SHAPING AGRICULTURE IN THE 21ST CENTURY

JUNE 22, 1995 SACRAMENTO

PROCEEDINGS OF A SYMPOSIUM

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UC DIVISION OF AGRICULTURE AND NATURAL RESOURCES

UC AGRICULTURAL ISSUES CENTER
Dr. Kenneth R. Farrell served the University of California with distinction for nearly nine years as Vice President for Agriculture and Natural Resources. Although Ken's tenure will be remembered most frequently for an impressive list of administrative accomplishments, he is at heart a scholar of the agricultural research and education enterprise. Thus, it seemed fitting to mark the occasion of his retirement from the University of California with a symposium focused on the characteristics of agriculture in the 21st century and the implications of those characteristics for the research and educational missions of the Land Grant University. This volume contains the proceedings of that symposium. It includes three major papers authored by some of the most thoughtful and widely respected authorities in the agricultural and natural resource disciplines together with comments and reactions of a group of distinguished colleagues from California.

The contributions found in these Proceedings suggest that agriculture will face profound challenges in the coming decades. Perhaps the most daunting challenge for California agriculture is posed by the need to remain highly competitive in the global market place in the face of intensifying competition for natural resources, the continuing need for environmental protection and growing tensions at the expanding rural-urban interface. It
will be crucial to maintain and enhance the productivity of agricultural and natural systems in ways that are natural resource-conserving and environmentally benign. This challenge will be shared to some extent by other regions of the United States and, indeed, around the world. It seems clear that the University of California and other great research and educational institutions are uniquely positioned to take the longer view in developing effective responses to the challenges of the 21st century. But the University itself will have to adapt even more to changing circumstances if it is to fulfill its part of the bargain. There could be no greater tribute to Ken Farrell than to begin that process of adaptation today.
ACKNOWLEDGEMENTS

The success of the symposium was due to the efforts of a number of people. Drs. Harold Carter, Keith Knapp, Warren Johnston, Jerry Siebert and Henry Vaux were responsible for planning the program and identifying the principal speakers. The UC Agricultural Issues Center, under the direction of Dr. Carter, was responsible for organizing the event. Stephanie Weber Smith served as conference coordinator while the logistical arrangements were capably handled by Sandy Fisher, assisted by Liz Schroeder and Vicky Boesch. Assistance in all phases of the symposium was also provided by Pat Day, Lynne Buenz and Judy Craig from Vice President Farrell's office. Mike Poe produced the introductory videotape and oversaw the presentation of visuals during the conference. Ray Coppock wrote the script for the video (see page 15) and worked with Stephanie Weber Smith to edit the Proceedings. Suzanne Paisley was responsible for the photography. Sandy Fisher prepared the Proceedings for print. The reception following the symposium was sponsored by the California agricultural industry and was coordinated by Steve Nation.
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Kenneth R. Farrell

Vice President
Division of Agriculture and Natural Resources
1987-1995
A Biography

Dr. Farrell has served as Vice President, Division of Agriculture and Natural Resources at the University of California since January 1, 1987. In this role, he is responsible for administration of systemwide research in the agricultural, environmental, and natural resource sciences conducted by the Agricultural Experiment Station on the campuses at Berkeley, Davis, and Riverside, and at nine field locations. He also is responsible for Cooperative Extension programs at the Berkeley, Davis, and Riverside campuses and in each of California’s 58 counties. The Division also includes the Natural Reserve System, Kearney Foundation for Soil Science, Water Resources Center, Agricultural Issues Center, Center for Cooperatives, the Giannini Foundation of Agricultural Economics, and the Center for Pest Management Research and Extension.

From 1982 to 1986, Dr. Farrell established and directed the National Center for Food and Agricultural Policy at Resources for the Future—a nonprofit, independent research and education institution in Washington, DC. The National Center conducts policy studies, communication, and leadership development programs on interrelated national and international public policy issues involving agriculture, food and nutrition, natural resources, and the environment.

Before joining RFF, Farrell held a succession of positions in the U.S. Department of Agriculture including that of Administrator of the Economic Research Service and the Economics and Statistics Service—agencies responsible for economic analysis and statistical programs of the Department.

From 1957 to 1971, Dr. Farrell served in several positions
at the Giannini Foundation of Agricultural Economics, University of California, Berkeley, as an economist and Associate Director. In several of those years, Farrell was on leave on special assignments at the University of Naples, Italy, the National Commission of Food Marketing, and the U.S. Department of Agriculture in Washington, DC.

The author of more than 100 professional articles and papers, Farrell is widely known for his work in agricultural policy, natural resource economics, international trade and marketing. A frequent consultant to both public and private organizations in the United States and abroad, he has served on two Presidential commissions, two Presidential task forces, as well as committees of the National Academy of Sciences and numerous professional and administrative committees of national and international significance.

Dr. Farrell holds degrees in agricultural economics from the University of Toronto and Iowa State University. He is past president and director of the American Agricultural Economics Association and in 1980 was elected Fellow of that Association. In 1992 he was elected Fellow, American Association for the Advancement of Science. He is a member of the American Agricultural Economics Association, American Association for the Advancement of Science, American Men of Science, International Association of Agricultural Economists, World Affairs Council of Washington, DC, Commonwealth Club of California, Phi Kappa Phi, and Gamma Sigma Delta.

In 1989 he was appointed by Governor Deukmejian to the State of California Board of Food and Agriculture; he was reappointed in 1992 by Governor Wilson. He served as chair of the National Association of State University and Land Grant Colleges’ Division of Agriculture 1991 Budget Committee, and chair of the NASULGC’s Division of Agriculture Legislative
Committee. He currently serves as chair of the NASULGC's Commission on Food, Environment and Renewable Resources Legislative Committee.
Symposium
Pictorial Montage

Henry Vaux, Jr.

William Baker

Kenneth Farrell, Richard Reminger, and Gordon Rowe
William and Jean Allewelt and Robert Webster

Henry Voss, Barbara Schneeman, and Mike Campbell

Cynthia Giorgio, Susan Laughlin, and Tom Perring
Shaping Agriculture: California’s Role

To provide an introductory glimpse at the central issues, the conference opened with an eight-minute video, setting the stage for the main presentations. This is the script of the videotape which is available from the AIC.

As we consider what global agriculture in the next century might look like, we need to keep in mind its underlying purpose: to produce food for a world population that has reached six billion—and is still growing.

This means that the real test of whatever systems of agriculture are developed during the next lifetime or two will be their impact on the living standards of the world’s inhabitants. Of course, that will depend on human choices of many kinds. But one of the most important of those choices will involve systems for producing and distributing food. Throughout the world, those systems are continually being shaped by three forces:

- increasing numbers of people who live, work and produce in a particular region;
- increasing competition for the available natural resources; and
- the effects of new technology or applied science on the system itself.

The combined effects of population pressure, resource scarcity and technology obviously take different forms in various parts of the world. In some regions—in parts of Africa for example—food in its most basic form is all that really counts: calories and how to produce and distribute them.

Meanwhile, many nations in economic transition have developed systems for acquiring and distributing food that have
taken them farther from the edge of starvation. But the threat is still there; for them, food supply remains a fundamental political and social consideration.

In contrast, people in more economically-developed nations tend to think of their agricultural systems almost entirely in terms of economics and lifestyle—for example, marketing of processed foods, changes in diet, international trade. For these consumers, resource conservation and environmental quality also are important considerations—and may even be seen as affordable.

Among these highly developed agricultural systems of the world, the state of California may be viewed as a test case of the interaction of population, resources and technology.

For example, it is obvious that California's spectacular population growth is linked to a significant degree to this state's natural resources—its land, its water, its climate, its other resources. But, as we all know, the presence of 32 million people in this state today—with more on the way—creates a serious threat to the quality and quantity of those same resources. Meanwhile, applied research and technology play a complex role. More sophisticated methods enable us to use and to conserve our resources more efficiently; but pressures on the system are increasingly difficult to deal with.

If California can be considered as a test case for highly-developed agricultural systems, it seems appropriate to ask a question: What historical trends have shaped modern agriculture in this state?

One of the most important of these forces has been the increasing pressure over time on the supplies of natural resources—and the resulting intense competition for those resources. Clearly, this has changed the shape of agriculture in California. Of course, competition for water supply is the classic
example. Degradation of air quality also influences agriculture—and vice versa. But probably the most visible effect has been the expansion of urban and suburban land uses—housing tracts, business parks, shopping malls—onto farmland and other open land. This explosive growth at the city's edge is what has made California, agriculture and all, into a so-called "urban" state.

This does not mean that California is being paved over from border to border. In fact, if you look at the areas in California that are classified as entirely urban, you will see that there is a lot of land left—including farmland. But it is outside the official metropolitan boundaries, in the partially urbanized areas—including much of the great Central Valley—where agriculture will have to continue its uneasy co-existence with subdivisions and shopping centers and industrial parks.

Of course, this problem is not restricted to California. Over much of the nation, there is an evolving rural-urban mix. Only two percent of the U.S. population now lives on farms.

A second historic trend—this one largely driven by society and by politics—also is reshaping California agriculture. This is the pressure for environmental protection, and particularly for more emphasis on long-run sustainability of the agricultural system and the resource base. This, of course, has important implications for the amount as well as the quality and safety of our future food supply.

A third portentous change affecting California agriculture has been the growth of world-wide marketing systems. Some California crops—raisins, almonds and cotton, for example—have long found buyers overseas. But in recent years, agricultural marketing in general has been transformed by new high-tech methods of global information exchange, and by the lowering of international trade barriers. These trends are
influencing many California crops.

Still another historic trend that has shaped California's agriculture—as well as the nation's—is something we have already talked about: Technology itself, growing out of scientific research and adaptation of research results. This kind of applied science has given California farmers a competitive edge in the nation's and the world's markets, as well as the flexibility to deal with rapid and relentless change. Technology also has resulted in dramatic increases in the basic capacity of farmland to produce food and fiber.

How do we know that productivity itself, as distinct from actual production, has increased? Well, if you look at the effects of all the additional inputs to California agriculture after World War Two—for example, all the irrigation water and fertilizer—you can account for part of the enormous jump in aggregate farm output—but only for part of it. The rest of that increase was a result of more efficiency within the system. In fact, a recent study by UC researchers shows clearly that basic agricultural productivity nearly doubled during those postwar years—almost entirely the result of research and technology.

So, whether we are talking about yields of strawberries per acre or of milk per cow, the basic capability to produce on the available farmland has increased dramatically in California, as well as in the U.S. as a whole. Obviously, this trend—driven by applied research, technology and extension—is one of the forces that influence agriculture.

To summarize, today's agricultural system in California has been fundamentally shaped by:

- relatively scarcer resources within an increasingly crowded state;
- the pressure for environmental protection and sustainable agriculture;
- the emergence of a global marketplace; and
• the development of technology.

As we approach the 21st century, it seems likely that these sources of change will continue to shape agriculture. But perhaps we had better include yet another component of change—and that is uncertainty itself. As agricultural systems adapt to the future, we can expect some surprises.

Still, as this conference looks ahead toward agriculture in the 21st century, we have the experience of the past to build on. We are in a position to acknowledge the forces that have shaped today's patterns of agriculture and resource use. That understanding of our history, in addition to the influence of applied science and of enlightened public policy, can strengthen our hopes for the future.
As the 21st century overtakes us, many different areas of science—biological, physical and social—will impact agriculture in many different ways. However, my remarks are limited to one area of the biological sciences: Biotechnology—particularly the influence of biotechnology on crop agriculture and domestic animal agriculture in the 21st century. This choice of topic is influenced not only by my personal research interests but also because of the great deal of attention that this area is receiving, both scientifically and commercially.

The first fruits of crop agriculture biotechnology have received regulatory approval for field production and marketing—the Flavr Savr tomato, of Calgene, Inc. of Davis, California, the virus-resistant crook-necked squash of the Asgrow Seed Company of Kalamazoo, Michigan (now a division of Empresas La Moderna of Monterey, Mexico), the herbicide-
resistant cotton of Calgene, and the insect-resistant potato of Monsanto Corporation, St. Louis.

At this point a definition is in order. A textbook definition of biotechnology is “the use of living organisms or their components to produce useful products, processes or services.” As this broad definition implies, biotechnology is concerned with a very wide range of biological materials and reactions, including antibodies, enzymes, enzyme-catalyzed reactions, fermentations, viruses and so on. However, two technologies have had the greatest impact and have thoroughly revolutionized both fundamental and applied aspects of biology related to agriculture and food and fiber processing. These are recombinant DNA methods and the ability to transform animals and plants genetically, including the regeneration of the plant from a single cell and the intact animal from an early stage embryo. Transformation is the process of introducing new genetic material, in the form of DNA, into the DNA of a particular organism. The new nucleotide sequences from the introduced DNA are duplicated with the cell DNA and encoded traits may be passed to progeny of the organism.

A third technology is less well known but has the potential also to have a great impact—the use of transient expression systems. “Transient expression” differs from “transformation” because the germ line of the target organism is not altered in transient expression as it usually is in transformation. That is, in transient expression the target organism can be induced to create new products of biological and commercial interest, including medical products, although any progeny of the organism will not have such capability. Transient expression systems are of particular interest for their potential in creating certain kinds of new small-scale agriculture.

In one sense agricultural biotechnology is a very new
endeavor; in another sense it is a natural extension of a very old agricultural practice. The fermentations and food processing that produce wine and beer, cheese, bread, and so on probably are the oldest examples of biotechnology. However, plant and animal breeding also were practiced, although perhaps not systematically, early in human prehistory. The ancient Nataufians, residents of the Dead Sea area, made pictographs thousands of years ago representing the mechanics of genetic crossing of cereal crops (i.e., the transfer of pollen from the flower of one plant to the flower of another). So the crossing of plant lines appears to be a very old technology indeed. Plant and animal breeding, although very powerful technologies that will remain important even as transformation and regeneration become more prominent, are inherently imprecise. In traditional genetic crosses of plants, for example, there is no control over what genes are transferred from one plant line to another. Subsequent backcrossing of the progeny of the initial cross to the parent with the most desirable traits, selecting for the one or small number of traits to be derived from the second parent, usually must continue for several generations. Ultimately, only a limited segment of DNA from the second parent, encompassing the gene or genes of value, is retained in the newly developed plant line.

