TRENDS IN AGRICULTURAL RESEARCH

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We are in a very crucial period as we look at the future of American agriculture and examine the promise of science. On one hand we can look at the past 30 or so years and be impressed with contributions that science and technology have made to agricultural productivity. Let us look for a moment at the history of American agricultural productivity as shown in Figure 1 from an Office of Technology Assessment Report (3). We see that it can be divided into four major periods—hand-power, horse-power, mechanical-power and finally, science-power. The transitions from one form of power to another were marked by the Civil War, World War I, and World War II.

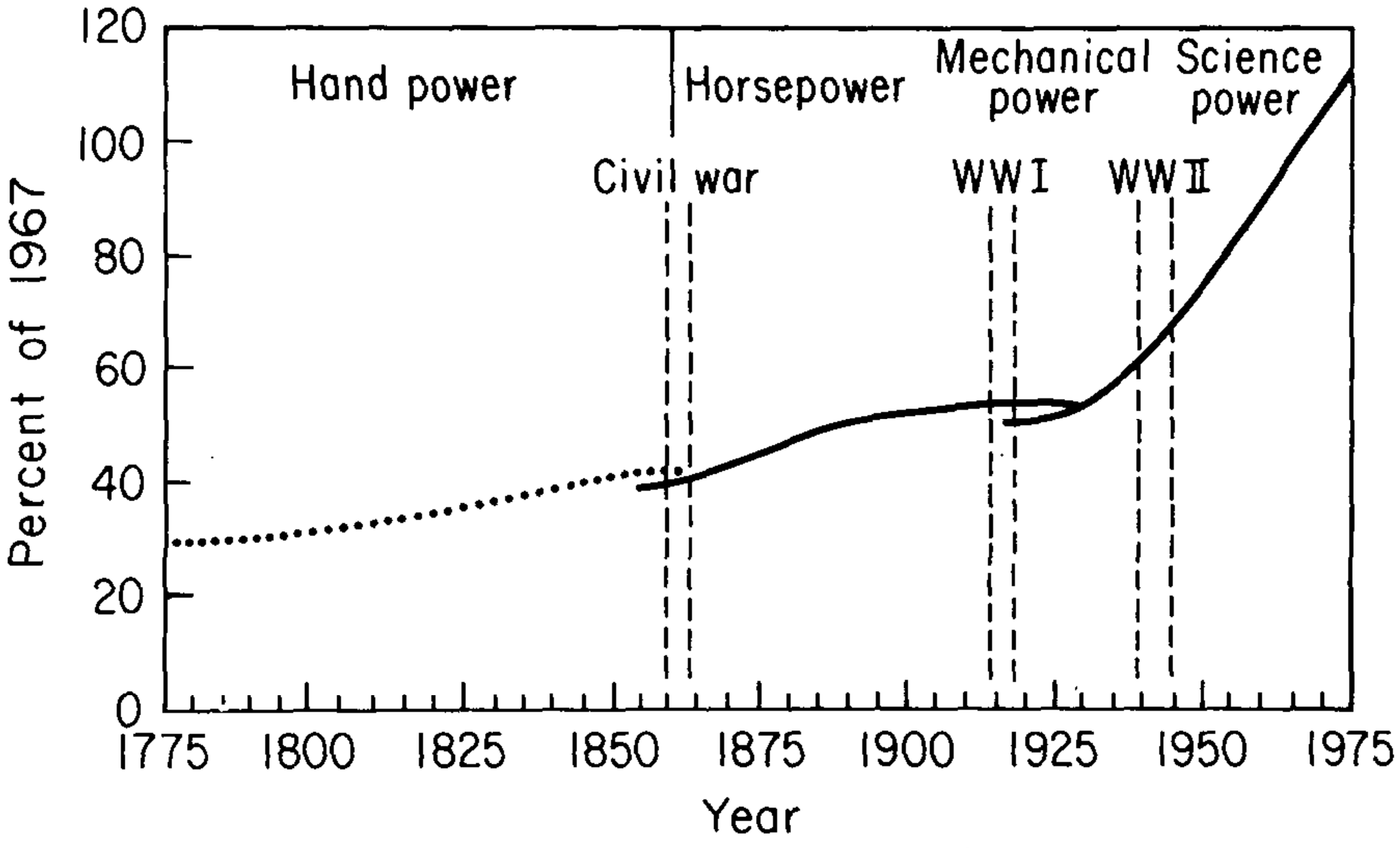

Figure 1. U.S. agricultural productivity growth during the past 200 years

From Figure 1, it is clear that during the period called "science power," or more correctly, the period of science and technology, is when dramatic gains in productivity were achieved. Evenson, Waggoner, and Ruttan, in their article, "Economic Benefits from Research: An Example from Agriculture," provided several indices to measure productivity from the 1950s to 1978 (1). As shown in Figure 2, land productivity increased at a rate of nearly 2 percent per year. There was a dip in productivity in the early 1970s, when in

