Investing in Research: A Proposal to Strengthen the Agricultural, Food, and Environmental System

Board on Agriculture, National Research Council

ISBN: 0-309-53597-2, 168 pages, 8.5 x 11, (1989)

Investing in Research

A Proposal to Strengthen the Agricultural, Food, and Environmental System

Board on Agriculture
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1989

NATIONAL ACADEMY PRESS 2101 CONSTITUTION AVENUE, NW WASHINGTON, DC 20418

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Library of Congress Catalog Card No. 89-63090
International Standard Book Number 0-309-04127-9
Additional copies of this report are available from: National Academy Press 2101 Constitution Avenue, NW Washington, DC 20418

S036
Printed in the United States of America
First Printing, September 1989
Second Printing, October 1989
Third Printing, July 1990

Board on Agriculture

Preface

The United States was once much richer than the rest of the world and, particularly in agriculture, was more productive. Once, the United States could manufacture products that the rest of the world lacked the technology to make, and could grow and export farm products in quantities and with a quality that no other country could match. U.S. exports did not compete with products from the rest of the world—rather, the United States was the locomotive of the world economy.

Now, however, this nation's economic superiority can no longer be assured. The United States is only one of several countries of major industrial and agricultural strength. As the United States' almost effortless economic superiority was replaced by equality, the U.S. share of the world's gross national product fell from more than 50 percent after World War II to about 22 percent in the late 1980s. The products that the rest of the world lacked the technology to make are now made by many countries in a world of increasing technological parity. Advances in agricultural production in the developed and developing regions have sharply curtailed foreign markets for U.S. farm products. Instead of being a major exporter of raw materials, the United States is now a major importer of some products (Thurow, 1989).

New and complex challenges therefore confront U.S. agriculture—the challenges of responding to aggressive competition on a global scale, ensuring good nutrition and a high-quality food supply for all our people, safeguarding our natural resources, and enhancing our environment. But at the same time, we are still leading the world in the biological sciences central to our agricultural sector. It is therefore encouraging to consider the manifold opportunities for progress. For example, advances in modern genetics can be applied throughout the agricultural, food, and environmental system; and new environmental and engineering methods can help maintain both the quantity and quality of groundwaters and surface waters.

The challenges confronting agriculture must be addressed in two stages. First, leadership is required to set and implement new priorities so that the most critical problems can be solved and opportunities exploited. Second, the necessary physical and intellectual resources must be allocated.

In this report, the Board on Agriculture of the National Research Council presents a proposal for a major new funding initiative designed to meet these challenges. The report describes a course of action that will resolve key problems in agriculture, advance the sciences that undergird the nation's agriculture and the quality of U.S. natural resources, and enhance the nation's well-being. The board calls for a substantial increase in federal funding for research and recommends application of these funds through competitive grants. At the same time, the board recognizes the nation's need to meet federal deficit reduction goals and the need to balance alternative priorities.

Agriculture, as the Board on Agriculture defines it, encompasses the entirety of the system that grows and processes food and fiber for the nation. It also encompasses the related natural resources, public policy issues, social systems, and physical and biological environments. The term agriculture, food, and the environment is used to communicate the full meaning of agriculture in this broad sense.

Self-initiated activity of this kind is unusual for the Board on Agriculture, which generally provides detailed assessments and analyses of issues only at the request of a federal agency or the U.S. Congress. However, the significance of agriculture for the U.S. economy and the critical role of research in ensuring agricultural progress impelled the board to prepare this proposal. The board believes that now is the time to take advantage of recent scientific and technological advances to solve problems in the areas of competitiveness, the food supply, and natural resources stewardship. The sectors contributing to the agricultural, food, and environmental research system—the land-grant universities, other universities, agencies of the U.S. Department of Agriculture, the scientific societies, and others—are also now making the case for strengthening U.S. agriculture through science. Indeed, concurrent with and wholly independent of the board's initial work, a group of state agricultural research leaders discussed a need for action similar to that proposed here.