In contrast, the biotechnology of transformation and regeneration allows introduction of a defined segment of DNA into the target plant or animal. The process of transformation and regeneration alters the genetic composition of a single somatic plant cell or of a single nucleus in an early stage animal embryo. A new, intact plant or animal is derived from the transformed cell. This process makes the manipulation of the plant or animal genome more predictable, more precise and not limited by the usual species barrier, potentially creating a new
genetic line for the species in question. This highly-precise procedure allows researchers to transfer genes even among organisms of different kingdoms and to introduce chemically synthesized DNA sequences into the plant or animal. It is the potential of introducing exotic genetic materials that has caused some to become concerned about the possible consequences of applying transformation and regeneration technology, in spite of the advantages inherent in precise control over just what sequences are introduced into the plant or animal. As I have indicated, lines of tomato, squash, cotton and potato have been found to satisfy current regulations and have been approved for crop production.

Most of the current efforts in agricultural biotechnology fall under one or more of these headings:

- Diagnostics
- Improved crop agronomic traits
- Improved and new food, fiber and ornamental products from crops and domestic animals
- Assisted breeding
- Food processing
- Improved and new chemicals and pharmaceuticals
- Biomass production and conversion
- Bioremediation

Several of the technology areas indicated will undoubtedly have important environmental, as well as agricultural, implications. For example, the production of chemicals and biomass energy from plants can replace petroleum derivatives with products from solar energy.

Diagnostics is largely concerned with, but certainly not limited to, detection of agents of disease. There have been a number of important advances in other areas of diagnostics, and one that deserves particular attention is the development
of highly specific and highly sensitive assays that are not dependent on radioisotopes. Non-radioactive diagnostics can be used in the field, in remote areas and in places where licensing procedures and radioactive disposal are a particular problem. Biologically-based sensors and assays have provided the necessary sensitivity and specificity for successful non-radioactive diagnostics. DNA analysis, also known as "DNA typing," finds applications not just in forensics but also in traditional plant and animal breeding programs, by providing genetic markers for desired traits.

I will discuss some specific examples for the topics of improved crop agronomic traits and new and improved crop products. Listed here are some agronomic traits already introduced into crop plants or likely to be introduced before 2010:

- Resistance against pathogens
- Resistance against nematodes
- Resistance against insects
- Tolerance to herbicide
- Tolerance to low temperatures
- Tolerance to heat/drought
- Tolerance to salinity/heavy metal ions
- Male sterility for production of crop hybrids
- Modified ripening rate

One crop agronomic trait, tolerance to metal ions, may be helpful not just in traditional agriculture but also in the bioremediation of contaminated soils. Biotechnology approaches to tolerance against herbicides, to male sterility and to slow ripening have been demonstrated by several laboratories. Approaches to inducing genetic tolerance to low temperatures, to heat or to drought are subjects of intense efforts at this time with commercialization perhaps more to the future. However,
genetically engineered resistance against plant viruses and against insects is well advanced and must be regarded as a biotechnology success story.

The only widely applied approach to engineered resistance against viruses that currently is available falls under the aegis of "pathogen-derived resistance." The development of pathogen-derived resistance received its inspiration from observations from the late 1920s. Tobacco plants were found to be protected against the effects of infection by severe virus strains by prior inoculation of mild strains of the same virus. This phenomenon of "cross protection" suggested that protection against a specific plant virus might be achieved by transformation of the crop plant to express a gene of the virus. A gene or other discrete segment of nucleic acid sequence is removed from the virus genome and is transferred to the plant genome. In many instances, the result of expressing the virus-derived nucleotide sequence in the plant has been the demonstration of resistance against infection by the corresponding virus. This is a valuable technology that is having and is likely to continue having great impact.

Perhaps the most interesting example of virus-derived resistance involves the expression throughout the plant of a mutated version of the virus movement protein. The unmutated protein normally is found only in those parts of the plant that have been infected by the plant virus. Movement proteins allow the virus infection to spread from cell to cell in the plant, and when no movement protein accumulates after virus inoculation or an inactive, mutated version of the movement protein is formed, the virus infection does not spread beyond the few cells initially inoculated. Several laboratories have demonstrated that expression in the plant of a mutated version of the movement protein, a version demonstrated to be inactive in supporting cell-to-cell spread of the infection, results in
resistance against the virus from which the unmutated version of the movement protein had been derived. The most interesting aspect of these experiments is that, unlike other forms of virus-derived resistance so far investigated, the engineered resistance is effective against several viruses in addition to the virus that was the source of the movement protein sequence. Broad spectrum resistance against several groups of viruses is of obvious advantage.

Genetically-engineered resistance against insects has been achieved by transgenic expression of an insect-specific, actually insect species-specific, toxin from the bacterium Bacillus thuringiensis. This insecticidal protein, generally referred to as Bt Δ endotoxin, is highly insect-specific. The Δ endotoxin is so effective and specific because the protein undergoes a protein cleavage step in the alkaline environment of the insect gut that releases the active toxin. The active toxin is recognized by and binds to a receptor of the insect gut that is distinct from any receptor of the vertebrate gut, providing an additional measure of insect specificity. Several crop species have been genetically engineered to express various Bt genes obtained from Bacillus thuringiensis. Field trials of a Bt-expressing, engineered gene in cotton have been very successful, especially as part of an integrated pest management scheme. As is indicated in Figure 1, a doubling of cotton yield has been achieved for the genetically-engineered cotton, compared to the control cotton line, when both were exposed to insect pressure in the field and neither was protected by conventional insecticides. Damage due to boll worm and bud worm were held to low levels in the Bt-expressing cotton plant.

An alternative strategy for controlling insects is to genetically engineer an insect-specific virus rather than the plant. The research groups of Bruce Hammock and Susumu
Maeda at the UC Davis campus have altered naturally occurring baculoviruses to express an enzyme that interferes with the usual hormonal control of the insect. These genetically-engineered baculoviruses kill insects much faster than their natural counterparts because of their ability to alter the hormone balance of the insect. Other approaches employ other insect-specific hormones and toxins. This presents the prospect of expressing several insecticidal agents in the same insect virus or the same crop line, that is, to “pyramid” resistance genes. Simultaneous deployment of several genes effective against one
or a particular group of insects offers the prospect of more stable resistance, better able to protect the crop against newly evolving lines of insects.

At this point I wish to turn to the products of crops, and particularly to new crop products. It is convenient to categorize improved and new crop products, both developed and being explored, into six groups. Arranged from the common and obvious to the less common, these are:

- Foods
- Feeds
- Fibers
- Flowers
- "Farmaceuticals"
- (Chemical) feedstocks

Although new developments in biotechnology provide potential for improved or new agricultural products in each of these categories, the opportunities may be especially great for new crops that generate feedstocks for the chemical and pharmaceutical industry. Published results and presentations by scientists from non-profit and for-profit institutions indicate that any list of crop products from biotechnology available now and or likely to be available before 2010 must include:

- Long shelf-life fresh market tomatoes and melons
- Long shelf-life carnation
- High-solids tomato
- Slow-ripening broccoli and tomato
- C8-C14 fatty acids (detergents, food)
- Highly saturated triglycerides (natural margarine)
- Altered flower color
- High-starch potato; high-sucrose potato

Shaping Agriculture in the 21st Century
- High methionine and cysteine soybean
- Phytase-expressing soybean (improved digestibility)
- Polyhydroxybutyrate (biodegradable plastic)
- "Vaccine foods"
- Transiently-expressed proteins, drugs and vaccines

The long-shelf-life tomato was the first improved crop product to receive regulatory approval, and it is on the market. New food products, including the long-shelf-life tomato, must meet standards of safety and nutritional quality. Such considerations limit a particular genetically-engineered soybean line to use in the production of animal feed. This soybean has improved content of the sulfur amino acids cysteine and methionine because it is genetically engineered to produce a protein derived from the Brazil nut, which is allergenic in some people.

The high-starch potato must be considered another biotechnology success story. A bacterial gene, encoding the enzyme ADP-glucose pyrophosphorylase, was introduced into the DNA of the potato by transformation and regeneration. ADP-glucose pyrophosphorylase is known to be a critical enzyme in starch biosynthesis and under some circumstances is the most influential control over the amounts of starch synthesized. The bacterial gene was placed under the control of a potato tuber-specific promoter. Because the promoter controls the timing of expression of the gene under its control and the tissue in which the expression occurs, synthesis of the bacterial ADP-glucose pyrophosphorylase is limited for the most part to the developing tuber. The bacterial and plant ADP-glucose pyrophosphorylases have their activities regulated differently. Thus, the bacterial
ADP-glucose pyrophosphorylase, once synthesized in the tuber, behaves differently than the endogenous potato enzyme. The result is that starch is overproduced relative to its synthesis in the non-transgenic control potato tuber. The increased starch content of tubers from the transgenic potato plants readily can be demonstrated by the standard iodine test, familiar from high school biology courses, applied to the freshly cut tuber surface.

Engineered oilseed crops have the potential to produce chemicals that normally would be derived from petroleum sources. Where a petroleum source can be substituted by a crop source, the result is at least a partial substitution of carbon fixed by solar power for a non-renewable source of fixed carbon. The untransformed oilseed rape crop plant has been subject to very successful traditional breeding in two directions. Some lines of the same or closely related crop species have been optimized for the production of industrial oil (erucic acid) and others for canola oil, a food oil valued because its fatty acid composition resembles that of the much more expensive olive oil. The seed of the rapeseed plant may have 40-45 percent of its dry weight as oil. Lauric acid is a fatty acid that is used in the production of detergents and other chemicals as well as in food products. Lauric acid production by transgenic oilseed rape, as developed by Calgene, can be considered the first new crop product to be derived from agricultural biotechnology. Although the principal source of laurate is the oilseed palm rather than petroleum, the temperate zone oilseed rape crop is considered to be more reliable and to be grown at lower cost than the tropical zone crop.

The California Bay tree is one of a small group of plants that produces the 12 carbon lauric acid rather than some longer chain fatty acid as the principal storage oil of the seed. The prospect of domesticating the California Bay into a suitable crop
plant is a daunting one, perhaps an impossibility. However, recombinant DNA methods and the processes of transformation and regeneration offered the possibility of domesticating a gene from the California Bay. Through their investigations of the basic biochemistry of lipid synthesis in the developing seeds of the California Bay tree, Calgene scientists demonstrated that a single enzyme from the California Bay, a specific thioesterase, was likely the key to short-circuiting the usual 18-carbon fatty acid production that predominates in the developing rapeseed (Figure 2). That is, action of the thioesterase was expected to generate 12-carbon fatty acids. The California Bay gene that encodes the thioesterase was identified, isolated and transferred to rapeseed under the control of a promoter specific to the developing seed. The result is a significant accumulation of 12-carbon fatty acid to about 45 percent of the lipid of the rapeseed, compared to barely detectable amounts of this fatty acid in the untransformed rapeseed.

Another new plant product, one that has been engineered to accumulate in the leaves, probably is completely foreign to plants—the bioplastic polyhydroxybutyrate. The polyhydroxybutyrates are useful for making self-dissolving sutures and for other medical uses because both the plastic and its breakdown products are biocompatible. Polyhydroxybutyrate also has many other potential applications, including biodegradable soft drink bottles. However, this plastic, as currently produced by bacterial fermentation, is far too expensive for such applications and cannot compete economically with petroleum-derived plastics. If polyhydroxybutyrates could be derived from a plant source, so that the carbon and energy required for synthesis were derived from the atmosphere and the sun, it is possible that the polyhydroxybutyrates could be produced sufficiently cheaply. The research group of Chris
Figure 2. Modification of seed storage lipid achieved by transgenic expression and transport to plastids in developing seed of a thioesterase specific for hydrolysis of the lauryl-acyl carrier protein (C12:0-ACP). The diagram represents a cell in a developing seed. The usual cascade of two carbon additions, directed at the synthesis of C16 and longer chain fatty acids, is interrupted by introduction of the C12 specific thioesterase, resulting in significant accumulation of lauric acid in seed lipids.

Somerville at the Carnegie Institution of Washington at Stanford demonstrated polyhydroxybutyrate synthesis in the "laboratory" plant Arabidopsis, by introducing singularly into individual plant lines the three enzymes from bacteria that are required for synthesis of polyhydroxybutyrate. By subsequent, ordinary genetic crossing, all three genes were co-located in a single Arabidopsis line. A critical part of this accomplishment was the engineering of the amino acid sequences of the enzyme molecules so that the enzymes accumulate in the chloroplasts. The significance of this is that the chloroplast, unlike the
surrounding cytoplasm, is the subcellular site at which acetylcoenzyme A, the substrate for polyhydroxybutyrate synthesis, is available in abundance. Targeting of the three enzymes to the chloroplast increased accumulation of polyhydroxybutyrate by 100 fold over the accumulation observed when the three enzymes were targeted to the cytoplasm. The result of targeting to the chloroplast was accumulation of polyhydroxybutyrate to 14 percent of the dry weight of the leaves without undue negative influence on growth. This is close to a commercially-suitable level for the production of bioplastics from plants.

I turn now to the notion of animals and plants as factories—as transient expression systems for high level production of valuable biochemicals. When an animal or plant is genetically transformed, the intent usually is to alter the germ line so that the character introduced by genetic transformation will appear also in the progeny of the transformed organism. In transient expression, the germ line of the plant or the animal is not modified; rather, the genetic expression during a certain phase of the life cycle and in certain tissues is altered. Transient expression has the potential not only to produce specific products in abundance but also to produce compounds that perhaps would not be tolerated by the plant or animal throughout its full life cycle.

