-agribusiness writer.

G. EDWARD SCHUH is director, Department of Agriculture and Rural Development, the World Bank, located in Washington, D.C. Before assuming that position in 1984, he was head of the Department of Agricultural and Applied Economics of the University of Minnesota. He has had extensive international teaching, consulting, and advising experience in Latin America and India, and with the U.S. government (USAID, Council of Economic Advisors, and USDA). His areas of subject matter interest include agricultural and food policy, economic development, and international trade. He is the author or coauthor of three books, has edited six books, and has over eighty technical and scientific papers to his credit. Schuh has received numerous professional awards and in 1977 was elected a Fellow of the American Academy of Arts and Sciences and in 1984 a Fellow of the American Agricultural Economics Association.

THEODORE M. SMITH has served as president of the Agricultural Development Council, which was established by John D. Rockefeller III. The council provides international technical assistance in agricultural policy training, mainly in Asia. Smith has been instrumental in recruiting top professionals for overseas assignments, raising support in foundation, corporate, and government grants, establishing the council's first programs in China and Africa, and expanding its strong record of professional assistance to developing countries. Smith is a consultant to the vice-president for programs of the Rockefeller Foundation, dealing with the establishment of new international directions and strategies for implementing programs. He is also a consultant to the Education Projects Division for the design and oversight of management policy studies in Indonesia's system of public education. He spent many years in Indonesia working as a country representative for the Ford Foundation.

SYLVAN H. WITTWER is a former university dean, plant scientist, lecturer, and writer. After receiving his Ph.D. from the University of Missouri and serving as an instructor there for three years, Wittwer accepted a position at Michigan State University as an assistant professor. He moved through the ranks to become associate dean of the College of Agriculture and Natural Resources, and after serving in this capacity for eight years, he became director of the Agricultural Experiment Station. Wittwer has received many awards for outstanding service in the area of plant physiology and horticulture.

ALVIN L. YOUNG, a commissioned officer in the U.S. Air Force, was detailed to the Office of Science and Technology Policy as the senior policy analyst for life sciences in 1984. He advises the OSTP in the areas of risk assessment, environmental toxicology, carcinogenesis, and agricultural research. He serves as an adviser on environmental toxicology to both the Italian and Australian governments. In addition, he is the chairperson of the Committee on Radiation Research and Policy Coordination. Young's Ph.D. in environmental sciences from Kansas State University has given him important insights into opportunities for program growth of agriculture. He has been nationally prominent as an advocate for agricultural research. He has authored or co-authored three books and more than one hundred scientific articles.

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