Investing in Research is the latest in a series of Board on Agriculture reports that began with the 1972 *Report of the Committee on Research Advisory to the U.S. Department of Agriculture*. Subsequent reports dealt with problems of world food production, genetic vulnerability, genetic engineering, natural resources, education in agriculture, control of pesticides in food, designing foods, and research priorities. *Investing in Research* builds upon that foundation.

Chapter 1, the executive summary, summarizes the proposal for an expanded competitive grants program within the U.S. Department of Agriculture and an infusion of new money into it. Chapter 2 presents the proposal and describes its major parts. Chapter 3 explains the rationale for major points of the proposal. Chapter 4 gives a review of the major challenges facing the agricultural, food, and environmental system. Chapter 5 delineates the six program areas necessary to encompass the needs of the system satisfactorily. Chapter 6 outlines the institutional and administrative issues involved in the implementation of the proposal. The report concludes with a set of appendixes covering funding trends for the agricultural, food, and environmental sector; budget priorities; current program objectives; and other documents relevant to this report.

The board expects—indeed, welcomes and encourages—discussion and refinement of this proposal and then implementation of its recommendations.

This proposal presents an investment opportunity in the classic sense. The investment entails some risk and will not produce immediate results. Yet, it will provide the basis for a new competitive position for agriculture, an improvement in human health and well-being, and improved stewardship of our natural resources.

Strengthening, revitalizing, and energizing U.S. agriculture will be difficult but far from impossible. We have done it before.

THEODORE L. HULLAR

CHAIRMAN

Acknowledgments

The Board on Agriculture's proposal to strengthen the agricultural, food, and environmental research system is the synthesis of the creative thinking and ideas of the many individuals and organizations that share our concerns about quality science and innovation. We thank all those who generously contributed their thoughts, expertise, time, and encouragement.

These individuals include representatives of professional societies; leaders of the state agricultural experiment station system; faculty members and scientists at a number of universities; and senior scientists at the National Institutes of Health, the National Science Foundation, and the U.S. Department of Energy. We especially thank administrators and scientists at the U.S. Department of Agriculture not only for their assistance in data compilation but also for their insights.

The efforts of countless individuals throughout the scientific, agricultural, and public policy communities are far greater than can be represented by the contents of this book. For all those who are committed to a strong U.S. agricultural system, we thank you.

The members of the Board on Agriculture also acknowledge the contributions of the staff in preparing this proposal. We extend special appreciation to Mary Lou Sutton, whose diligence carried us through many drafts in the process of attaining our final report.

Contents

Investing in Research

A Proposal to Strengthen the Agricultural, Food, and Environmental System

1

Executive Summary

This is the technological age. It is also an age of opportunity. U.S. agriculture continuously evolves, but the pace of change is now more dramatic than ever. In the life sciences, new knowledge and instrumentation are rapidly expanding the understanding of plants, animals, and microbes; providing new opportunities to control disease and pests; and improving the quality of agricultural and food products. Equally complex changes are occurring in international trade, where the new rules of the global marketplace are transforming old patterns of competition.

In the agricultural system, as with other segments of U.S. industry, the problems of the twenty-first century intensify more quickly than ever before, and opportunities must be seized immediately, before their peak of potential benefit has passed. The ability of the United States to resolve the spectrum of issues and related problems in agriculture—nutrition, economics and international trade, production efficiency, natural resources conservation, control of pollutants, and others—depends on depth of knowledge, the available tools and technologies, and the skill and insight to apply them.

The United States needs to invest in the future—in human capital and the scientific knowledge base—to revitalize and reinvigorate one of its leading industries, the agricultural, food, and environmental system, in its broadest sense. A sound investment strategy for research is fundamental to sustain economic performance, to respond competitively to the increased economic strengths and manufacturing capacities of other nations, and to maintain the U.S. quality of life. The commitment called for in this proposal should therefore be part of a national agenda to strengthen the United States.

URGENCY FOR CHANGE

Major challenges confronting the nation now center on the competitiveness of U.S. agricultural products in global trade, the safety and quality of the U.S. food supply, and the management and sustainability of the country's natural resources.