William Dawson, formerly of UC Riverside, and his colleagues incorporated a new gene into the genome of tobacco mosaic virus. The new gene was incorporated at a site and with surrounding nucleotide sequences such that the presence of the gene is tolerated during replication of the virus. Tobacco mosaic virus accumulates to high titers in the inoculated plant. Therefore, tobacco mosaic virus genetically engineered to direct the synthesis of a particular protein has the potential to produce a very high level of the protein. Transient expression is
accomplished by inoculating the virus into standard tobacco plants. Thus researchers have an opportunity to convert the plant to the production of "your favorite gene" and, in the case of a gene encoding an enzyme, perhaps the product of a reaction catalyzed by such an enzyme. This high level production can be accomplished even for products of the gene that would not be tolerated by the plant throughout its full life cycle. Tricosanthin is a protein that may have drug use and in fact is in clinical trials as a potential anti-HIV drug. This small protein has been produced in tobacco plants by researchers at Biosource Technologies in Vacaville, California. The transient expression technology, based on tobacco mosaic virus vectors, has generated tricosanthin as two percent of the plant protein. Presumably tricosanthin can be produced at less expense in inoculated plants than by culture of its natural source, *Tricosanthes kirowloii*.

Plant viruses also are potential sources of veterinary vaccines. The nucleotide sequence corresponding to a specific segment of the coat protein of an animal virus has been introduced into the gene for the coat protein of a plant virus. The segment is chosen to correspond to an element of the surface structure of the animal virus, and the site to which it is transferred in the plant coat protein is designed to display the animal virus amino acid sequence on the surface of the plant virus coat protein. The resulting plant virus particles have been used to inoculate animals and to induce the formation of antibodies reactive against the animal virus. That is, the plant virus particles act as "immunogens" to elicit antibodies against certain "epitopes" of the animal virus particles, even though the plant virus is incapable of infecting the inoculated animal. Such vaccines may have advantages in cost and safety over more traditional killed or attenuated animal virus vaccines.

It is convenient for my purposes to categorize currently
prominent animal biotechnologies into:

- Diagnostics/veterinary medicine/assisted breeding (including DNA diagnostics, recombinant drugs and vaccines, marker assisted selection and DNA typing)
- Augmented animal production and transgenic animals (including genome mapping, embryo culture, cloning, gene transfer and targeting)
- Transient expression systems (including virus-derived vector systems and inoculation procedures)

I will focus on the third of these categories—Transient expression systems—because technologies in this third category have received less attention than those in the first two, and transient expression systems offer great promise. Transient expression in animal systems, just as in the tobacco mosaic virus system I have discussed already, depends on viruses—in this case animal viruses. A virus possesses a full set of functions to allow it to infect host cells and to induce the infected cells to produce new virus particles. These new virus particles are of course ready to infect yet other cells of its host. An animal virus vector is constructed by deleting one or more genes of the virus. The result is a non-virulent agent not capable of round after round of infection and replication. The animal virus vector usually is designed to infect ("transfect") cells and express foreign genes that have been introduced into the vector, but the vector fails to direct synthesis of new virus particles and therefore fails to initiate a spreading infection.

In some experiments, animal cells in culture have been exposed to particularly effective virus vectors, and extracts from the cells have been analyzed by the common laboratory technique
of polyacrylamide gel electrophoresis. An extract of a mere 25,000 cells has given a band corresponding to the protein product of the gene transiently-expressed from the virus vector, when the gel is examined after staining to reveal proteins. The new band is readily detected against the background of cell proteins, showing that a massive conversion of protein synthesis has occurred in favor of the transiently expressed gene. In fact, in these experiments 25 percent of protein of the animal cell was that expressed under the control of the virus-derived, transient expression vector, which is a really dramatic effect.

The use of transient expression vectors has been extended from animal cell culture to the intact animal. The mammary gland of goats and cows is particularly useful in this regard. The transient expression system can be designed so that the new protein appears in the milk, a biological fluid well adapted to convenient purification of the new protein (see Figure 3). The mammary gland of a goat or a cow contains many times the 25,000 cells in extracts of which, as indicated before, it was possible to detect a newly expressed protein readily. For expression in the mammary gland, the gene of interest is inserted into a retrovirus vector. The vector retains critical capabilities of the virus, including the ability to introduce virus DNA into the nuclear DNA of cells into which the vector has been introduced. No new virus particles form, and without new virus particles, the infection does not spread beyond the initially inoculated cells. Although the virus vector cannot direct synthesis of new virus particles, it is possible to enrobe the nucleic acid that composes the virus vector, and the gene that is to be transiently expressed, in the usual protein and lipid structure that forms the surface of a virus particle. Compared to the nucleic acid alone, these particles much more readily transfect cells, particularly cells in the intact animal. Enrobing
the vector is accomplished by introducing the vector into special cells in culture. These genetically-engineered cells supply the proteins necessary to form particles that resemble virus particles but that have vector nucleic acid rather than the usual virus genome. It is only in these special cells that infecting particles are formed. Solutions of the particles are introduced directly into the teat canal of the cow or the goat where they direct “transfected” cells of the mammary gland to produce the product of the introduced gene, a new protein. Although only small amounts of protein have been generated in published experiments, there is reason to believe that greater, and useful, concentrations can be produced in the milk of the transiently-expressing animal.

Figure 3. A system for transient expression of proteins in ruminant milk. A gene encoding human growth hormone (hGH) was inserted into a DNA form of a retrovirus vector, upper left hand corner of the diagram. The DNA was used to coat gold particles which were used to bombard special “packaging” cells in culture, lower left hand corner of the diagram. Packaged vector, which resembles virus particles physically and in their ability to introduce nucleic acid into a cell, was purified and injected into the teat canal to transfect cells of the goat mammary gland. hGH was detected in the milk produced over a two week period. Adapted from J.S. Archer et al., Proc. Nat. Acad. Sci. USA 91:6840-6844 (1994).
The summary table (Table 1) compares production of proteins from the mammary gland of a transgenic animal with transient expression by the mammary gland. The engineered DNA that is introduced into an embryo is replicated with the usual DNA complement of the animal, carrying the genetically engineered DNA sequences to all cells of the transgenic animal. Thus a new genetic line of goats or cattle or pigs can be established that bears the gene of interest, and it is not necessary to reintroduce the genetic material. This is an advantage for the transgenic animal approach. However, most other comparisons of transient expression and transgenic animal approaches favor the transient expression approach. The transient expression system is likely to be more versatile with regard to the range of proteins that can be expressed. This technology can be used to test, in a period of weeks or months, the feasibility of producing a given protein in a given species of animal. Investigators can determine whether the expressed protein is modified by the animal in characteristic ways that may be necessary, for example, for pharmaceutical applications. An example of such a modification is the attachment of specific sugar residues to specific amino acid residues in the protein. It is likely that transient expression systems will have a powerful impact in 21st century agriculture, possibly fostering the development of small operations dedicated to the production of small amounts of medically valuable proteins or protein products.

I already have mentioned recent successes in the development of potential vaccines based on recombinant plant viruses capable of acting as immunogens in animals but not of infecting the animal. Animal virus-based transient expression systems also have been developed as vaccines and have demonstrated success in combating rabies in Europe. Vaccinia
<table>
<thead>
<tr>
<th>Transient expression system</th>
<th>Transgenic animal</th>
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<tbody>
<tr>
<td>• Virtually every animal exposed to the retrovirus vector becomes an expressor of the protein of interest</td>
<td>• For injection of embryos with DNA and subsequent implanting, on the average 1 of 180 goats, 1 of 250 pigs, and 1 of 650 cattle becomes an expressor of the protein of interest</td>
</tr>
<tr>
<td>• From planning of an experiment to detection of product can be a few months</td>
<td>• A year or more is required from planning to production</td>
</tr>
<tr>
<td>• Engineered DNA sequences are limited to cells &quot;transfected&quot; by the virus vector</td>
<td>• Engineered DNA sequences are present in all cells of the transformed animal, although expression of the gene of interest usually is limited to specifically targeted tissue</td>
</tr>
<tr>
<td>• Female animal selected for production</td>
<td>• Transgenic progeny animal may be a male</td>
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virus is the agent of cowpox and is the virus used by William Jenner, in an unpurified form, to vaccinate people against smallpox. Vaccinia virus vectors have been engineered to produce proteins derived from a number of different pathogens, and it is possible with this system to express more than one immunogen, each derived from a different pathogen, from the same engineered construction. Rabies has been an important disease problem in Europe, where from 1983 through 1989 bites by wild foxes resulted in about nine hundred people per year undergoing the often painful and possibly ineffective post-exposure schedule of immunization against rabies based on the original work of Louis Pasteur. Vaccinia virus was engineered to express a rabies virus protein that is known to be immunogenic. The engineered vaccinia virus induces a mild infection that generates the rabies virus protein. Beginning in 1989, chicken heads laced with the genetically-engineered vaccinia virus were distributed from airplanes over forests of western Europe. In each subsequent year, there were typically
two such distributions. In 1990 the number of rabid foxes began to decline. The post-exposure schedule was received by more than one thousand people in 1989 but by fewer than five hundred in 1990. By 1993, the number of such treatments declined to about fifty. No adverse environmental effect has been noted. Thus a transient expression system applied in a natural environment provided an effective and rather quick solution to an important medical problem.

In closing, I turn to a quote by one the founding fathers of this country. Thomas Jefferson wrote: "The greatest service which can be rendered any country is to add a useful plant to its culture." I would add "a useful domestic animal" and "a useful biotechnology." I want to close with a notion mentioned earlier—the notion of the exotic and what fears we may have about the applications of exotic technologies. Agricultural products that currently are widely and extensively consumed, like the banana and the tomato, were in the 19th Century regarded in some quarters with suspicion. The technology of embryo rescue was introduced in the mid-20th century to allow plants from different species to be crossed, and introduction of embryo rescue occurred without much concern. In fact, attitudes about introducing new foods, new biological products and new biotechnologies into our culture, and about introducing new organisms into the environment, have fluctuated enormously over the decades, along a continuum from total acceptance in some instances to general distrust and points between. Thought experiments and debate about these matters likely, and rightly, will continue. Exotic and complex technologies must of course be evaluated for their feasibility and safety, but we must learn not to fear a technology merely because it is difficult to understand. To do so risks not benefiting from any number of potentially valuable technologies.
Acknowledgements

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It is useful, I think, to begin this discussion by asking why an environmental perspective on agriculture in the 21st century matters. If, as is the case in the industrialized world, an ample food supply is affordable, then the environmental issue about agriculture resolves down mostly to a choice about what we are willing to pay to mitigate the problems of excessive pesticide and fertilizer use, sediment production and the like. These problems are important, of course, but there is nothing much special about agriculture as a cause of them. There are, for example, non-agricultural sources of many of these problems, as well as other ones—smog in Southern California comes to mind—that may be seen as more serious than agricultural pollution.

The environmental perspective on agriculture is more compelling, however, when one takes the vantage point of global food security in the 21st century. The question of whether the
world can produce enough food for a rapidly growing and mostly poor population remains, as it has since Malthus, in dispute. Adding environmental considerations to the challenge of achieving global food security surely must make the problem harder and, in the view of some, potentially insoluble. In short, the interesting questions are: To what extent does the environment become a constraint on future food production? If there is such a constraint, how to go about relieving it?

In taking up these questions, I must first renounce any claim to expertise in analyzing the future of the agriculture system. In consequence, nothing that follows will add to the body of scholarly knowledge on this crucial subject, nor will it even stand as a critical review of the work of others. Rather, I have approached the issues from the position of someone lacking technical expertise but who is nonetheless charged with making sense of the work of those in the field who are the experts. In short, I have reviewed some of the literature and have tried to interpret what it means in policy terms.

**THE CONVENTIONAL WISDOM**

I judge that the past few years have been particularly fertile in producing forecasts of global food demand and supply. This, in turn, seems to have led to several careful appraisals of the differences among the various projections. Of these, Alex McCalla’s 1994 Crawford lecture is perhaps the best known (McCalla 1994).

McCalla makes a careful comparison of four representative food security scenarios, exploring the models and assumptions that lead to differences among the analysts responsible for the forecasts. What is remarkable, however, is the degree of consensus among the experts who have considered how the food
security issue might play out over the next 20-30 years. Three areas of near-universal agreement stand out:

- Demand for nutrition—food—has a limit set by dietary requirements and the number of persons that need to be fed. In consequence, forecasts of food demand cluster reasonably closely to one another. Only one article, written by David Seckler, managed to craft a demand forecast low enough to mitigate the food production problem in any significant way (Seckler 1994). I am more accustomed to demand forecasts in the energy business, which are notoriously wrongheaded, usually on the high side.

- There is a limited amount of new land and water resources that can bear the increased food production. A comparison to the energy business is again instructive, at least to me. As with oil, they are not making land anymore. Unlike oil, however, we have long since found all of the land that was made in the first place. The limitation on the amount of additional land and water available for agriculture therefore seems quite credible to me.

- The solution to the food production problem is to increase productivity—that is, crop yields. Given bounds on both demand and supply of incremental land and water resources, this conclusion is inescapable for all practical purposes. At any rate, I cannot find any significant opinion that suggests otherwise, nor can I offer an alternative conclusion on my own.

Such clarity and consensus in the formulation of the food
security issue is not necessarily reassuring, however. Although there is considerable agreement over what has to happen—increased productivity—there is plenty of dispute about whether it will. Some scholars are rock-solid in their view that technology will provide the necessary efficiencies, as it has in the past. Seckler, for example, concludes that:

The real threat to [his] optimistic scenario is not the lack of "sustainable" agricultural development processes but is the systematic dismantling of the tried and true processes of the Green Revolution that, it seems, people ranging from laissez-faire economists to equally dogmatic environmentalists wish to achieve.

