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USDA Agricultural Research Service - Biotechnology in Farm Policy

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USDA AGRICULTURAL RESEARCH SERVICE—BIOTECHNOLOGY IN FARM POLICY

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This paper is divided into four parts. The first part, or background section, discusses the role of federally-supported agricultural research, the mission of the Agricultural Research Service (ARS), and the public benefits of agricultural research. The second section is concerned with the process of setting national research priorities. The third part deals with the ARS commitment to biotechnology. The paper concludes with a discussion of operational planning in ARS.

I. A Research Partnership

The technology used today in the highly successful American agricultural production complex is the direct result of a partnership involving the following contributors: the Federal government; the land-grant university system, including State agricultural experiment stations; and the private sector, including American industry and research foundations. No single group could even approach the contribution made by this tripartite effort.

The current Federal research role is defined by two broad criteria. First, research should be federally-funded when the Federal government is the user of the research, as for defense research and research to maintain federally-owned resources. Second, research should be federally-funded when responsibility is shared between the Federal government and others—State, local, and private interests.

Both the Administration and the Congress recognize the following areas as appropriate tasks for Federal agricultural research:

1. To provide leadership for the nation's food, agricultural, and forestry research, and educational and rural development programs;
2. To support science and education programs that

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ensure long-term efficiency in performance of the agricultural production and marketing systems that enhance the competitive position of U.S. agriculture in world food markets;
3. To conduct research relating to Departmental action and regulatory functions;
4. To foster research and knowledge—that is, transfer programs that provide broad societal benefits and significant economic gain to the nation; and
5. And to undertake research where studies show that private sector and State-supported research are deemed unlikely to make investments adequate to serve the national interest.

The process of setting research priorities also involves the cooperation of the Federal government, the States, and industry. A number of participants have played roles in priority setting for USDA—various advisory boards, commodity groups, and other government-industry cooperators in research planning.

This organizational complexity is further compounded by the characteristics of agricultural research. To a larger extent than is true for other domestic areas which enjoy public support for research, public policy initiatives in agriculture relate to a broad spectrum of research activities that range from basic research to applied research, and from relatively local problems, primarily of State concern, to problems of national significance.

U.S. agricultural research must be responsive to immediate problems—the citrus canker, for example—but must also be flexible enough to provide a scientific offset to long-range phenomena—like soil erosion—that would otherwise reduce agricultural production. Research must encompass not only the hundreds of projects that reflect the geographic and climatic breadth of the United States, but also the several national goals advanced for American agriculture—production efficiency, environmental safety, nutritional soundness, and equitable distribution.

The Agricultural Research Service (ARS) is the principal scientific research agency of the United States Department of Agriculture. It is the largest agricultural research organization in the world, with about 8,500 employees working at 128 different locations in the United States and 8 in foreign countries. One-third of these employees—2,800 men and women—are scientists and engineers working in research.

The rest are technicians, laboratory assistants, and support personnel.

The mission of the ARS is to develop new knowledge and technology which will ensure an abundance of high-quality agricultural commodities at reasonable prices to meet the increasing needs of an expanding economy and our export markets in other countries. This mission focuses on the development of technical information and technical products which bear directly on the need to: (1) manage and improve the nation's soil, water, and climatic resources; (2) provide an adequate supply of agricultural products; (3) improve the nutrition and well-being of the American people; (4) improve living in rural America; and (5) strengthen the nation's balance of payments.

The total Agency budget for fiscal year 1986 was 478 million dollars. Budgetary funds are appropriated annually by the Congress, and the level of funding has remained relatively constant, when adjusted for inflation, over the past decade.

Agricultural research more than pays for itself. Almost every estimate of the rate of return to investment in agricultural research over the past three decades is between 35 and 45 percent per year. Analysis of the agricultural figures for the last five years shows a rate of return on investment higher than 45 percent. It is hard to imagine any investment, in either the public or the private sector, that would consistently produce such favorable rates of return.

One discovery alone, a vaccine against Marek's disease, has already saved the U.S. poultry industry 2 billion dollars. In 1971, the first year the ARS-developed vaccine for Marek's disease was made available for national use, savings from the vaccine amounted to 30 million dollars. This meant that in one year, the benefits returned nearly 100 percent of the total 10-year investment of 32 million dollars.