part, less productive land was removed from the soil bank in response to world grain shortages. The index of labor productivity is widely used in agriculture and industry and, as shown in Figure 2, since 1950, labor productivity has grown far more rapidly in agriculture than in the nonfarm sector. Total productivity, which is calculated by dividing the index of farm output by the index of total farm input, has also grown rapidly since the 1950s. According to Evenson *et al.* (1), in the 30-year period from 1949 to 1979, scientific and technological innovation increased agriculture output by 85 percent with no change in the aggregate level of agricultural input.

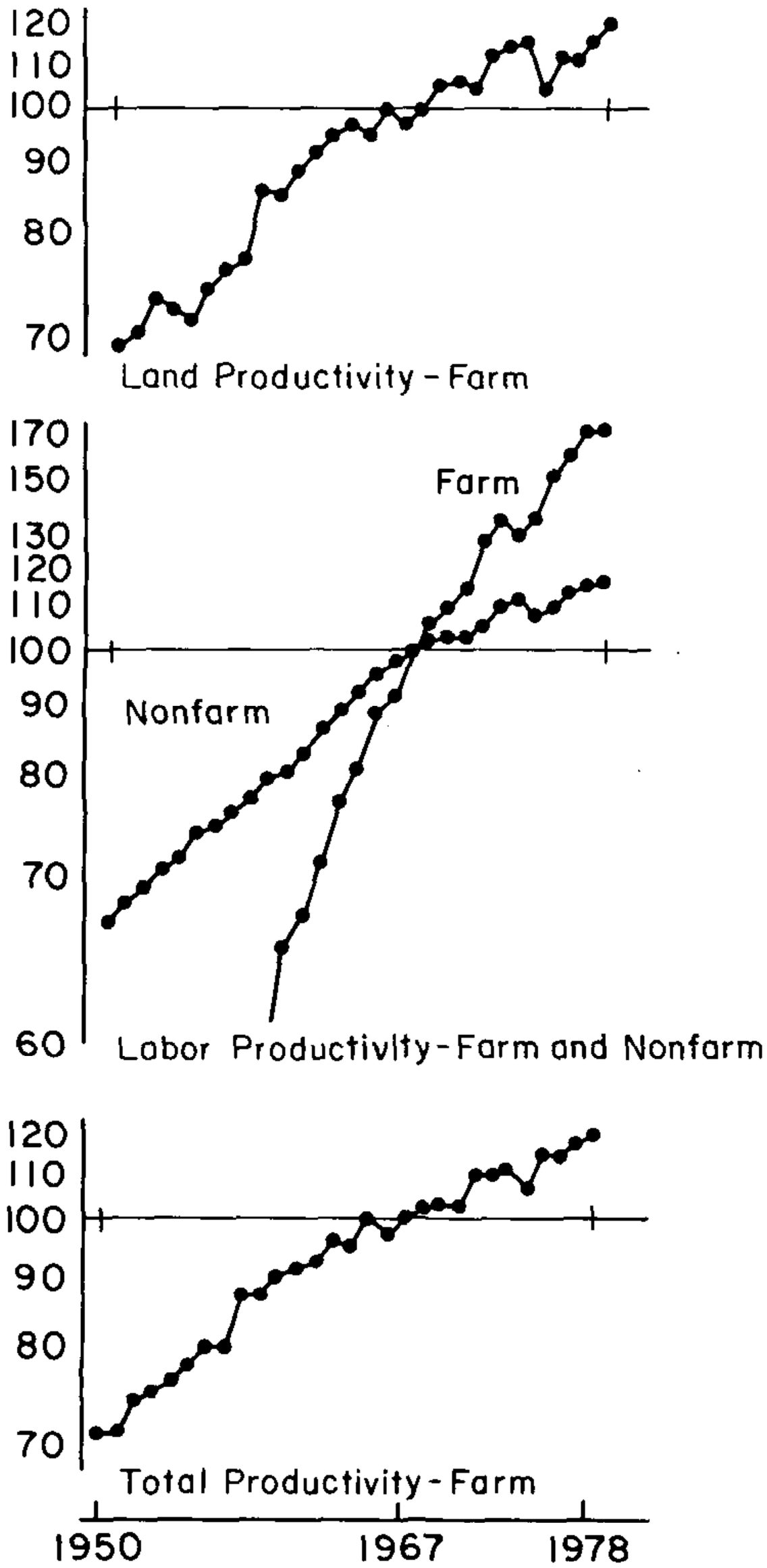

Figure 2. Increases in land, labor, and total productivity from 1950 to 1978 (1).

Another frequently used index is that in 1900 one U.S. farmer supplied seven other people with food and fiber. Today the average U.S. farmer supplies more than 75 people and, in view of the current economic conditions facing American farmers, the ratio of people fed per farmer will continue to increase. I should point out here that science and technology cannot be given all the credit, or blame, for increased productivity. There are external forces such as farm policy, tax incentives, or shortages of inputs that play a major role in the adoption of new technologies developed through science.

A most dramatic example of the interplay between science and government policy is seen in the tremendous growth of agricultural productivity in China. In seven years China has gone from a country which faced shortages in grains and fiber to where it is now able to export both. The agricultural sciences in China have been extensively rebuilt since the Cultural Revolution through government investment and World Bank loans which have permitted the exchange of scholars and the renewal of the research infrastructure. But, equally important was the government policy which changed the production unit from the commune to the individual household. After a household meets a specified quota of crops or animals, the surpluses can be sold to the state at higher prices or sold on the open market. The combination of science and technology and incentive has facilitated an agricultural revolution in China.

But what have been the costs of increased productivity. Farmers in the 1930s were largely self-contained, but now purchase about three-fourths of their production staples, such as pesticides, machinery, fuel, genetically improved cultivars, and fertilizers from outside sources. Extensive purchase of production supplies from nonfarm sources requires that farmers maintain adequate cash flow or be able to obtain operating credit. This situation makes the farmer far more vulnerable to economic externalities while still being subjected to the vagaries