In stark contrast, Lester Brown [1994] of the Worldwatch Institute finds it hard to see where the new technologies are coming from. To him, the technological roots of the Green Revolution trace back almost a century. This intellectual capital has been used up, nothing has replaced it, and we cannot rely on continuing increases in productivity to solve the looming food production problem. Lest Brown be dismissed as an outlier in this judgment, note that Vernon Ruttan [1989] shares at least some of his skepticism about the technology pipeline.

There is no way to say who is right in predicting the future, of course. Still, McCalla’s review of the range of forecasts current in the literature leads him to conclude that “...regardless of which view you prefer, the productivity challenge facing world agriculture in the next 30 years is enormous.” McCalla and other commentators then point out that research and development is not getting the support it should if new technology is to be available to solve this “enormous” problem.
Restating the Conventional Wisdom

As is often the case with Malthusian arguments, the conventional wisdom about food security lends itself to the temptation of "gapology." In other words, forecasts tend to present a picture of demand exceeding supply, resulting in considerable discussion of the "gap" between the two. In the real world, of course, there are never such gaps—only changes in price levels that bring supply into balance with demand. It is instructive, therefore, to introduce consideration of price into the conventional wisdom about agriculture.

Introducing price into the debate is not merely a knee-jerk reaction. In the case of food, price is a good measure of sustainability. Rising food prices over time would suggest a scarcity of resources, and scarcity is the antithesis of sustainability. For example, at constant prices, most analysts agree that relatively little new land and water resources would be summoned to the service of food production. Absent yield increases, however, prices would rise, and more land and water resources would be employed in agricultural production. These newly recruited resources would lower average agricultural productivity and tend toward unsustainability. In other words, without yield increases, Malthus is probably right.

One way of formulating the question of food security, therefore, is to ask whether the world can afford to feed itself. Crosson and Anderson [1992] conclude that, with the supply of knowledge resources fixed, which is a more elegant way of phrasing the lack of productivity improvements, "...the demand scenario would imply rising economic and environmental costs of agricultural production." Even Mitchell and Ingco [1993], a pair of technological optimists, note that if cereal yields remained frozen at 1990 levels because of biological or environmental
limits, cereal prices would more than double over a decade. The less sanguine Bongaarts [1994] concedes that feeding a growing population a diet that improves over time in quality and quantity is technologically feasible, but the economic and environmental costs incurred may prove too great for many poor nations.

Reformulating the conventional wisdom in terms of affordability has the virtue of focusing attention on the real dangers of slow growth in agricultural productivity. The problem is not some troublesome gap between supply and demand that is easily closed by letting prices rise. Food is not an amenity of which one willingly buys a bit less. Rather, the danger is the potential diversion of resources into food production and away from other investments essential to enhancing economic well-being in developing countries. And in the worst cases, some countries may not be able to afford adequate food supplies as prices rise.

**The Environmental Constraint in Context**

But what of the environment in all of this? Not every study of food security systematically evaluates the possibility of an environmental constraint on food production. Most mention it, however, reciting essentially the same set of environmental problems related to agriculture. Rob Paarlberg [1994a] summarizes the litany of issues that threads its way through the literature:

The 'mining' of soil nutrients has recently pushed average crop yields into decline in those parts of Africa where yields will have to increase. In much of South Asia, old irrigated lands are becoming saline and waterlogged and thereby unproductive.
almost as fast as new irrigated lands are coming into production. From Java to Honduras, trees are being cut and soils are washing away on newly exposed sloping lands, and in East Asia, South Asia and Central America natural biological controls for crop pests are being poisoned while the pests themselves are becoming more poison resistant.

Paarlberg may be deceptively precise in his description of these environmental problems, pinning them down to particular locations. Others are less precise, leaving an impression of more widespread troubles than the facts probably warrant. Nevertheless, I would not argue with the conventional wisdom that is accurately summarized by McCalla when he says, “The global requirement for production systems to be non-degrading to the environment (i.e., sustainable production systems) increases an already enormous research and development challenge. Few systems have sustained increases of over two percent per year, and these have often been at the expense of resource degradation.”

Despite this widely accepted conclusion, it is my impression that prudent researchers in the field have felt a need to sort out the potential environmental constraint with a bit more precision. Crosson and Anderson provide one important extension by distinguishing carefully between economic and environmental costs, noting that environmental costs are not priced in markets. Environmental costs, therefore, do not ordinarily influence the economic behavior of individual farmers. This familiar but powerful distinction carries with it the conclusion that since farmers may well behave in an environmentally-destructive way, unpriced costs should be considered in calculating overall
agricultural productivity.

Paarlberg [1994b] takes a different tack by partitioning the environment-agriculture connection into first- and second-generation problems. First-generation problems arise from trying to increase food production by traditional, low-yield farming methods. He notes, for example, that India could not have relied on such methods to meet the food demands of its huge population without serious deforestation, habitat destruction and soil degradation. Second-generation problems are the price of successful high-yield farming. To continue the example of India, Paarlberg cites the issues of groundwater mining, nutrient runoff, pesticide use and loss of biodiversity due to monocultural farming practices as second-generation problems.

**So What is the Constraint?**

Given the understanding of the agriculture-environment relationship that I have tried to outline, let me at last return to the policy issue that I posed at the outset of these remarks: Is the environment likely to be a constraint on food production? I have concluded that the answer to this question is "no." This is not to say that agriculture does not create environmental problems, but only that the problems it does create are not a first-order constraint on food production. To explain this conclusion, I need to examine two kinds of agriculture-related environmental problems.

The first kind of problem involves off-farm environmental effects that accompany practices intended to improve agricultural productivity. For example, the use of pesticides may affect the health of non-farm workers; nutrient runoff can cause eutrophication of estuarine waters; on-farm erosion may
create siltation that impairs performance of a downstream dam; and so on. None of these adverse outcomes is to be desired, and certainly their environmental costs belong in any calculation of overall agricultural productivity. But these issues become constraints on agricultural productivity only if one wants them to be. That is to say, for example, the decision to buy less eutrophication in exchange for reduced agricultural productivity through some sort of limitation on fertilizer use is a policy choice that could go either way.

It seems to me unlikely that environmental problems of this nature will become much of a constraint on agricultural productivity. The reason is simply that food production is such a basic human need that the policy choice will generally tilt toward agriculture. Put in economic terms, it is hard to imagine that even the full social costs of food production will outweigh the benefit of having enough food. In this sense, the environment becomes at most a weak constraint on food production.

Having said this, however, I need to acknowledge a couple of likely objections. One is that I am suggesting that poor countries should ignore the environment. This is not the case, for there is much that can be done to protect the environment cheaply. Some management techniques may produce environmental benefits at little or no cost to agricultural production—the literature is peppered with references to successful uses of integrated pest management, for example. Such techniques should be used where possible, although one needs to take care that their costs are, in fact, low.

The other objection is that environmental controls cost farmers plenty, and that I am passing off this cost too lightly. One only needs to look at U.S. controls over pesticides, irrigation practices, prairie potholes and the like to be convinced that environmental considerations encumber food production. This
is true, of course, and it would not be surprising to learn that many of these costs are burdensome, at best. Even so, they fall far short of turning the U.S. into a green, but underfed, nation. Irksome as they may be, these environmental costs are not a serious constraint on food production.

The second kind of problem involves activities that simultaneously degrade the environment and food security. These are on-farm environmental problems:

1) Wind and water erosion that lead to soil loss and, thereby, reduced agricultural productivity.

2) Soil nutrient depletion arising from overly intensive use of land. Erosion also causes nutrient depletion but for different reasons.

3) Desertification, defined as land degradation in dryland areas. Erosion and nutrient depletion are the culprits, but the dryland setting appears to pose special problems.

4) Reduced water quantity and quality. In some areas the supply of water may be limited and so become a constraint on food production. And water re-use for intensive irrigation can increase salinity to the point that productivity drops.

5) Opening up less productive, environmentally-sensitive land and water resources for agricultural use. This is the familiar problem of cutting down rainforests to grow food.

While these are real and serious problems, it is important to keep them in perspective. Each has a counterpoint that suggests that the problem is less pervasive or relevant than it might first appear. For example, some scholars assert that the net productivity loss associated with erosion is relatively small, certainly compared with the productivity increase needed to produce food for a growing population. Replacing lost nutrients

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*Shaping Agriculture in the 21st Century*
is not a difficult matter for modern agricultural technology. Land subject to desertification is inherently marginal and not a major factor in global food production. The main irrigated cereals are fairly insensitive to moderate levels of salinity. At present prices, the contribution of new land and water resources to food production is likely to be modest.

On the other hand it is fair to point out that I have probably not included all of the environmental effects on agricultural productivity that I could have. John Antle [1993] has shown that excessive pesticide use can damage the health of farm workers, thereby reducing productivity in the agricultural sector itself. But it is hard to imagine that the effects are of the magnitude of the resource degradation problems I have listed above. Accordingly, I conclude that these five issues constitute the great bulk of the agriculture-environment issue.

WHAT TO DO ABOUT IT

From the policy perspective the interesting point is that none of these problems is initially caused by environmental degradation. Instead, each arises from an attempt to increase food production in a way that leads to environmental degradation that in turn reduces the productivity of the agricultural system. The policy question that stands out quite starkly is: Why would anyone knowingly engage in practices that reduce the productivity of the food production system and that damage the environment?

In a rational world, surely individual farmers would be eager to take advantage of production technologies that increase revenues more than they add to the economic costs of farming. In the same world, one would hope that national governments would want to make food as affordable as possible, if for no other reason than to maximize the surplus that could be invested in
other economic development activities. And to make matters even more improbable, adding unpriced environmental costs should only increase the incentive to behave in such rational ways.

Explanations for this perverse behavior abound, but few of them approach the stature of general applicability. Paarlberg, for example, does a convincing job of undermining as reasons for this destructive behavior the familiar excuses: the greater fragility of land in the tropics, the inability of the poor to make resource-conserving investments, the stress of high-population density, the use of excessive inputs and overemphasis on cash cropping. Writing as an African, Mabogunje [1995] agrees and rejects the notion that people of his region are "highly irresponsible toward the environment." Finally, Crosson and Anderson go so far as to say that one of the economists' favorite market failures—weak property rights in agricultural land—has not been much of an impediment to the adoption of available agricultural technologies to improve productivity. I suspect that this skepticism is a very healthy development.

As a rule, resource policy seems to improve as the debate returns to the fundamentals of political economy, leaving behind the badly-beaten hobby horses of special interests and single disciplines. In the case of agriculture, the policy fundamentals seem to boil down to two.

First, of course, is the need for new technology—or better, perhaps, new knowledge—that significantly increases both agricultural productivity and environmental quality. This conclusion challenges the conventional wisdom. In particular, it holds that yield-enhancing knowledge can also remove the chief environmental constraints on increased agricultural production, since these constraints derive directly from attempts to grow more food in the absence of such technology. Thus, this extension is a non-trivial one.
Second, the conditions for promoting the use of new knowledge appear to be much more political and institutional than economic and technical. Paarlberg argues that farming communities with sufficient control of resources rarely engage in self-inflicted destructive practices. He concludes that agricultural resource abuse in developing countries often reflects power abuse. It grows out of unbalanced power relations among farmers, between farmers and nonfarmers, or between farmers and their own governments.

I am in no position to judge firsthand whether Paarlberg is right or not in this conclusion. I can say that the ascendancy of political power over otherwise rational behavior is a familiar feature of public policy. It is reassuring that Mabogunje's on-the-ground perspective on the agricultural problem in Africa—certainly the world's worst—echoes Paarlberg. Mabogunje argues that development of indigenous institutions is the best hope for protecting the environment. The three aspects of institutional development that he considers to be paramount are:

- Promoting democracy.
- Expanding individual property rights.
- Increasing the knowledge base.

In other words, doing something about the environmental constraint on food security boils down to responsive government, institutional arrangements that allow individuals to maximize their own welfare, and investment in research that reveals more efficient ways to use resources. This prescription rings true, for it is consonant with the growing evidence that environmental quality, like other aspects of human welfare, depends far more on these fundamentals than on one-dimensional environmental policy. That these fundamentals are hard to put in place makes them no less important. After all, no one should think that feeding a planet is an easy task.
REFERENCES


ECONOMIC FACTORS AFFECTING AGRICULTURE IN THE 21ST CENTURY

CLAYTON YEUTTER
FORMER SECRETARY OF AGRICULTURE
USDA

Agriculture in the 21st century will be global. This is nothing new and profound; you have been told this over and over again. I repeat it because people have to mean it. Most people do not really understand what a "global economy" is, and most are not acting on the concept. A global perspective is more dominant here in California than in most other parts of the U.S. because you are geographically closer to the international marketplace and have been a part of it longer than most of American agriculture. We in the central part of the U.S., in contrast, are still fairly parochial, but we are learning.

A GLOBAL ATTITUDE

All of us must make sure that a global attitude is pervasive throughout American agriculture as we enter the 21st century.
We cannot afford to have it any other way. The same is true of the non-agricultural marketing sector. No segment of the American economy can separate itself from a global approach, and anyone who operates on a different basis will not be part of the economy very far into the 21st century. We will all be functioning in the international sphere, and that is the foundation on which we must build our businesses.

As agriculturists, we have to ask ourselves what kinds of markets we will have for American agricultural products a decade or two from now. What will we sell? And will people beyond our borders want to buy U.S. farm and food products? Will they have the wherewithal to do so? In my view our export market opportunities will be greater in the 21st century than they are today. Of course, some of that depends on how well we negotiate between now and then, but the trends are in the right direction. We now have the North American Free Trade Agreement (NAFTA) in place, and we recently completed the Uruguay Round of GATT negotiations on a multilateral basis. These accords have helped to open up additional agricultural markets around the world, and, more importantly, for the first time they have provided some discipline on other nations’ agricultural export subsidies.

The challenge over the next few years is to sustain that negotiating momentum. In 1999 negotiations on agriculture will again take place in the World Trade Organization (WTO). In addition, other trade agreements comparable to NAFTA are likely to emerge in the next 10-20 years.