By 1974, the first year of full adoption of the vaccine by the poultry industry, gross benefits had climbed to 628 million dollars. Since then, net benefits stemming from use of the vaccine are estimated at 170 million dollars annually.

Gaining the full advantage of ARS-sponsored research depends upon productive relationships with industry. In 1985, the ARS had over 60,000 contacts dealing with technology transfers. Clearly, a large number of the ARS scientists were involved at some point in transferring their findings into practical application. At the same time, the National Program Staff and other research management personnel met with over 150 representatives of user groups. This commitment is the basis for a very productive exchange between Federal research and private sector research technology.

Agricultural research has made a major contribution to the unparalleled standard of living enjoyed by the American people. Technological developments—the products of scientific research—have enabled the nation's farmers to:

1. Increase livestock production and yields for every major crop;
2. Improve productivity of most farm lands;
3. Overcome food and fiber losses caused by disease and insects;
4. Grow crops in areas once barren;
5. Use more efficient equipment; and
6. Protect soil and water resources.

The nation's consumers are the ultimate beneficiaries of investments in agricultural research. Year round, American agriculture provides reliable and economic supplies of meat and other foods of superior quality and wholesomeness. Americans spend a smaller percentage of their disposable income for food than do the people of any other nation.

II. Setting Research Priorities

Beginning in the fall of 1981, the ARS carried out an intensive strategic planning effort. With input from some 500 scientists, the National Program Staff developed the ARS Program Plan. This long-range plan, published in January 1983, established the ARS research goal of sustaining the production of food and fiber. It grouped ARS research efforts to reach that goal under six specified objectives. This document also described organizational policies which guide the implementation of the plan.

The six objectives of the program plan are to:

1. Manage and conserve the Nation's soil and water resources for a stable and productive agriculture;
2. Maintain and increase the productivity and quality of crop plants;
3. Increase the productivity of animals and quality of animal products;
4. Improve the system for delivery and conversion of raw agricultural commodities into food and useful products for domestic consumption and export;
5. Promote optimum human health and performance through improved nutrition; and

6. Integrate scientific knowledge on agricultural production and processing into systems that optimize resource management and facilitate the transfer of technology to end-users.

These six objectives describe the aims of ARS science, and each objective proposes to develop the means to address a specific problem area. The ARS is a research agency. Farmers and ranchers, action agencies, and business and industry must apply the research if the objectives are to be achieved.

In February 1983, the *6-Year ARS Implementation Plan* was published. The implementation plan described three strategies. Briefly stated, they were to emphasize: (1) mission-oriented research; (2) integrative systems research; and (3) research to increase the efficiency of production and marketing.

These strategies were needed to address the following problems:

1. Increasing world food needs;
2. Declining quantity and quality of natural resources;
3. Declining rate of growth in agricultural productivity;
4. Continuing surpluses of many commodities; and
5. Static stores of fundamental knowledge.

Although these problems still confront us, other national problems of concern to the ARS have also become critical. These include:

1. The declining competitive position of U.S. agricultural products in international markets and increasing surpluses of many commodities;
2. The threat of low profitability and return on investment to farmers and businesses that supply and finance them;
3. The continuing perception that agricultural chemicals, sediments, and biotoxins are environmental hazards;
4. Increasing consciousness on the part of both domestic and foreign consumers that the quality, nutritional value, and safety of U.S.

agricultural products must be maintained; and

5. Finally, unacceptably high losses of agricultural commodities during production, harvesting, transport, processing, and marketing.

As the national agricultural research agency, the ARS must concentrate available resources on the most critical national problems—particularly those that are not being adequately addressed by other research organizations.

Faced with both continuing resource constraints and the complex problems just outlined, the ARS revised its previous strategies and arrived at four strategies for the 6-year period from 1986 to 1992. These were published in late 1985 in a revised *6-Year Implementation Plan*. A summary of the new strategies follows.

First, the ARS will address technical problems that are determined to be the most critical to the U.S. food and agricultural sector. To increase program relevance, the ARS has improved its communications with research user groups and policymakers. The ARS must focus more resources on fewer problems to maximize the probability of success and make the most effective use of its resources. For example:

1. A recent analysis of problems associated with the poor competitive position of U.S. agricultural products in world markets showed that we have little fundamental knowledge of what constitutes product quality. Such knowledge is necessary if we are to develop new products and technologies to compete in the international marketplace; and
2. While we have the skills needed to transfer genes between organisms, we lack knowledge as to which genes to transfer and are limited in applying these skills to agricultural problems. Mapping these genes and determining their functions are tasks for which private industry lacks incentives.