Competitiveness

The United States faces new and aggressive competition from abroad. The balance of trade has gone from positive to negative, making the United States a debtor nation. The strong role that agricultural exports played in the U.S. balance of payments has weakened. U.S. global competitiveness in agricultural commodities and food products has eroded because of increased costs of production at home and heightened competition from foreign producers in the marketplace. Given the high U.S. production capacity, regular surpluses of major commodities, and the imperative of deficit reduction, the needs for profitable new uses for agricultural products, more cost-efficient production, and new markets remain high.

Human Health and Well-Being

Nutritious and high-quality food is available to U.S. citizens. However, problems are arising that must be resolved, such as excessive fat in the diet, the incidence of microbial contamination, and pesticide residues on food.

U.S. citizens consume too many saturated fats. Although red meat and dairy products provide 36 percent of food energy and 100 percent of certain nutrients, they also contribute more than half of the total fat, nearly three-fourths of the saturated fatty acids, and all of the dietary cholesterol in the U.S. diet (National Research Council, 1988a). Agricultural research is focusing on ways to produce leaner animals and to process nutritious foods with reduced levels of saturated fats and cholesterol.

Salmonella species and *Campylobacter jejuni* from all sources are each responsible for up to 2,000 cases of gastroenteric disease per 100,000 people per year in the United States (National Research Council, 1985a). Illnesses caused by these microorganisms tend to be most severe among the very young, the very old, or patients with immunosuppressive diseases. New research can determine points at which known pathogens enter the food supply and can contribute to improving methods for detection, monitoring, and control.

Although potential cancer risks from ingesting pesticides in the diet are small in comparison with the potential risks from other known causes of cancer, the pesticide residues on fruits and vegetables are a growing public concern. Research can provide new insights into levels of dietary risk and can identify new alternatives that will ensure the producer a high-quality crop while reducing the need for pesticide application.

Natural Resources and the Environment

Concern for prudent natural resources stewardship and a clean and sustainable environment is now focusing on issues such as contamination of surface water and groundwater by natural and chemical fertilizers, pesticides, and sediment; the continued abuse of fragile and nutrient-poor soils; and suitable disposal of municipal, industrial, and agricultural wastes.

Water pollution is probably the most damaging and widespread environmental effect of agricultural production. Various estimates of the potential financial costs of surface water contamination from agricultural production are in excess of $2 billion per year. Ground-water is the source of public drinking water for nearly 75 million people. This fact is significant because accumulating evidence indicates that a growing number of contaminants from agricultural production are found in underground water supplies. Although research is being conducted in these areas, a major increase in support will be required to adequately investigate and apply new knowledge and technologies to curtail surface water and groundwater contamination.

Soil erosion remains a serious environmental problem in parts of the United States, even after 50 years of state and federal efforts to control it. New data indicate that the intensive tillage practices associated with continuous monoculture or short crop rotations may make soils more susceptible to erosion. New knowledge will provide improved ways to estimate erosion, decrease the displacement of soils by wind and water, and develop federal policies for conserving fragile lands.

Waste disposal facilities all over the United States are reaching their capacities to contain and decompose plant and animal residues, pesticides, food processing wastes, sewage, and industrial sludges. Research in the agricultural, food, and environmental sciences can help minimize the production of waste materials, develop technologies to increase recycling, and develop improved systems for ecologically safe waste disposal systems.

New Knowledge

Solving the problems of competitiveness, a high-quality food supply, and natural resources and the environment will require much more new knowledge than was required to solve previous problems. An example illustrates the point: Genetically engineered biocontrol agents for pest management are now being designed on the basis of current knowledge, but it will likely take a 10-fold increase in understanding of the biology of such agents and their survival and action in various ecosystems before such engineered biological control agents can be effectively developed and used. The knowledge needed must come from a number of disciplines, such as biochemistry, genetics, physiology, plant pathology, entomology, plant biology, ecosystems analysis, agronomy, and economics, among others. The specific disciplinary knowledge must then be integrated into effective production systems. The knowledge required far transcends that necessary for the current chemical-based technologies.