Other countries have already begun to emulate our aggressive market-opening activities. Australia and New Zealand now have a free trade agreement of their own. They are talking about adding Chile to it. At the same time we are considering adding Chile to NAFTA. And we could even have a
Western Hemisphere Free Trade Agreement by the year 2010. There is also a possibility of free trade agreements with some or all of Asia by the year 2020. That may be a bit optimistic, but it is by no means impossible. I recently wrote an opinion editorial for the Wall Street Journal suggesting that it would be preferable to negotiate a free trade agreement between NAFTA and the European Union before we do so with Latin America or with Asia, and that possibility has generated considerable interest.

We do not yet know precisely how all this will evolve. What we do know is that every one of these agreements would provide additional opportunities for American agriculture.

If we are to insist that other nations further open their markets to American agricultural products—and we should so insist—we must realize that other nations will insist that we further open up our agricultural markets. We can, therefore, expect changes in programs like those for peanuts, sugar and others where we continue to be protectionist. It is in the overall interest of American agriculture to open our markets over time as we ask other nations to open theirs. If we have confidence in our competitiveness, our objective should be to compete.

PRODUCTIVITY

Now let's get to productivity—the heart of the competitiveness issue. If we are going to have a healthy agriculture in California or anywhere else in the U.S., we must sell products somewhere. We should indelibly stamp in our minds the fact that only five percent of the world population resides in the U.S., and 95 percent resides elsewhere. That makes it readily apparent that much of the growth potential of American agriculture resides beyond the borders of the U.S.

The need for food in the 21st century will be palpable.
Whether that need will be translated into effective economic demand is another matter, but the need will be there as a result of population growth. Rob Paarlberg has concluded that developing countries of the world will have to increase food production in the first 20 years of the next century by an amount equal to what they produced in the past 10,000 years. That will be an enormous challenge, and hopefully, American agriculture will be in a position to help meet it.

Whether we will sell California agricultural products, or anybody else’s products, in the next century really comes down to two principal determinants: 1) population growth, and 2) purchasing power. Singling out the countries that are likely to have the best combination of economic and population growth over the next half century is not all that difficult. Most of them are in Asia along the Pacific Rim—Korea, Japan, Taiwan, China, Hong Kong, Thailand, Malaysia, Singapore, Indonesia, perhaps the Philippines, India and even Vietnam. California is in a very good position to meet the food needs of that part of the world. The Pacific Rim countries will continue to have substantial population growth rates as they enter the 21st century, and they have been leading the world in economic growth rates in the past decade or two.

We also need to look carefully at the demand potential of Mexico, Canada and Western Europe. Europe, for example, is not likely to have population growth comparable to the Pacific Rim, but it certainly will be an affluent part of the world going into the 21st century. And so will Canada. Mexico, on the other hand, will clearly have the population, and NAFTA will give it a boost in purchasing power.

Will we be in a position to take advantage of those market opportunities? Only if we put a quality product in the international market place at an attractive price. Buyers around
the world are becoming just as smart as buyers in California or anywhere else in the U.S. We must assume they will be knowledgeable and economically rational. If they can find a quality product at a lower price from somewhere else, they are going to buy it there. That means productivity will be exceedingly important as the century unfolds.

Agricultural research must, therefore, be one of the highest priorities for USDA, our land-grant institutions and our private-sector agribusiness firms in the coming years. When I was Secretary of Agriculture, we were very supportive of agricultural research. I considered it one of our best investments in the future. It was the right kind of investment then, and it may be even more important today. Funding agricultural research is not going to be easy, especially with the federal budget deficit that exists today, but it ought to be high on our priority list.

NEW TECHNOLOGIES

We now have a big advantage over most of the world in agricultural technology, but we must methodically take steps to retain that advantage. To do so we must not only support traditional basic and applied research, primarily in our land-grant systems, but we must also take advantage of other sources of useful technology. For example, biotechnology research is incredibly important, and it can be sourced from numerous public and private institutions here and abroad. Information technology, whose agricultural applications are just beginning to emerge, must also be on our radar screens. Some of the new products in that arena are just mind-boggling. For example, you soon will be able to communicate with your computer by voice rather than having to use a keyboard. Voice technology in telephones is already here. Soon you will be driving down
California tell roads with a microchip on your windshield that allows you to go right through the toll booth. You will no longer have to drop in coins. These are just some of the innumerable applications that are already here or about to arrive.

Farmers in California and elsewhere will be spending more and more time in their dens or offices as the 21st century approaches. They may even be too busy there to get to their fields! But that may not even be a problem if, by then, they can run their tractors from the office.

Irrigation will also become far more sophisticated. Farmers will be able to speed up or slow down their sprinkler systems and alter rates of application of water, chemicals and fertilizers in different parts of a field in a host of different ways. This will constitute environmental friendliness at its best, and it will help conserve our most precious resource—water.

The 21st century will be a completely different world for farmers—a frightening one for people who are intimidated by computers—but it is the world in which we will be living.

Risk Management

Risk management will also be more sophisticated. Farmers will have to understand futures markets, options, forward contracting and other sophisticated hedging instruments, for they will be the safety net of the next century. If there is to be a government-provided safety net, it will be far less generous than today's.

When I joined the Chicago Mercantile Exchange in 1978, it handled seven and a half million contracts in the prior year, primarily in agricultural products. When I left in 1985, the Exchange was trading 50 million contracts annually. Last year it traded 226 million contracts worth trillions of dollars, of which
more than 90 percent were financial rather than agricultural. If non-agricultural firms all over the world can learn to hedge risk, so can U.S. farmers and livestock producers.

The advantage of California and American agriculture lies with technology, as I have already emphasized, and management. Those running farms in the next century must understand both. Farm management will be increasingly sophisticated, and it will involve the continued substitution of capital for labor.

**Farm Structure**

Will we have a family farm agriculture in the 21st century, or will our food be produced by corporations, as some fear? Will the population transfer from farm areas to the cities continue? We are now down to two percent farm population so there is not a lot of additional transferability. But there will be some, for farm size will continue to increase as management skills improve and economies of scale continue to emerge. My personal view, however, is that we will still have family farm agriculture as the heart of the industry for many years to come.

The economic benefits of integration will generate more corporate activity in some areas. There is already more corporate agriculture here in California than in the midwest, but even there we are seeing the corporate structure evolve in the broiler industry, more recently in hog production, and even in some facets of beef production. We also see it nationwide in some of the more specialized crops such as vegetables.

At least some corporations have proven that they can succeed in agriculture. I remember Earl Butz, former secretary of agriculture, saying we will always have family farms because the employee of a corporation is not going to get up at 4 o'clock
in the morning to care for the sow! Secretary Butz was correct in recognizing the importance of personal motivation and incentive, but corporations have found effective ways of motivating their employees. If there is enough corporate economic incentive, the employee will get up at 4 o’clock in the morning. American agriculture will have attractive job opportunities in the 21st century—on family farms and in farm partnerships and farm corporations.

**Government’s Role**

Where does government fit into this picture? Farm programs as we know them may not be around in the 21st century or at least very far into the century. Supports and benefits, some of which will be transitional in nature, will still dominate the 1995 farm bill, although they will be reduced from present levels. Then we will likely have one more farm bill at the beginning of the century which will phase out these programs. A “catastrophe” safety net will probably be maintained in some areas, and export promotion programs of various kinds will continue to be important.

We finally are moving more and more toward unleashing the private sector in U.S. agriculture—something we should have done years ago—and we are doing so with enthusiasm and commitment. Most American farmers are eager to function on their own so long as the inequities of the global marketplace are eliminated, or at least reduced, so they can be competitive.

Regulation will still be a function of government as we move into the 21st century, but there will be a little more balance in that sphere. In food safety, for example, we now have laws and regulations which prohibit economic input in regulatory decisions. Fortunately, that pendulum is swinging back the other
way, and the merit of benefit-cost analysis is again being recognized, particularly in the Congress.

Obviously, our tax, fiscal and monetary policies will be of great relevance to farmers and other businessmen in the 21st century. Regrettably, there is no time to delve into those issues here. It is important, though, to emphasize that farmers should not take such macroeconomic policies for granted. They should try to influence them, for the outcome of those debates may have more impact on their incomes than anything that transpires in traditional farm policy.

EXTENSION OF INFORMATION

The role of the agricultural extension service in the 21st century will be dramatically different from what it is today. Agricultural producers in the next century will be well-educated, talented and sophisticated. Workers in the extension service will have to be very good, or their counseling function will shift elsewhere.

CONSUMERS

Finally, consumers will be much more demanding in the future than in the past, and American agriculture will have to respond to those demands. If we do not, U.S. consumers will find someone who will! Consumers want a wide variety of wholesome, quality foods delivered in a form that makes it possible for them to be quickly, easily and conveniently prepared. And they intend to define those terms. Producers will have to accommodate to that reality, for the customer is always right!

What is the bottom line for farmers? All of us in agriculture would like to see a larger share of family budgets devoted to
food. Much of that budget obviously goes to automobiles, clothing, housing and other necessities and luxuries. That will continue, of course, but we want to get the numbers for food a little higher in the overall budget in priority and amount. We also want a larger share for American food products in the family budgets of the rest of the world, and that is the ultimate challenge. I believe we have the skill—in production, processing and marketing—to bring that about.
PANEL PRESENTATIONS
George Bruening presented exciting opportunities that agricultural biotechnology offers in the 21st century. I would like to ask why agricultural biotechnology has been so slow in achieving its promise? It has been 20 years since the invention of recombinant DNA technology. With the invention of gene splicing, it became evident that we could learn an enormous amount about the organization of genetic material and that we could exploit this knowledge in ways that could greatly benefit both medicine and agriculture. Much of that promise has been borne out in medicine. The pharmaceutical industry, for example, has been greatly impacted by the development of biotechnology, which has had major economic consequences. That is not so true for agriculture.

The first two genetically modified crop plants are only now in the process of introduction. It has taken us twenty years to reach that point. I think it is fair to ask: Why has it taken so long? There are two answers to that question: 1) Our
fundamental knowledge base is limited, particularly in plant biotechnology, and our national investment in plant research is very small; and 2) We have experienced a complex regulatory environment that has limited the legitimate growth of agricultural biotechnology in ways that are neither useful in protecting the environment nor in achieving economic development.

To address my first assertion that we are research limited, I would like to talk in broad terms about the development of modern biology. Biology has two contradictory features. There is fundamental unity to all biology, particularly at the level of basic biochemical processes. Superimposed on that unity, however, is an enormous diversity that is reflected in the great range of organisms that we see on the earth and that we have adapted to agricultural uses. With regard to the unity of biology, one of the great triumphs of 20th century science has been to reveal that certain fundamental processes like oxidative phosphorylation, photosynthesis, nucleic acid metabolism, and so forth, are common to essentially all life forms on earth, and these basic biochemical building blocks are exploited by all organisms in very similar ways.

We have managed to understand these fundamental processes largely through concentrating on a small subset of model organisms. This trend began early in the 20th century but reached its height in the 1940s and 50s with concentration on the common bacterium, *E-coli*, which lives in the intestines of humans and on viruses that attack *E-coli*. This model has been used to dissect and understand some of the fundamental biochemical processes that are common to all life. From *E-coli* we moved on to analyze the most primitive eucaryotic organisms like baker's yeast and then on to the fruit fly, *Drosophila*. Within the last decade in the world of plant science, we have focused on
a small weedy plant called *Arabidopsis thaliana* which has no particular economic value, but great scientific value because it has a very small genome which is easy to analyze and manipulate.

In agriculture we are confronted with the diversity of biological life. We are often concerned with the improvement of specific commodities which range through the broad diversity of plant and animal forms that exist on the earth. To take California as an example where the issue of diversity is most acute, there are more than 200 different commodities, and each of these differs in important ways—in genetic architecture, in development and the way in which they produce a product that is useful to humans.

I would like to say a couple of words about a specific commodity, the cultivated avocado, which has an interesting history. It appears that avocados may have been domesticated two or even three times independently by primitive man in Mexico and Guatemala and, perhaps, in the West Indies. It is an important crop in southern California, and most of the research funding is derived through marketing orders from the California Avocado Commission. I do not have the latest figures on their level of research support, but it is roughly in the neighborhood of $500,000 a year. This is a relatively small research investment directed largely to short-term, applied goals. The avocado is a tree crop that belongs to the sub-class of flowering plants that includes magnolia and other primitive plants—most of which have not been the subject of modern genetic research so we do not have much fundamental knowledge with which to approach biotechnology in avocados. Problems of economic importance concern the taste of the fruit, its shape, its skin texture and the trait of alternate bearing. A very important issue is resistance to *Phytophthora cinnamomi* root
rot which is a major pathogen of avocados. Most of these traits, including root rot resistance, are polygenic—they are influenced by a number of different genes scattered throughout the genome. This makes them less accessible to the approaches of biotechnology. Thus, the avocado exemplifies the problems encountered when we attempt to improve specific commodities. Our fundamental knowledge base with regard to specific commodities is still very shallow.

At this point I would like to make a distinction between two different kinds of research. One is opportunity driven—for example, the engineering of plants to produce polyhydroxybutyrate for plastic production described by George Bruening. The opportunity to make these linkages was presented by the development of transgenic modifications. An enormous new opportunity was recognized, based upon fundamental knowledge. The other kind of research is problem-driven research, which is often commodity based—for example, the avocado. In this area we are research-limited. Hence, my argument is that one of the reasons agricultural biotechnology has been slow to develop is simply that we lack sufficient fundamental knowledge for various important commodities.