of weather and the marketplace. Therefore, critics of technology contend that, in part, the current depressed state of American agriculture is caused by the dual effects of excess production resulting in low prices and high costs of achieving that production through the use of agricultural chemicals and energy consuming equipment. In addition to economic effects of technology, critics also point to environmental problems such as soil erosion, the pollution of surface and ground water by pesticides and fertilizers, and the depletion of aquifers and the salinization of surface soils through irrigation.

You may ask then, what is the promise of science and its application? My view is that potential impact of science is as great as it was at the beginning of the period of "science power" in the 1950s and perhaps even more exciting. Advances in science are essential if we are going to be economically viable and be able to

compete on international markets. We must continue to increase our efficiency of production. That does not mean producing more—unless there is a demand—but it does mean producing the same for less cost providing greater economic viability or competitive advantage. Furthermore, we not only have to reduce costs, but we have to assure ourselves and the public that we have a sustainable form of agriculture in which we conserve our natural resources and eliminate adverse effects upon the environment, and deliver a safe product.

What kind of science can promise these ambitious goals? One possibility is the new biotechnology or genetic engineering.

Biotechnology is a word that probably has no equal in meaning so much or so little to so many. However, it does convey an exciting concept in that we have new tools and technologies enabling us to modify living organisms with a precision not formerly possible and to combine traits from organisms that are unrelated or incompatible.

Biotechnology, broadly defined, includes any technique that uses living organisms or parts of organisms to make or modify products, to improve plants or animals, or to develop microorganisms for specific uses (2). Using this definition, biotechnology can be said to have originated at least 10,000 years ago when the transition was made from a food gathering society to one which cultivated plants and animals. The early farmers selected crops and animals for desirable traits which improved productivity or adaptability to a given environment. Thus, the earliest farmers were taking advantage of genetic variability inherent in plants and animals. They also developed the biotechnology of fermentation to produce wines, beer, and sauerkraut and the use of yeast to make bread. More recently, microorganisms have been used to produce antibiotics for the control of disease and other substances such as interferon and insulin.