As a second strategy, the ARS will allocate resources to solve specific high priority national problems. Program implementation will be based upon two main approaches. The first is to conduct annual in-depth analyses of the research capabilities and resources of every laboratory in the Agency. The second approach is to conduct planning workshops and in-depth reviews of specific programs, problems areas, and laboratories.

The third new strategy will place increased emphasis on inter-disciplinary teams for problem solving. This strategy addresses the need to obtain the right kinds of scientific expertise and the proper level of resources to solve problems. Such teams are necessary to develop management systems that can reduce production costs, improve product quality, develop new uses for surplus commodities, reduce losses, and conserve resources.

The fourth ARS strategy will foster the development of communication networks and data-management systems to support research programs and facilitate technology transfer. Computer models of crop and animal production, soil erosion, and other systems are becoming useful vehicles for expressing state-of-the-art research in many areas for scientific research.

Expert systems can combine models and data from many disciplines and then integrate the massive quantities of knowledge into manageable decision support systems for users of research. Agriculture is rapidly moving toward using both computer models and data-management systems on the farm, in government, and in business.

U.S. agriculture is changing rapidly in response to a complex set of domestic and international dynamics. Recognizing this, the ARS is prepared to make appropriate changes in strategies to assure that its research meets America's long-term needs.

III. Solving Agricultural Problems with Biotechnology[1]

To say that biotechnology is a dynamic research area is an understatement. In fact, research in the biotechnologies is so rapid that articles written in scientific journals are often eclipsed by new developments before the articles are published. Biotechnology promises to yield a nearly infinite number of improvements in just about, every enterprise, from health care to waste management. Most predictions point to agriculture as the industry that will reap the greatest benefits.

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1. The Congressional Office of Technology Assessment has defined biotechnology as "any technique that uses living organisms to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses." OFFICE OF TECHNOLOGY ASSESSMENT, U.S. CONG., *Technology, Public Policy, and the Changing Structure of American Agriculture*, OTA-F-285 (Washington, D.C.: U.S. Government Printing Office, March 1986 at 31).

Biotechnology may be defined as those biological means used to develop processes and products employing organisms or their components. Those biological means include:

1. Controlled bioreaction and bioreactor research to improve the quality and processability of food, convert plant and animal material to more valuable new products, biosynthesize physiologically active compounds, and control intermediary metabolic and anabolic reactions;
2. Cell, tissue, organ, embryo, and organelle (including subcellular particles) culture to clone genes, express totipotency,[2] produce secondary metabolites, decode developmental programs, develop regulatory molecular and mechanistic functions, determine what factors limit physiological functions and desired competence formation, and control senescence;[3]
3. Recombinant DNA techniques and associated research on gene-transfer vectors and gene products to enhance desired characteristics of plants, animals, and microbes and eliminate their undesired characteristics; control expression of desirable or undesirable gene functions; transfer genetic material for production of such specific materials as microbial antigens or enzymes for food processing or bioconversions; and transfer genetic material for increased microbial-process efficiency;
4. Hybridoma[4] research to provide discrete gene products, as required, and isolate and preserve discrete genes, gene sequences, or chromosome fragments in functional condition; and
5. Genetically engineer viral and microbial insect pathogens for improved and more economical insect control.

These new techniques—microculture, cell fusion, regeneration of plants from single cells, and embryo recovery and transfer—are creating vast new opportunities all across the agricultural sciences. The tools of biotechnology are being

2. "Totipotency" is defined as capable of developing into a complete embryo or organ: said of a cleavage cell.

3. "Senescence" is defined as to grow old; aging.

4. "Hybridoma" is defined as offspring produced by crossing two individuals of unlike genetic constitution.

applied to viruses and bacteria, to insects and weeds, and to plants and animals in all stages of their life cycles, from replication through aging.