The other problem which has inhibited the development of agricultural biotechnology is the regulatory process. There have been numerous discussions in both the scientific and public arenas about the implications of gene splicing in agricultural biotechnology. It has been 20 years since the original National Academy of Science-sponsored Asilomar symposium, which led to regulation of transgenic organisms under the auspices of the National Institute of Health. In that 20-year history one thing that stands out most clearly is a progressive relaxation of standards which were originally instituted by the NIH to control DNA research, because as we learned more about the
technologies we found that many of our initial concerns about environmental or health threats were ill-founded. That trend, unfortunately, has not carried over into the regulation of agricultural biotechnology. A number of factors have clouded the development of commercial agricultural biotechnology in the regulatory arena. These include conflicts among government bureaucracies over who actually controls the regulatory apparatus. Frequently, perceived threats rather than real scientific information are the target of regulations. In this way, perception, even ill-founded perception, becomes reality.

To achieve an agricultural biotechnology for the 21st century, then, we must achieve efficient and low-cost regulatory schemes. Secondly, we must continue to make substantial, publicly-based investments in the fundamental research which allows for the elaboration of new technology.
I have been asked to take a look at the 21st century from a different perspective—that of the man who toils in the field to get the products to our table. When viewed on a global scale, I expect there will be little change in the area of farm labor. It will not be surprising to see animal-powered cultivation and subsistence farming well into the new century in many parts of the world. At the same time I expect to see cutting-edge, breath-taking technological breakthroughs that have not even been thought of at this time. The source of technology, of course, is coming in good measure from places like the University of California. When measured in caloric output for different parts of the world, however, methods of production will continue to be fairly primitive. In contrast to this scenario is the situation in developed countries where calories come from a variety of sources in great abundance and, perhaps, in excess.

This disparity among the nations will continue at least well into the new century. However, disparities also exist in other
disciplines such as electronics, medicine and engineering, so while we are doing our computations on powerful, handheld, multi-use computers, somewhere in the world someone is counting sheep by cutting notches in a stick or tying knots in a string.

One important factor in the global agriculture industry is not farm production per se but post-harvest innovation and improved transportation. For example, the availability of winter peaches in California is not the result of a great scientific breakthrough, but rather the simple process of growing peaches in Chile and transporting them to the United States in the middle of December. A decade ago store managers never considered the option of having to stock plums, peaches and grapes in the middle of winter. Now modern supermarkets have a constant supply of exotic and seasonal fruits year-round.

One impact is that you do not have to import the labor to produce an item, you can import the product. Transportation advances now have fruits, vegetables, meats and even flowers criss-crossing the world, especially the developed countries.

One could pose an interesting question: Should the university or industry spend the necessary funds to develop an off-season peach or should we just import it from a from a different latitude? Further complicating the issue is the fact that many undeveloped countries have an excess of unskilled labor. This labor force will continue to increase well into the next century. These people need to be employed, and an economy that requires a high degree of labor fits their needs nicely.

At times, labor needs are not recognized as very demanding when compared with scientific breakthroughs such as genetic engineering. Yet, when CEOs of the world are asked what they spend the most time on, their answer is likely to be labor issues or personnel problems. One might even say that much of the
recent debate over immigration policy is over labor, either too much labor or not enough labor—depending on one's point of view.

Labor is usually a large expense of production agriculture, particularly in California. These significant expenditures affect all but the most highly mechanized crops like cotton and other field crops. This is also true in such countries as Mexico where even though labor costs per day are less, it usually requires more labor to bring a crop to harvest. Much of the advantage they might have with the so-called cheaper labor is nullified by lower productivity, so even Mexican growers have to be concerned with high labor costs.

The farm labor issue has been caught up in the quagmire of the recent immigration policy debate. This is unfortunate. The last immigration reform we had in 1986 followed a more rational discussion, but even it produced uneven and uncertain results at best. I shudder to think what kind of reform this latest debate might bring us.

To a great degree the kind of work that will be done in the first quarter of the new century depends on the number of people who are born and the education provided to them. Even in the United States, as a result of immigration and poor educational opportunities, there still will be significant numbers of people not qualified to do anything but manual labor.

Consider the technology that a piece of fruit goes through before it reaches the consumer. In many cases it is the result of some highly-technical science, but it is not unusual to have it planted or weeded by hand or stoop labor. The harvest of many California crops is handled in the same manner as it was a hundred years ago. The fruit is then processed with the latest technology. Transportation, warehousing and distribution channels use the latest technology. When consumers purchase
a piece of fruit, it has been handled with a combination of the latest technology and also the most primitive.

One way many growers are resolving their current labor problems is by not dealing with the problem at all but by using intermediaries such as farm labor contractors. While this system of labor allocation is not new, it has mushroomed in importance in recent years. For example in my area, farm labor contracts were the exception, now they are the rule. This phenomenon is not exclusive to the farm; these intermediaries, called temporary labor service providers, used to be identified with the clerical industry. Now one can get a “temp” for anything. It is interesting that many of the laws and regulations that were passed to better the farm workers’ lot have instead made it worse by forcing employers to distance themselves from the worker. A few years ago it was common for many companies to say in their literature that employees were their most important asset. Now with the proliferation of confusing laws and regulations, employees have become a liability instead of an asset. The irony is that all these laws were made to improve employment.

However, there is hope. First, I assume the people in Washington and Sacramento will discover that employees cannot stand too much of this kind of help. Second, I think employers will soon find out that it is very hard to get dedication, loyalty and productivity from casual or temporary employees as competition gets keener and technology more complex. The employee will have the key to their success. This has already been demonstrated in the computer industry.

On the other hand, one way to make employers forge a closer link is to make labor a scarce commodity. Labor relations and efficiencies improve quickly when plums start hitting the ground, or grapes are still in the field and you can see clouds on the horizon.
I would be remiss if a discussion of farm labor in the future did not include a few comments about unions in the field. As you all know, union membership has been declining with the exception of the public sector. Unionization in the field does not have a long history, but it can be said that the performance of the union has been erratic at best. The current law is perceived by both camps as unfair and poorly managed by those in charge. Growers have learned that unionization is not inevitable. This is especially true in times of labor surplus. The main union in this fray has undergone a change in leadership and seems to be taking a new tack. While it appears that the union has made an emotional connection with farm workers in this state, it has been unable to translate this to worker economic improvements or job stability. Union successes in the future, I think, will be in direct proportion to the availability of labor.

I am optimistic about the future of California agriculture and am eagerly looking to the next century. I am particularly optimistic because of the legacy of Ken Farrell leaves us. This solid foundation will be fundamental to our success in the future.
I have been asked to respond to some of the comments made by Robert Fri regarding the environmental perspective on shaping agriculture in the 21st century. I have three broad categories of comments which are intended more to suggest a dialog than to be a criticism because I agree with much of what Fri said.

My first comment concerns his statements regarding food security from a global perspective. He mentioned two factors prominently—dietary requirements and the number of people who need to be fed. In his paper he also focuses on rising food prices over time as a strong influencing factor and the scarcity of resources and how that affects agricultural sustainability. I would suggest that there is another strong factor in the global perspective—cultural constraints. These constraints fall into broad categories such as ethnicity, religious and class preferences. This factor tends to be overlooked in a lot of economic discussions, but I think it has a very strong influence. There is still a lot of resistance to accepting certain kinds of agricultural productivity if it is not a normal part of the diet in that part of the world, so I would suggest adding the consideration of cultural diversity to the
discussion of conventional wisdom.

Next, in discussing environmental constraints, Fri states that environmental costs do not ordinarily influence the economic behavior of individual farmers. I find this a rather surprising comment primarily because I practice law in California. The Endangered Species Act and the Clean Water Act are very powerful influencing factors in the economic behavior of farmers. There is always consideration about how to meet regulatory constraints. If you are not prepared to meet such requirements, you can end up with a very unpleasant surprise somewhere down the road. Although there is a lot of movement in Congress right now to lessen the economic impact of regulatory constraints, I think we will still be dealing with these issues in the future.

With regard to environmental degradation, if there is a policy choice, it can result in either reduced agricultural productivity, through limitation on some kind of input, or more agricultural productivity through development of technology-driven alternatives. There is very little choice, however, if certain inputs are banned by the government. Again we go back to the regulatory constraints on what a farmer can do in the productivity process. If a pesticide that helps to produce a high-yield crop is banned by EPA, there is no longer a policy choice regarding the level of environmental degradation. I would add that new technology can be driven more by consideration of how to avoid or control environmental degradation in order to avoid a lawsuit than by consideration of productivity.

In discussing what is to be done about environmental restraints on agriculture, Fri states the real environmental constraints on food security are self-inflicted. He also states that increases in productivity or yield may have a direct influence on environmental degradation. I certainly agree with the latter
statement and think we have seen that kind of effect in California, although it is arguable whether the influence on environmental degradation is more a function of building subdivisions than increasing agricultural productivity. In regard to the constraints being self-inflicted, is it not inevitable that you will have the constraints because of the balancing and power relationships in which agriculture has one goal—to produce food crops—and regulatory goals may vary in both intent (e.g., prevention of environmental degradation) and implementation (e.g., control of land use choices)? To the extent that production requires resources that may lead to environmental degradation, is it not necessarily true, in the political climate in which we operate, that these kinds of regulatory constraints will arise as external forces regardless of a farmer’s decisions regarding sustainability?

Finally, Fri mentions responsive government, institutional arrangements which allow individuals to maximize their own welfare and investment in research as major factors influencing agricultural productivity. Technology is a very strong influence, and I agree that investment in research which reveals more efficient ways to use resources should be promoted. Technological developments are a plus in another sense; they can help overcome the environmental regulatory constraints by adding to efficiency and by producing alternatives such as soil enhancements so that nutrient loading and other factors are addressed. These types of technological advances are generally not available to developing countries.

Returning to the global perspective, given the limiting factors in the availability of research funds for technological development, does the future of agriculture seem to suggest that we will ultimately develop niches of productivity, which are charged with feeding the rest of the world? If so, I would strongly
urge consideration of cultural preferences in the production factors that go into development of these niches. Nationalism may be a strong influence on the development of the technology and the demand for agricultural end products.
The argument is that the interaction between population, resources and technology is critical for shaping the future of California agriculture. In particular, the expectation is that California agriculture in the 21st century will be shaped by relatively scarcer resources within an increasingly crowded state. Secondly, the pressure for environmental protection and sustainable agriculture will continue. Similarly, we must recognize the emergence of the global marketplace and at the same time pay attention to the development of technology.

My remarks about population relate principally to their implications for resource sustainability. Population and demographic changes will clearly continue to increase pressure on resources available to California agriculture. In particular, the carrying capacity of our ecosystems without substantial investment will continue to decline. Growth over the next 20 years will require even more diversion of land and water from agriculture. That growth will, of course, make California an
even more urban state with a high percentage of minorities.

One of the most threatening aspects of our future is what is likely to happen to the Central Valley. Look at the current growth rate in cities stretching from Bakersfield to Sacramento. Even if each of those cities grow at half their current rate, we will have an urban sprawl that stretches all the way from Sacramento to Bakersfield by the middle of the next century. Is that going to be a sustainable future that will preserve our role as one of the major suppliers of agricultural products on world markets? I suggest not. We have to take into account the external effect of one city’s planning on another city’s planning and recognize the value of those scarce resources.

Let me turn to California’s environmental resources. In a recent paper, Clayton Yeutter says that the environment and agricultural production are complementary rather than competitive. Another way of putting this is that the relationship is cooperative, rather than conflict-oriented. In particular, he says that American farmers have always been environmentalists. No one would argue that assertion with regard to shepherding a farmer’s own resources. The real issue is: What is the effect on common property resources—in particular, pesticide residues, groundwater contamination, water drainage, non-point pollution and so on? Over the last 20 years the pendulum has swung far in the direction of the environmentalists. They have what they wanted with regard to the Clean Air Act, the Clean Water Act and the Superfund. If you look at all those acts closely, they do not require any economic analysis of the tradeoffs involved with remediation or clean-up. It is time to recognize some costs, to recognize that these tradeoffs imply an optimal amount of clean up—not pristine conditions. We have to recognize that there is a level at which remediation efforts should be stopped. Long before the
Republicans won this last November, proposed legislation began to take into account benefits and costs. If you look at the legal system, you will find that juries and judges already have begun to recognize that there is a huge cost that society must bear in attempting to return to a natural state.

If agriculture is going to survive and flourish in the state of California, it must embrace societal demands for environmental quality and cooperatively develop workable policies and programs. It can be argued that the agricultural cooperative movement that emerged in this state over 70 years ago, largely motivated by marketing and concerns about monopolies, may well prove to be a vehicle for establishing collective and cooperative self-governing structures for resource sustainability and environmental quality. One example is the rice growers in this state and what might be described as their partnership with migratory waterfowl. For many years there have been concerns about the burning of rice straw and its effect on air pollution. Now rice growers have cooperated as an association to find a new solution—flooding their fields during the winter and providing a source of feed for migratory waterfowl. This is the type of action I have in mind when talking about cooperative solutions in the future.

If agriculture embraces the environmental movement from a rational and informed perspective, we will have cooperative conditions rather than conflict solutions. By informed perspective I mean incentives that align various stakeholders and interest groups and are compatible.

Robert Fri spoke about "rational world." I find that rationality is sometimes very narrow or myopic. For example, three years ago the World Bank did a major study on the state of the world’s environmental resources. It brought teams of people together with a number of consultants, and they wrote
an initial report. The chief economist at the World Bank at the time, Larry Summers, was concerned about this, in large part because the report contained no real economic or substantive-policy content. He wrote a confidential document saying why do you not consider the distribution of resources and the production of various products? For example, why not produce dirty products in poor countries—because poor people do not care about environmental quality and their average life span is much shorter than in developed countries. Hence, why not let them produce the environmentally-contaminating products and let the developed world produce the clean products? Unfortunately, an anonymous source shared this confidential document with the press. The Economist magazine initially supported this view, but the Financial Times said, “Wait a minute. Can economists, in fact, value human life?” The answer, quite obviously, is no.