So what, then, is new and the basis for all the excitement? What s new are two separate developments each having its genesis in the 1940s. I will briefly trace each development and show how they have now come together, bringing us to one of the most exciting times in the history of agricultural science.

The first accomplishment was the development of hormonal control of shoot and root regeneration in tobacco callus cultures and the subsequent discovery of cytokinins by Skoog and his coworkers in 1948. A practical use of tissue culture was the production of virus-free plants from meristems. Using this technique, Morel, in 1964, found that shoot tips from cymbidium orchids proliferated into masses of protocorms which could be divided and recultured to produce new plants. In the same year, F. C. Steward, a Cornell University faculty member, reported that carrot callus produced in tissue culture could be separated into single cells and that a single

cell could be regenerated into a whole plant. Thus, the concept of "totipotency" was introduced—that is, a single cell contains all the genetic information needed to form a total plant. As scientists began to master the art and science of plant tissue culture, increasing the number of plant species that could be regenerated from single cells, they found that there were some unexpected variations in the progeny, or what is called "somaclonal variation." It is now recognized that the rate of mutation increases and can be expressed more easily when culturing large populations of plant cells. The selection pressure can be increased by placing the cell population under conditions of stress, such as the presence of high salts, a toxin from a disease-producing organism, or low temperature. It is possible, therefore, using the culture of cells or cell protoplasts to speed up the process of finding and isolating genetic variability. Plants can be selected which are more adaptable or resistant to disease in a shorter time and in less space than conventional approaches require.

Cell and tissue culture also made it possible to begin asking some of the fundamental questions about differentiation. What are the mechanisms regulating the expression of genetic information contained in the cell nucleus? What causes a group of cells in an undifferentiated mass of callus to become organized into a shoot or root? What causes a single lettuce cell to develop into an embryoid and eventually into a plant? There is still much to be learned from and about cell and tissue culture. I refer to tissue culture as an art and a science because, at this point in time, both are required for success. The number of species that can be regenerated from single cells is still unlimited, and the traits selected from somaclonal variation are not always stable and the genetic basis for the variation is not completely understood.

Let us now turn to the other area of science which was evolving during the same time period, often in conjunction with health-related research, using micro-organisms as a research tool. This is the area of recombinant DNA technology. Starting in the 1940s, Oswald and others presented evidence that genes were made up of DNA, deoxyribonucleic acid. In 1953, Watson and Crick described the three dimensional structure of DNA, and later the process of transcription and translation was established.

How then does an individual select a single gene from among the many thousands or more genes occurring along the strands of DNA that make up a chromosome? In the 1970s, scientists found in bacteria restriction enzymes which cut DNA strands into pieces thereby eliminating foreign DNA. The restriction enzymes each have a unique specificity for nucleotide sequences, and therefore, they will cut the DNA strand only when it locates a specific sequence.

By selecting the proper restriction enzyme, it is possible to remove a specific gene from the donor DNA molecule. It is also pos-

sible to use the restriction enzyme to open a plasmid (circular strands of DNA) and then insert into this opening the gene removed from the donor DNA. If the plasmid is inserted into a bacterium and the gene is expressed, large amounts of the specific protein will be produced following manipulation of the bacteria.

In addition to cloning genes to produce specific proteins, the plasmid may be used to insert a gene into a higher plant. The methods available to insert the new genetic information into a plant include direct insertion into a protoplast, the use of a virus, and the use of a plasmid from the crown gall bacterium, *Agrobacterium tumefaciens*, as a vector. After a gene is inserted into a cell genome, tests have to be conducted to see if it is expressed. If the trait is expressed, the next step is to regenerate a plant from the transformed cell and determine if the foreign gene functions in the intact plant and in subsequent generations. It is at this point that the two areas of science come together: the merger of recombinant DNA technology and plant and cell culture.

How is this technology being put to use? Recently, scientists at Calgene in Davis, California developed a strain of *Salmonella* which is resistant to the herbicide "Roundup" (Glyphosate). The gene responsible for the resistance was isolated, identified, and inserted into tobacco and tomato cell genomes. The regenerated plants are expressing resistance to the herbicide. This accomplishment may be among the first of the commercially important applications of biotechnology in the plant sciences.