The U.S. Department of Agriculture's progress in biotechnology goes back seven decades, long before the concept was so named. A milestone achievement came from classic research in photoperiodism.[5] This pioneering effort, begun by Wrightman Garner and Harry Allard in 1918, culminated when Harry Borthwick and Sterling Hendricks showed that flowering and seed formation are controlled by a chemical, now called phytochrome, which can be manipulated as desired to switch plant growth on or off.

The ground-breaking work of these four scientists pointed the way to exploiting other natural substances to control plant growth and development. Today, this field of research conducted at the level of cells and molecules is called bioregulation.

Another ARS milestone in biotechnology was deciphering the molecular structure of a ribonucleic acid, tRNA, by a team of ARS and Cornell University scientists. That achievement won the research team's leader, former ARS biochemist Robert W. Holley, a share of the 1968 Nobel Prize for medicine or physiology.

The team's work enabled other scientists to determine the structure of the remaining tRNAs. A few years later, the method was modified to track down the sequence of nucleotides in various bacterial, plant, and human viruses. Modified further, the Holley team's approach is playing a role in determining the sequence of DNAs in today's chromosomal research.

Other examples of ARS achievements in biotechnology include:

1. A vaccine against foot-and-mouth disease, developed through recombinant DNA technology, with collaboration by scientists from Genentech;
2. New rice plants, developed through tissue culture, with more and better quality protein;
3. Gene transfer, through recombinant DNA technology, from one plant through a bacterium to another plant; and
4. A genetically engineered antigen which helps pro-

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5. "Photoperiodism" is defined as physiological reaction of an organism to variations in the intensity of light.

tect chickens against one parasite that causes coccidiosis. This disease, which afflicts chickens and turkeys, is estimated to cost the poultry industry 300 million dollars a year in lost production and medication.

ARS research on cell membranes is internationally known. A top membrane research priority is developing crop varieties that "harvest" more sunlight, resulting in healthier, more efficient plants and larger yields.

Other current ARS research involving biotechnology includes:

1. Devising a way to microinject genetic material into plants whose tough cell walls currently limit the practice to animal and human cells;
2. Genetically engineering a vaccine against vesicular stomatitis,[6] a viral disease of livestock that also affects humans;
3. Use of specific enzymes rather than physical methods to break down surplus fats and oils into desirable foods and commercial products; and
4. Transferring organelles and their DNA genes between plant species so that breeders can raise crop yields or impart resistance to herbicides, pests, or diseases.

The ARS 1986 budget included 30 million dollars for research in biotechnology. Some 200 ARS scientists are focusing on biotechnology in 165 projects at laboratories throughout the United States.

The ARS will expand biotechnology research at two major locations—at Beltsville, Maryland and at the Plant Gene Expression Center at Albany, California.

Major efforts are being placed on finding ways to culture single cells from a wide number of agronomic plants and to regenerate them into whole organisms with the genetic message intact and properly expressed. In animals, embryonic single cells—the fertilized egg—may well be the recipients for gene transplants. Modern techniques of embryo recovery, splitting, and transfer are playing critical roles in genetic engineering efforts.

Other new and promising techniques now make it possi-

6. "Vesicular stomatitis" is defined as inflammation or blistering of membranes in the mouth.

ble to determine much more quickly the precise chemical makeup of genes and their protein products, condensing into days what might once have required years to accomplish.

Genes can also be located in their chromosomal packages relative to each other much more easily than in the past. More difficult, however, is the identification of the mechanisms regulating gene expression—what turns any given gene's activity on or off. Finding the answers will require years of experimentation.

It is not gene transfer capability that will constrain biotechnological solutions to problems. Rather, it is the lack of base data relating to gene identification for selection of genes to transfer, gene expression, plant differentiation control, and a host of other functions.

A number of research areas in agriculture are being considered as candidates for the new biotechnologies. For example, new techniques now allow much more detailed study of the defense systems in plants and animals than was possible in the past. New knowledge of the immune system in animals promises improved approaches for disease and parasite control and faster, more accurate diagnosis.

The ARS envisions more effective ways for increasing a plant's or animal's own genetic resistance to pests and other stresses. Conversely, improved techniques for sabotaging the defense systems of insects, weeds, and other pests also seem possible.

A growing understanding of how the chemical messengers known as hormones operate as intermediaries in growth and development processes also shows promise. This area has been studied extensively and has produced much progress.