They brought in a group of us to evaluate this controversy, and we concluded that the debate was ignoring the fact that the preservation of environmental and natural resources is really an investment in the future. If some countries degrade their environment, their options and opportunities in the future are going to be restricted. Moreover, in the context of Clayton Yeutter’s comments, they are going to be less competitive. If we are to maintain a competitive posture with regard to our future in the global marketplace, we have to maintain the best environmental and natural resources. This is, in economic jargon, the distinction between consumption and investment. Too often the public debate about the future of environmental resources and natural resource quality or sustainability focuses on current consumption and flows. The general view is if one can degrade the environment they will do so to enhance their profitability in the short run. But what is the effect in terms of
investment for the future? The focus should be on making longer-term investments to position ourselves to take advantage of opportunities that may arise down the road.

Robert Fri asked: Are environmental values likely to restrain food production? I would argue that the answer is clearly no for those communities, societies or countries that effectively recognize that their natural and environmental resources are an investment in the future much like research and technology. Collective groups who implement self compliance or self governance and only allow the government or the public sector to design default options for the negotiation process can reach collective decisions that will be sustainable in the future.
Animal agricultural industries account for 31 percent of the total agricultural cash receipts of this state. If you add the animal feedstuff industries, especially alfalfa, the total is even higher. Milk is the number one agricultural commodity in California, and this state leads the country in milk production. Beef, poultry, egg, turkey and swine production are all major industries in California. All have bright futures.

In the 21st century California's success in agriculture will depend more and more on the assurance of healthy animals and high-quality, safe, animal-derived food products. Today's livestock and poultry are the healthiest in history, and our animal-derived food products are the safest in history. Yet, the public expects more, and some international customers expect even more—at least from the standpoint of non-tariff trade barriers.

Veterinary medicine rides the razor's edge between agricultural and health sciences. It is evolving comprehensively.
with a fine sense of serving society—in this case, California's animal agriculture. The public already looks to the veterinarian for advice and services on matters relating to the health and utilization of animals, but in the future the veterinarian is going to play an even greater role. We have a lot of data indicating that the public has rising expectations in this regard. So there are great opportunities and challenges at this razor's edge.

For example, California's extensive livestock and poultry industries might be characterized as follows: they often bring together very large numbers of animals and confine them at very high densities—conditions that favor disease transmission. They often involve asynchronous production and removal of animals—again, favoring disease introduction and transmission. They often depend upon a few inadequately trained personnel caring for very large numbers of animals. Under these conditions early signs of problems are often missed. They often employ elaborate housing systems and complex mechanical ventilation, heating and waste disposal systems. Often these systems are beyond the understanding of on-site personnel. They often involve the manipulation of natural biologic rhythms, artificial daylight, estrus synchronization, etc.—adding to animal stress levels and consequent risk of disease.

These characteristics and others favor the emergence and spread of endemic diseases, opportunistic diseases, the animal equivalents of AIDS. These characteristics also favor the introduction of epidemic diseases, some of which represent risks to humans. These characteristics favor multiple disease problems, diseases working synergistically further complicating diagnosis, prevention and treatment.

None of the basic characteristics of intensive livestock production systems are going to change because of disease constraints. The economics of these systems is such that losses
due to diseases are always weighted against the gains—gains due to management advantages, feed-use advantages, labor-efficiency advantages and, in the past, gains due to the ability of the producer to write off the burden of endemic disease as a constant cost of doing business. But now competition from other modern animal agriculture systems, nationally and internationally, has invaded California's markets and nothing short of world class systems for maintaining animal health will do. The disease loss write-off is dead and gone. So how is veterinary medicine going to help maximize livestock health systems and minimize the impact of disease and the perception of disease risk? One answer lies in the extension of herd health management to encompass a whole concept of preventive medicine. This might be described under several themes. The first concerns disease-prevention strategies. This is the traditional model in the health sector. It is based on early detection and treatment of disease—screening, diagnosis and early treatment activities. These strategies include some of the most successful, the most powerful cost-effective health strategies ever conceived—vaccine use, disease surveillance, vector control, etc.

The second theme concerns health-promotion strategies. The health promotion model uses a broad array of strategies including economic value-added strategies to encourage changes in management. These changes require the veterinarian practicing herd health management to spend more time with the producer and less with the cows, but there is great leveraged economic value to be gained.

The third theme involves environmental protection strategies. In the human health sector, environmental protection strategies such as safe water supplies and safe highways generally require societal commitment for the implementation
of each incremental intervention. The same is true with animal agriculture and animal health. Once changes are made however—and they would continue to require some effort and cost on behalf of the producer—maybe the heat would come off as the public would realize that everything is in good hands. We are just entering this arena in livestock agriculture, and the role of veterinarians as doctors for the health of the environment is about to be tested. Would it not be interesting if the public gave these doctors a chance to see what they might be able to do?

I have been talking about what I think is the number one responsibility of California's veterinary medical profession and our School of Veterinary Medicine to the people of California—that is, to help California's livestock and poultry producers make a profit. As we head toward the new millennium, this number one responsibility to assure the fiscal success of California's animal agriculture should stay number one. Number two is the interface between environmental risk and animal agriculture. There are other subjects of equal importance for the next century—for example, animal welfare issues and food safety, food quality issues.

I would add continued development as a final major theme for the biomedical scientific base for modern agriculture. It is a powerful scientific base that we must take better advantage of in animal agriculture. Veterinary medicine will continue to serve as one of the bridges between biomedical research and agricultural productivity.
CONCLUDING REMARKS

KENNETH R. FARRELL
VICE PRESIDENT
DIVISION OF AGRICULTURE AND NATURAL RESOURCES

As concluding speaker in an afternoon featuring numerous speakers, I am tempted to declare this symposium a success and adjourn to the reception! As tempting as that may be, I do have a few observations I would like to leave with you.

First, I wish to thank each of the three principal speakers—George Bruening, Bob Fri, and Clayton Yeutter—for providing us with an excellent overview of forces shaping the future of agriculture. To Bob Fri and Clayton Yeutter, each of whom I have had the pleasure of working with in the earlier stages of my career, a special thanks for traveling cross-country to be with us today.

Second, I wish to express my gratitude to Director Hal Carter and the very able staff of the Agricultural Issues Center for planning and orchestrating this symposium. Hal and his staff have once again demonstrated their uncanny ability to define and select a topic of major public policy significance and to stimulate interdisciplinary discussion by scientists, educators...
and policy leaders with diverse perspectives.

I also wish to thank my panelist colleagues whose comments have adapted and extended the information presented by the principal speakers to the unique characteristics of California and California agriculture. For the deans on the panel and the morning and afternoon moderators, Terry Salmon and Barbara Schneeman, I am sure you regard your assignment today as a superior alternative to another meeting of the Council of Deans and Directors (CODAD) regularly scheduled for this date. I assure you that I share that sentiment!

To my colleague, close friend, and Associate Vice President, Henry Vaux, and the dedicated staff in our offices who worked behind the scenes with the Agricultural Issues Center in staging this event, a special note of appreciation is due. Thank you for recognizing and accepting my strong preference for an “end of tour” occasion marked by professional dialogue rather than by personal reflections and recollections.

Last, but by no means least, I thank each of you for participating in this symposium. For those of you from the University and the Division in particular, my sincere appreciation for your support, and, above all, your dedication to UC’s research and education missions during my tenure. You are the Division. The excellence with which our research and education programs are regarded nationally and internationally is a credit to you, the people who conduct research, teach students, and extend information throughout the state.

To those of you in agriculture with whom the Division has long enjoyed a close, productive and publicly beneficial relationship, thank you for your presence today, for your steadfast personal and institutional support throughout the nearly nine years of my vice presidency, and for the reception that you are generously hosting upon conclusion of these remarks.
Five years of budget cutting at the University and the inevitable downsizing of our research and extension programs have sorely tested the strength and commitments of the unique public-private partnership upon which the Division of Agriculture and Natural Resources was founded. Although you may not always have agreed with our sometimes laborious, opaque decisionmaking processes and their results, you have been there on numerous occasions when it counted—both within the University and in Sacramento and Washington. To the critics within and outside the University who fail to understand the nature of our unique partnership, who feel that we are “too close” to the state’s agricultural industry and that the benefits of agricultural research and extension devolve to a relative few in agriculture, I respond by asking where else is society earning long-term returns of 20 percent or more annually from its public investments than in agricultural research and education?

Now let me turn briefly to the substance of today’s discussion and then conclude with a few observations on the implications for higher education, research and extension in particular.

The 21st century as sketched by the speakers and panelists will be one of great change, challenge, and opportunity for agriculture.

As Clayton Yeutter has noted, nations and their agricultural and food sectors are likely to become ever more closely linked and interdependent in the 21st century. I agree with Yeutter that the trend will be towards more liberalized terms of global agricultural trade and that such liberalization will be accompanied by, indeed induced by, evolutionary but cumulatively major changes in domestic agricultural policies in the United States and elsewhere to the point of rendering many of our current policies obsolete or redundant.

California agriculture is well positioned to participate,
indeed lead, in the globalization of agricultural markets by virtue of its geographic proximity to markets that are likely to grow rapidly for high-value commodities and value-added products, its orientation to science, its leadership which has long recognized the importance of trade and its characteristic flexibility in the use of resources. However, there are constraints (economic, policy, and technological) to continued growth for California agriculture that will need to be addressed in the 21st century if the full potential of a globalized, expanding world market for food and fiber is to be realized. Let me briefly mention two such constraints.

Population and Economic Growth

By the year 2000, California's population will approach 36.5 million—predominantly urban and larger than many nation states. Although current growth rates can be expected to slow, population of this state is projected to grow well into the next century. Economic growth in the state will be primarily in non-agricultural sectors—service industries; high technology industries; communications; financial, for example.

In the absence of major changes in policies, population growth is likely to follow patterns of recent decades—extension of urban agglomerations including the metro areas of the Central Valley in which agriculture is currently concentrated.

The implications for agriculture are obvious: economic pressure on natural resources (prime farmland, water) and possibly higher real prices for those resources; heightened conflict and higher costs of conducting agricultural business at the rural-urban fringe; congestion and environmental pollution; immense pressures on local public institutions; increasing dominance of an urban population with little understanding of
agriculture; and urban dominance in state, local, and congressional political institutions.

THE “GREENING” OF CALIFORNIA

I believe Californians—increasingly urban, affluent, and well-educated—will continue to place high social value on environmental quality as manifested in various forms: clean water, clean air, accessible and protected open spaces, food safety, and protection and preservation of wildlands, wetlands, and wildlife.

California agriculture has a major stake in how this quest for enhanced environmental quality and conservation of natural resources “plays out.” On the one hand agriculture has an inherent long-term interest in sustainability of the natural resource base on which it is vitally dependent. On the other hand, environmental regulations pose potentially adverse economic consequences for agriculture. I am less sanguine than Bob Fri about the economic implications of environmental regulation for agriculture, at least California agriculture.

I believe that environmental regulations and policies will become gradually more pervasive and stringent into the 21st century, the result of the most recent elections and political rhetoric notwithstanding. If so, agricultural producers will have to reckon with increasing regulation of the environmental effects of their activities.

To weave these strands of thought together, California agriculture of the 21st century will function in the context of increasingly open, globally interdependent and competitive product and input markets. However, prospective growth in the state (economic and population), coupled with the “greening” of the state, pose formidable challenges and potential constraints
to future productivity growth in agriculture and thereby its competitiveness in global markets, given current technology and management regimes.

If these are reasonably accurate perceptions of the future, the bottom line is that California agriculture will continue to be highly dependent—perhaps even more than in the past—upon a continuous flow of productivity-enhancing technology and improved management systems into the 21st century as implied by all three of our principal speakers.

George Bruening has given you a glimpse of an exciting potential technological future for agriculture resulting from research advances in basic biology during recent decades. As these technologies become economically attainable, they could be huge stepping stones towards resolution of the conundrum I have posed—the need to advance productivity and competitiveness of California agriculture with technologies that are natural resource-conserving and environmentally friendly. To the technologies which George has focused upon, others might be added—for example, those in the exploding field of information and communication technologies, which may ultimately revolutionize current agricultural management systems, as intimated by Clayton Yeutter.

Now to some summary observations on the implications of this “brave new world” of the 21st century for higher education, the University of California in particular. For over a century, the UC DANR and its component parts—the AES, CE, and resident instruction—have been a primary source of research-based information and highly trained managers for advancement of productivity and efficiency in California agriculture. To maintain this mission in the context of the 21st century as sketched here today, adjustment of several types will be needed. Permit me to express some personal judgments on the nature of those adjustments.

Shaping Agriculture in the 21st Century
First, the Division will need to continue to realign its research, extension, and resident instruction agenda to more fully incorporate natural resource and environmental dimensions related to agriculture. The fact is that this realignment has been evolving in the Division for some time. Promising biotechnology research is underway on the three campuses at which the AES is located; many of the classical agricultural production sciences have explicitly incorporated natural resource and environmental quality dimensions into their research and extension programs; there are excellent examples of CE programs focusing on waste management and other agro-environmental topics; we have the nation's strongest IPM research and extension programs; and at Davis we have begun the systematic research necessary to undergird extension programs in sustainable agricultural production systems.

However, these programs are somewhat fragmented and sometimes uncoordinated across campuses, across disciplines, and between the research and extension functions of the Division. We need a more holistic, interdisciplinary framework within which we can fit science and education components in a systematic, additive manner. The Division should attach high priority to development of such a framework as part of its ongoing strategic planning.

Clearly, the physical and biological sciences will have a large role to play in the research and education agenda for the 21st century. But social scientists (yes, even economists!) also need to rise to the occasion. Public policies (national and state) dealing with the interrelationships of agriculture, natural resources, and environmental quality are fragmented, sometimes inconsistent, and frequently without economic logic. Better informed public policies attuned to the realities of our times are needed to induce appropriate behavioral and institutional
change. There is, I believe, a great opportunity for the Division to address such policy issues. Cooperative Extension should play a much-expanded role in applied research and education programs dealing with topics such as land-use planning, coordinated local and regional planning related to growth, and conflict resolution at the agricultural-urban interface. It should seek out ways to work with state and local planning agencies, local government, CSU and community colleges to bring the tremendous resources of the University of California to bear more fully on the policy making and education processes essential to planning. The Division is seriously underinvesting in these issues.