The necessary new knowledge is unlikely to be acquired and expediently applied without substantial new funding.

This proposal for investment in research for the agricultural, food, and environmental system aims to establish the new knowledge base necessary to address the problems.

THE PROPOSAL

The purpose of this proposal—as well as the challenge it presents—is to mobilize the nation's scientific and engineering communities to advance the quality of agriculture, the food supply, and the environment.

This proposal presents a program to strengthen the focus of U.S. science on agriculture. The premise is that a judicious but substantial increase in research funding through competitive grants is the best way to sustain and strengthen the U.S. agricultural, food, and environmental system.

Implementation of this research proposal will

- Capture the proven high economic return on investment in agricultural research.
- Secure for agricultural research a full array of talent from the entire U.S. science and technology research sector.
- Expand knowledge in all the disciplines underpinning agriculture while also contributing to advances in other broad areas such as biomedicine, ecology, engineering, education, and economics.

This proposal, which is composed of the following specific elements, should be evaluated as a singular strategy for action.

An Expanded Public Investment

Research support for agriculture, food, and the environment should be increased by $500 million annually. This increase should support competitive grants administered through the U.S. Department of Agriculture's Competitive Research Grants Office.

This competitive grants program should be increased to support the need for research in public and private universities and colleges; not-for-profit institutions; the U.S. Department of Agriculture's (USDA's) Agricultural Research Service, Economic Research Service, and U.S. Forest Service; and other research agencies of the state and federal governments.

Funds should come from new monies, not from the redirection or reallocation of existing research and education programs, including formula-funded programs.

Program Areas and Scientific Scope

The expanded proposed competitive grants program should encompass all science and technology relevant to research needs for agriculture, food, and the environment. To do this, six program areas should be established: (1) plant systems; (2) animal systems; (3) nutrition, food quality, and health; (4) natural resources and the environment; (5) engineering, products, and processes; and (6) markets, trade, and policy.

Agriculture has vastly overgrown its early bounds of planting and harvesting crops and nurturing livestock as sources of food and fiber. It is a major influence on and component of industry, world trade, and global ecology. The six program areas establish a framework that will accommodate all areas of research relating to agriculture, food, and the environment. Research in the six program areas using all relevant disciplines of science and technology is essential to solve current and emerging problems.

Examples of some of the major topics within the six program areas are as follows.

- *Plant Systems:* plant genome structure and function; molecular and cellular genetics and plant biotechnology; plant-pest interactions and biocontrol systems; crop plant response to environmental stresses; improved nutrient qualities of plant products; and new food and industrial uses of plant products.
- *Animal Systems:* cellular and molecular basis of animal reproduction, growth, disease, and health; identification of genes responsible for improved production traits and resistance to disease; improved nutritional performance of animals; and improved nutrient qualities of animal products.
- *Nutrition, Food Quality, and Health:* microbial contaminants and pesticide residues related to human health; links between diet and health; bioavailability of nutrients; postharvest physiology and practices; and improved processing technologies.
- *Natural Resources and the Environment:* fundamental structures and functions of ecosystems; biological and physical bases of sustainable production systems; minimizing soil and water losses and sustaining surface water and groundwater quality; global climatic effects on agriculture; forestry; and biological diversity.

- *Engineering, Products, and Processes:* new uses and new products from traditional crops, animals, by-products, and natural resources; robotics, energy efficiency, computing, and expert systems; new hazard and risk assessment and mitigation measures; and water quality and management.
- *Markets, Trade, and Policy:* optimal strategies for entering and being competitive in overseas markets; new decision tools for on-farm and in-market systems; choices and applications of technology; and new approaches to economic development and viability in the rural United States and developing nations.

Grant Types

In each of the six program areas, four types of competitive grants should be available: (1) principal investigator grants, (2) fundamental multidisciplinary team grants, (3) mission-linked multidisciplinary team grants, and (4) research-strengthening grants.