Another area of challenge is to develop entirely new food products using plant protein. This is a challenge to food scientists—to produce an acceptable product that does not attempt to mimic animal protein. The result could give us entirely new foods unlike anything we consume today.

The ARS believes other major innovations may be available within the next twenty years. For example:

1. Crops that will be less susceptible to diseases caused by viruses, bacteria, fungi, and insects;
2. More efficient crops that will better absorb and use fertilizer;
3. Crops genetically modified to fix their own nitrogen;

4. An increase in plants' photosynthetic efficiency by manipulating their energy conversion systems; and
5. A greater resistance to stresses brought on by drought, salinity, chill, and frost.

Genetic regulation of plant growth might also achieve such goals as:

1. Higher ratios of edible to nonedible parts, longer seed filling times, corrected structural weaknesses, and higher yields of economically important plant constituents;
2. Improved food quality, such as improving the amino acid balance and nutritive value of small grains for animal and human consumption; and
3. Regulation of plant growth to allow harvest of fruits and vegetables of uniform ripeness. This will help maintain and deliver desired quality produce to consumers through complex systems of transport, processing and marketing.

Applied and fundamental research in agriculture are so intimately intertwined in the biotechnologies that many practical spin-offs may emerge. At the same time, fundamental inquiries will continue to pursue the basic knowledge necessary to make wide-ranging applications.

Thus far, these remarks have concerned the relatively short-term application of the new biotechnologies over the next 15 to 20 years. Now let us consider the impact of the new biotechnologies over a longer time frame, such as 50 to 100 years into the future.

Some futurists—both outside and within the ARS—have described a totally revised system of agriculture in the mid-21st century. In the interest of conserving our natural resources needed for long-term sustained agricultural production, such as soil, water, and fossil fuels, they foresee more conservative production of components of foods by biotechnological or combined systems as opposed to producing plant organs.

They visualize reconstitution of the components into consumer-acceptable traditional foods. They foresee these technologies deriving food components from chemical feed stocks made from nonedible parts of plants such as celluloses and lignins. These would then be converted, for example, into sugar syrups. These syrups might then be moved by pipeline or tank car to biotechnological food production facilities close to population centers in any part of the country.

This is the agricultural equivalent of reaching the moon. As a research agency, the ARS has the responsibility to develop all future food production options. The ARS expects that the economics of agricultural production, and the availability of water, land and energy, will shape the future application of these biotechnologies.

Having provided a brief perspective on some of the exciting challenges and opportunities presented by the biotechnologies—where research efforts are now, and where research is going—let me conclude this section with three personal observations.

First, it should be remembered that biotechnologies are not a panacea. They will not displace traditional plant breeding anytime in the near term—perhaps never. Biotechnologies are tools, but they are not our only tools.

Specifically, the biotechnologies will provide the means for creating new and pure sources or combinations of genetic variation having specific desired traits. Certainly the use of biotechnology will allow germplasm enhancement and plant breeding to proceed at a faster rate with a more predictable outcome. But we still must use classical breeding techniques to develop new varieties.

Second, recommendations for new biotechnology centers—both at the Federal and State levels—may not represent the best use of our limited funds. Rather than investing in more brick and mortar, it would be more effective to put the money directly into research. It is more important to give the money to scientists, in order to pursue research, than to build yet another tower.

Therefore, our research system needs to have a low tolerance for the administrator, or the dean, or the vice president for research, who sees the new biotechnologies primarily as opportunities to develop more real estate. I do not know what to call this point. It is not intellectual honesty, nor is it academic honesty. Perhaps it is best described as administrative honesty.

Third, I want to express my concern that America's higher education system must be stimulated to supply the large numbers of talented young scientists, trained in the biotechnologies, who will be in demand for the balance of the century. The Federal system, the State system, and the private sector are presently competing aggressively for the available talent. Those of us in the public sector need to be equally assiduous in recruiting and retaining first rate scientists.

Some people assume that pumping enough new dollars into the agricultural research system will automatically result in more graduate students and, ultimately, in more scientists of exactly the sort needed. I feel strongly, on the other hand, that higher education is a science unto itself and not just a by-product of research.

In any case, it behooves agricultural researchers to give increasing attention to the educational system. Our universities need to turn out more young scientists, especially with graduate training in the biotechnologies, if the United States is to have a pool of scientific talent adequate to meet the demands of the research marketplace.