A traditional response to challenges and opportunities outlined by today's speeches would be to say "Give us more money and great results will emerge!" Clearly more money would help after the state funding debacle of the past several years.

However, in my judgment, we would be deluding ourselves in assuming a likelihood of any substantial real increases in public funding for agricultural research and extension in the near-term. I believe funding limits will apply "across the board" to state, federal, and county funding. I hope to be proven incorrect in this forecast, but the most likely scenario is for near-term substantial cuts in federal support through USDA for both research and extension, static or declining support at the state level for the University, and withering support for CE from county governments hamstrung by Proposition 13 and unfunded mandates.

Major fiscal reform in Sacramento that would make a larger share of state revenues available for higher education could prove me wrong, but don't hold your breath for that possibility. Even if fiscal reforms were to occur in Sacramento and funding of higher education was increased, the prospects of funding of
agricultural research and extension would be problematic. The University is likely to experience a major surge in the numbers of UC-eligible students seeking access toward the end of the decade. The result will be that funding of agricultural research and extension in the UC budgeting process will continue to be seen as residual to the teaching function.

Perhaps we can rely on faculty entrepreneurship to increase support from non-agricultural public organizations (NIH, NSF, etc.) and philanthropic foundations to enhance resources. Our faculty does well in obtaining competitive grants, and we might well be able to gain additional support for some of our more basic research needs from those sources. However, in the penchant for downsizing of public institutions of all types and in competition with the non-agricultural sciences, it is difficult to visualize that we can do much better than in recent years.

As to the private sector, I believe it must ultimately be prepared to shoulder a larger portion of the Division's applied research and extension program costs. The Division should explore with the private sector possibilities of enhanced funding of research and extension through state enabling mechanisms such as marketing orders and commissions, as suggested by Charles Hess on another occasion. UC Riverside's approach under leadership of Chancellor Orbach to encourage formation of special assessment districts to support research merits further attention and possible extension to other locales and purposes.

The reality is that we must find ways to enhance support for our highest priority programs from limited, perhaps declining, public resources. That means we must look seriously at consolidation of programs and administrative functions; find more effective means of coordinating programs across a decentralized Division; develop a higher degree of research specialization among the campuses based on principles of
comparative advantage; develop mechanisms to enhance flexibility in the allocation and use of scarce resources; design systems to provide faculty incentives for interdisciplinary research and extension programs; accelerate investments in distance learning and other electronic means of communication to ultimately conserve resources and restructure our organizations, particularly resident instruction and CE; elevate the importance of outreach (extension) programs in the University; create a more seamless web of research and extension organizations and programs; and cast aside pedantic, archaic personnel systems that now differentiate these functions. And we must simply stop doing some things of low priority in order to do more things of higher priority! The new Vice President will not be lacking in challenges and opportunities! I wish him well.

I do not wish to conclude on anything but a positive note regarding the future of California agriculture and the DANR. We have emerged somewhat battered and downsized from what has been one of the worst crises in state funding in several decades. But the basic strengths of the University and the Division are intact. Rebuilding and reinvigoration of our programs are underway on the campuses and in Cooperative Extension. Although there are difficulties to be addressed, there are exciting new research and educational opportunities to attract the best and brightest in the academic community. In many respects, I envy you for the opportunities you will have to redesign the Division to meet the needs of the 21st century. I have confidence that both California agriculture and the Division will adapt successfully to the realities of the 21st century.

The Division is a great educational asset to the University, agriculture, and the people of California. It has an excellent, dedicated faculty and staff. Those of you in the Division have
every right to be proud of what you represent and can continue to represent. To those of you in agriculture, your involvement, constructive input, and support will continue to be vital to the future of the Division and to the long-term development of California agriculture itself.

I appreciate your indulgence in these observations and musings. It has been a privilege for me to serve the University, agriculture, and the public as Vice President for the past eight and one-half years. I have given it my best shot. And to paraphrase lyrics popularized years ago by Frank Sinatra, “I did it my way”—well, at least some things some of the time!

Now the time has come for me to move into a new stage of my career and pass the leadership mantle to a younger generation. As to my just fading away as old soldiers are supposed to do, don’t count on it—at least not yet! I intend to remain professionally active, but with an agenda I intend to control!

I wish each of you well in what is certain to be a challenging and rewarding future chapter for California agriculture and for a great organization in a great university. Thank you again for participating in this symposium and honoring me with your presence.
GEORGE BRUENING, a professor of plant pathology at U.C. Davis, is the acting director of the U.C. Biotechnology Program and the project director for the Center for Engineering Plants for Resistance Against Pathogens (CEPRAP). CEPRAP is one of the 25 National Science Foundation's Science and Technology Centers in all areas of science. Dr. Bruening's research focuses on the molecular biology of plant viruses, subviral agents and plant resistance against viruses. He was elected to the National Academy of Sciences in 1992, elected a Fellow of the American Phytopathological Society in 1986 and served as councilor of the American Society for Virology from 1987 to 1989. He received a Guggenheim Fellowship in 1974 and the Superior Achievement Award in Research from the USDA Cooperative State Research Service. Dr. Bruening received his doctoral degree from the University of Wisconsin, Madison.

MICHAEL T. CLEGG has been the acting dean of the College of Natural and Agricultural Sciences at U.C. Riverside since July 1994. He is a professor of genetics in the Department of Botany and Plant Sciences. Dr. Clegg chairs the National Research Council Board on Biology and is a member of the NSF Advisory Committee on Biological Sciences Directorate and the NRC's Commission on the Life Sciences. He has been awarded many honors, including the Guggenheim Fellow in 1981-82, elected member of the NAS and elected fellow of the American Academy of Arts and Sciences. He is currently serving as associate editor for Molecular Phylogenetics and Evolution, as senior
contributing editor of *Proceedings National Academy of Sciences* and as co-editor of *Evolutionary Biology*. Dr. Clegg received his B.S. and his Ph.D. from U.C. Davis.

**Robert W. Fri** is the president of Resources for the Future, a nonprofit research organization that conducts independent research and policy analysis on issues affecting natural resources and environmental quality. Mr. Fri was the first Deputy Administrator of the U.S. Environmental Protection Agency from 1971 to 1973, and he held the same position from 1975 to 1977 in the Energy Research and Development Administration. He also served for extended periods as acting head of both agencies. He is a current member of the National Petroleum Council and has served as an advisor to the Secretary of Energy, the Electric Power Research Institute and the Gas Research Institute. Mr. Fri earned his bachelor's degree from Rice University and his M.B.A. from the Harvard Business School.

**Alfonso A. Guilin** is the executive vice president and corporate secretary of the Limoneira Company and has been associated with the company since 1966. His professional activities have been extensive, having served on the board of directors of Ag. Producers, the advisory board for the U.C. Agricultural Issues Center, the Ventura County Citrus Growers Committee and the Council of California Growers. Mr. Guilin recently completed an eight-year term as a board member of the California Avocado Commission. He was chair of the board from 1992 to 1994. Mr. Guilin received his B.S. from Cal Poly, Pomona and continued his education at the UCLA Graduate School of Business Management. He was also a member of Class I of the California Agricultural Education Foundation.
BRENDA W. JAHNS recently became counsel for the Central Valley Project Authority. Prior to this position she was a member of the law offices of Nossaman, Guthner, Knox & Elliott. Her areas of expertise lie in water rights, natural resources and environmental issues. In addition to her legal expertise, she has written numerous articles and has served on many committees, including the Water Education Foundation's Education Committee, the Commission on California Agriculture and Higher Education and the U.C. Agricultural Issues Center Advisory Board. She was appointed by Governor Wilson to the State Reclamation Board, and she is a lawyer delegate of the Eastern District to the Ninth Circuit Judicial Conference. Ms. Jahns earned a B.A. from Duke University and graduated with honors from the Boalt Hall School of Law, U.C. Berkeley. She was a member of Class XXII of the California Agricultural Leadership Program.

FREDERICK A. MURPHY, a professor of virology, has served as dean of the U.C. Davis School of Veterinary Medicine since 1991. Prior to that he was the director for the National Center for Infectious Diseases at the Center for Disease Control. He is a member of many societies including the American Society for Virology, the Infectious Diseases Society of America and the American Society for Tropical Medicine and Hygiene. He has been involved in numerous international activities as well and currently serves as president of the International Committee on Taxonomy of Viruses. Some of his more recent honors are the Presidential Rank Award from the U.S. Government, the U.C. Davis School of Veterinary Medicine's Alumni Achievement Award and Elected Member of the USSR Academy of Medical Sciences. He currently serves as editor-in-chief for the Archives of Virology, as editor for Advances in Virus Research and as senior editor for Infectious
Agents and Disease. Dean Murphy received his B.S. and his D.V.M. from Cornell University and his Ph.D. from U.C. Davis.

GORDON C. RAUSSELL is dean of the College of Natural Resources and the Robert Gordon Sproul Distinguished Professor at U.C. Berkeley. He is the president of the Institute for Policy Reform and former chair of the Department of Agricultural Economics at U.C. Berkeley. Dr. Rausser served on the senior staff of the President's Council of Economic Advisors and as chief economist of the U.S. Agency for International Development. He is a Fellow of the American Association for the Advancement of Science, the American Agricultural Economics Association and the American Statistical Association. His research focus is in public policy for food and agricultural sectors, futures and options markets, economic regulation, asset evaluations and portfolio analyses, political economics, statistical decision analysis and environmental and natural resource analysis. Dean Rausser received his Ph.D. in Agricultural Economics from U.C. Davis.

TERRELL P. SALMON has served as the regional director for the U.C. Division of Agriculture and Natural Resources since 1989. Prior to that he spent 11 years as a wildlife specialist with U.C. Cooperative Extension with expertise in the area of wildlife damage control. His research interests include ecology, behavior, population dynamics and control of vertebrates with particular emphasis on those affecting agricultural production and public health. He has developed Integrated Pest Management programs for various wildlife species, and he disseminates information to agricultural producers, wildlife managers and others dealing with both new and existing techniques of reducing wildlife damage. Director Salmon is a member of the American Society of Mammalogists, the California Vertebrate Pest Council,
the National Animal Damage Control Association and the Wildlife Society. He earned his B.S. in Renewable Natural Resources, his M.S. in Animal Ecology and his Ph.D. in Ecology from U.C. Davis.

BARBARA O. SCHNEEMAN is dean of the College of Agricultural and Environmental Sciences at U.C. Davis and the director of programs for the Division of Agriculture and Natural Resources. As dean, she oversees more than 30 departments and divisions on the Davis campus. She is also a professor in the Departments of Nutrition and Food Science & Technology at U.C. Davis and in the Department of Internal Medicine at the U.C.D. School of Medicine. Dean Schneeman has received many awards including the Farma Food International Fibre Prize. She is on the Board of Trustees of the International Life Sciences Institute, the Editorial Board for the Academic Press: Food Science and Nutrition, is an Advisory Director for the Blue Cross of California and served on the 1990 and 1995 Dietary Guidelines Advisory Committees. In addition, she is a member of the American Institute of Nutrition, American Physiological Society, the Institute of Food Technologists, the American Association for the Advancement of Science and a Fellow of the Arteriosclerosis Council for the American Heart Association. Dean Schneeman received her B.S. in Food Science & Technology at U.C. Davis and her Ph.D. in Nutrition at U.C. Berkeley.

CLAYTON YEUTTER is Of Counsel to Hogan & Hartson and practices in the international trade and food and agricultural areas. Between 1985 and 1988, Ambassador Yeutter served as U.S. Trade Representative. While in this position, he maneuvered the 1988 trade bill through Congress, helped to launch the 100-nation Uruguay Round of GATT negotiations
and led the American team in negotiating the historic U.S.-Canada free trade agreement. In 1989 Ambassador Yeutter was named Secretary of Agriculture and was instrumental in getting the 1990 Farm Bill through Congress. He was the Republican National Chair in 1991, and in 1992 he served in the White House as counselor to President Bush. He was president and chief executive officer of the Chicago Mercantile Exchange from 1978-1985. Prior to that, he held three subcabinet positions in the Nixon and Ford Administrations, including Assistant Secretary of Agriculture for Marketing and Consumer Services, Assistant Secretary of Agriculture for International Affairs and Commodity Programs and Deputy Special Trade Representative. In 1981 he was appointed by President Reagan to chair the Agricultural Development Task Force to Peru. He has been the recipient of numerous public honors, including several honorary doctorates. Ambassador Yeutter earned his Ph.D. in agricultural economics and his law degree, *cum laude*, from the University of Nebraska.
Registration

No-host Luncheon

Symposium Program

Moderator: Terrell P. Salmon,
Director, Agriculture & Natural Resources Programs, UC Cooperative Extension Northern Region

Video

Shaping Agriculture: California's Role

Speaker Presentations

George Bruening, Director, Center for Engineering Plants for Resistance Against Pathogens, UC Davis: *Impact of Science on Agriculture in the 21st Century*

Robert W. Fri, President, Resources for the Future: *The Face of Agriculture in the 21st Century: An Environmental Perspective*

Clayton Yeutter, former Secretary of Agriculture: *Economic Factors Affecting Agriculture in the 21st Century*

Break
Panel Discussion
Moderator: Barbara Schneeman, Dean, College of Agricultural & Environmental Sciences, UC Davis

Panelists:

Michael T. Clegg, Dean, College of Natural & Agricultural Sciences, UC Riverside

Alfonso A. Guilin, Executive Vice President, Limoneira Company, Santa Paula

Brenda W. Jahns, Environmental Attorney, Central Valley Project Authority

Gordon Rausser, Dean, College of Natural Resources, UC Berkeley

Frederick A. Murphy, Dean, School of Veterinary Medicine, UC Davis

Audience Response

Concluding Remarks

Kenneth R. Farrell, Vice President, University of California Division of Agriculture & Natural Resources

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