Another application of biotechnology which appears to be close to commercial application is the genetic modification of *Pseudomonas fluorescens*, a bacterium which inhabits the soil of midwestern corn fields. The Monsanto research laboratories have been able to transfer the gene from *Bacillus thuringiensis* that regulates the production of a protein that is toxic to insect larvae. *Bacillus thuringiensis* is already used to "biologically control" tomato hornworm. It is planned to coat corn seed with the genetically modified *Pseudomonas fluorescens* so that it will produce a natural pesticide in the corn field soil and control black cutworms.

A third application that is ready for field testing is an ice-minus bacteria, a bacteria from which a single gene has been removed. Dr. Steven Lindow at the University of California has been working with *Psuedomonas syringae*, a bacteria which lives in the epidermis of many plant species including beans and potatoes. The naturally occurring *Psuedomonas syringae* releases a substance which serves as the nucleus for ice crystal formation as the temperature drops to freezing. The ice crystals pierce the epidermal cells and cause injury. It was found that a gene could be removed and the modified bacteria no longer caused the ice nucleation. Greenhouse tests indicate that if the wild strain is replaced by the genetically modified

bacteria, the plants will tolerate exposure to temperatures as low as 22°F without injury. Naturally occurring strains of *Psuedomonas syringae* are used to enhance artificial snow making at ski resorts.

Examples of other research that is underway includes a dwarfing gene for fruit and nut trees, a gene which increases salt tolerance in organisms, and attempts to increase the efficiency of bacteria which biologically fix nitrogen.

In the area of post harvest physiology, a gene which regulates tissue softening have been isolated. If the expression of the gene can be regulated, it may be possible to extend the quality of fruits.

Much of the current research in biotechnology is designed to reduce our dependency on agricultural chemicals through the development of disease and insect resistant varieties, to increase the range of biological nitrogen fixation, to provide greater resilience to environmental stress, to develop new crops; and to preserve genetic diversity in plants. If we can develop genetic resistance to pests or increase the number and effectiveness of biological control organisms, we should be able to reduce production costs as well as reducing adverse effects upon the environment. It is even possible to correct problems such as pesticide disposal sites by selecting or genetically modifying bacteria which can biologically degrade the pesticide residues.

Although we are in a very exciting time in terms of research trends, we are also in a very challenging time. In view of surpluses, some growers are saying we should stop research that leads to increased productivity. As I have said earlier, research does not lead to surpluses; it is grower decisions to increase the production of more profitable cultivars or techniques that lead to surpluses. Second, the public is skeptical about new advances in technology. You may have read or heard about the concerns expressed about the field testing of the ice-minus bacteria. The experiments have been blocked for several years through protests and legal actions in the courts.

What can be do to head off these restrictions to free inquiry? First, we must be sure our own house is in order. Beyond the traditional objective that technology must be profitable for the user, we must *continue* to apply additional criteria in agricultural research and development. We must also be certain that society is aware of what criteria we are using. Included are: 1) energy efficiency, 2) acceptable long-range physical impacts on the environment, 3) that we have studied and minimized health and safety risks, and 4) that we are aware of any social consequences and that they will be acceptable to society, or we must find ways to address the expected social costs.

Second, we must be sure the research that we do is necessary and that if there are risks, such as the possible release of a pathogen, that all possible precautions are taken. The fact that the scientific

community established its own stringent restrictions at the beginning of recombinant DNA research gave assurance to a majority of society that we placed a high value on their safety and concerns. In return, there was self-policing rather than overregulation from outside groups.

Beyond these activities, we have a special responsibility as educational institutions to do all we can to ensure that our graduates, whether from agriculture, engineering, or the liberal arts, have scientific and agricultural literacy. Part of the current problem is due to a lack of background on which to base rational decisions. We are attempting to do research in an environment in which the public is underinformed, misinformed, or wholly ignorant of the issues, but at least a part of that public wants to play a role in the decision-making process. This is perfectly appropriate in a democratic society. However, we must educate the public and the policy makers about our research and the benefits to society and to assure them that we are aware of the risks and the costs as well as the benefits. Then their participation in the decision-making process will be based on knowledge rather than ignorance.

The concerns I have given are not simply California anomolies or issues that will go away. Unless we counter our attackers with equally articulate and active programs of information, society will in fact have placed scientific inquiry on the endangered species list to the detriment of all. As Congressman George Brown from California has said: "Misinformation can be enacted into law!" The promise of agricultural research is truly great. But we have an additional responsibility today to help insure that the promise is realized.

LITERATURE CITED

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