IV. Operational Planning in the ARS

Improving and sustaining the productivity of the food and agricultural systems will remain the overall research goal in the ARS. The term "productivity" relates to more than yield or quantity. Some of the most important gains in productivity are to be achieved by reducing production costs and improving commodity quality, value and utility.

The potential benefits of gains in productivity are threefold:

1. increased net farm income;
2. increased share of world markets; and
3. reduced surpluses of agricultural commodities.

For the near term, one of the most significant contributions that research can make is to reduce production costs. Therefore, accelerated research on efficiency factors must be among the highest national priorities.

The sustainability of agriculture depends upon more effective conservation of nonrenewable resources than has been achieved in the past. Research emphasis on these resources is needed to preserve their productivity for future generations.

While excess production capacity is a burden on most U.S. producers and the general economy—and will be for the foreseeable future—that extra capacity also allows the ARS to allocate a greater proportion of its scientific capability to obtaining the new knowledge and skills needed for solving the problems that cannot be solved with existing technology. This approach will help U.S. agriculture in the marketplace, where world competition is expected to increase into the 21st century.

The United States needs a renewed commitment to develop the basic knowledge for finding alternative uses for agricultural commodities. This means the commitment of a major amount of time and money, and a certain amount of faith, in the scientific process.

This research approach is a modification of the old utilization concept. Simply stated, that concept said, "Here's an ear of corn. What can I make out of it?" Now, we must ask, "Here's a market we're not in. What technology do we need to convert a surplus commodity into a product that fits that market?"

Plans and priorities must be dynamic to reflect changing needs and opportunities. The National Program Staff (NPS) continually reviews and assimilates information from diverse sources. With this information, the NPS systematically evaluates needs in terms of the ARS mission, national importance of the identified problems, roles and capabilities of other research organizations, limits of available ARS resources, and the current status of research projects and programs. The NPS then uses these evaluations to establish priorities, set targets for the next 6-year implementation plan, and allocate resources for an effective and relevant program.

A basic purpose of the 6-year implementation plan is to allow the ARS to achieve a realistic and functional balance among competing needs and opportunities. However, the profile of the kinds of research supporting any given commodity or problem area may well change as the needs of the nation and industry change, or as advances in technology provide new opportunities to solve long-standing problems.

Program changes in the ARS will continue to be made in an orderly and systematic way. Several factors make this possible. The areas of emphasis in any ARS 6-year implementation plan are the basis for developing the ARS annual budget. While budget increases in 1982-1985 were modest—approximately equal to the rate of inflation—most of the increases were targeted for high-priority research areas. Such increases not only minimize the need to shift base funds and personnel among program areas, but also provide the flexibility to obtain new expertise and equipment.

Normal project turnovers also provide opportunities to make program changes. All research projects in the ARS (approximately 3,000) have a maximum term of 5 years. Thus, in each year, 20 to 25 percent of these projects are completed or terminated and their resources can be allocated to other priority research areas or to new research approaches.

Another set of opportunities is provided by the normal turnover of personnel. The ARS employs approximately 2,800 scientists, and its yearly attrition rate is from 3 to 5 percent. Therefore, each year, the ARS can fill about 100 positions with scientists having the skills needed to address the problems identified and improve existing programs.

The ARS concentrates on problems of regional, national, and international scope and importance. Problems of more limited scope are generally addressed by State agricultural experiment stations or other research performers. The ARS will not pursue research that can be conducted better or on a more timely basis by industry.

For steady progress toward achieving the six objectives of the program strategy, the NPS balances efforts between basic and applied research. Basic research produces fundamental knowledge that is an essential scientific resource. In applied research, ARS scientists draw on that resource to meet the immediate needs of USDA action agencies, other Federal agencies, and users of ARS research findings.

The Agricultural Research Service is a dynamic organization responding to the formidable challenges facing American agriculture. The ARS is kept on a steady course by implementing clearly stated policies that are formulated as part of its program plan. As administrator of the ARS, my responsibility is to ensure that the Agency focuses its resources to provide timely and responsible solutions for the challenges facing our agricultural enterprise. Only by conducting whatever research is necessary to fulfill its mission can the ARS effectively address the critical problems confronting America into the 21st century and beyond.