Principal investigator grants should support individual scientists or coinvestigators working within the same, or closely related, disciplines. Principal investigator grants are the foundation of the highly successful competitive grants programs in the United States, and they are the major way to attract and retain talented scientists and their students into areas of research.

Fundamental multidisciplinary team grants should support collaborating scientists from two or more disciplines focusing on basic science or engineering questions. It is often at the juncture of disciplines that new discoveries and research strategies are made.

Mission-linked multidisciplinary team grants should support multidisciplinary research focusing on more applied problems of national significance and should be linked to, among others, the Cooperative Extension Service (CES), the Agricultural Research Service (ARS), and industry. Funding through this grant type will facilitate the application of knowledge and the transfer of technology to the user through joint research-extension studies.

Research-strengthening grants should competitively support institutions through program grants and individuals through fellowships to increase the U.S. research capacity.

Attention to Multidisciplinary Research

The expanded competitive grants program should give major emphasis to supporting both fundamental and mission-linked multidisciplinary research teams. Up to 50 percent of the funding awarded for USDA's competitive grants should support multidisciplinary research.

The significance of multidisciplinary research to the success of the competitive grants program cannot be overemphasized. Many fundamental scientific and technological questions—and certainly the more applied problems—are multifaceted. To deal with their inherent complexity and diversity, it is necessary to establish multidisciplinary grants and make them a major feature of the expanded program.

Strengthening Institutions and Human Resources

Research-strengthening grants to institutions and individuals should be a key component of an expanded competitive grants program.

Research-strengthening grants are essential for two reasons. Grants to institutions improve the research capability at institutions and in departments that aspire to, but have not attained, nationally recognized research and development (R&D) capabilities. Fellowships increase the training and experiences available to pre-and postdoctoral fellows in agricultural, food, and environmental research. Expanding the number of women, underrepresented minorities, and disabled individuals in the research system must be integral to the entire program. The research-strengthening grant is a major way to provide those opportunities. The grants are not intended to be used for buildings or major capital expenditures.

Size and Duration of Support

The size and duration of USDA competitive grant awards should be increased substantially. The average size of a grant should be at least $100,000 per year per principal investigator; the duration of a grant should be at least 3 and as many as 5 years.

The size and duration of awards reflect the capability of a program to attract top-quality scientific and engineering talent. The USDA Competitive Research Grants Office should award grants that are adequate to conduct effective research and that are comparable in size and duration to those awarded by the National Science Foundation (NSF) and the National Institutes of Health (NIH), the two institutions in the United States with the largest and most successful grants programs. The proposed changes in size and duration will attract more top scientists in a variety of disciplines and thus increase the capacity to educate their students—the nation's future scientists.

RATIONALE FOR THE PROPOSAL

Key parts to the rationale for the expanded program include the need for a federal initiative; the need for a large increase in funding; the justification for new money, not for the redirection of current funds; the suitability of USDA as the central agency for the expanded program; and the appropriateness of competitive grants as the funding mechanism.

A Federal Initiative

A federal initiative for increased research support is needed because the issues and fundamental research needs are national in scope, and the nation as a whole, not just a state or region, is the beneficiary. In addition, states lack the funding to advance basic science across the full range of areas requiring immediate attention. In the private sector, the rate of R&D growth, which has been strong since the mid-1970s, is likely to level off in the decade ahead, and it may decline somewhat. Moreover, private sector research is focused on creating opportunities to market products and services, whereas much of the research most important to society and the nation is not market-related.

A $500 Million Increase

A $500 million increase in research funding is justified for at least three major reasons. (1) The pervasive needs and problems require large amounts of new knowledge and technology for their resolution, as discussed earlier. (2) Agricultural research provides a high return on investment. (3) The agricultural research system, as presently funded, is unable to provide the necessary financial support for the quality, amount, and breadth of science and technology necessary to address the problems.

Agricultural research characteristically gives a high annual return on investment, more than 45 percent (Fox et al., 1987). The contributions of research conducted within the competitive grants program will, in addition, bring advances not only to agriculture, food, and the environment but also to other scientific disciplines and other sectors of society. Discoveries that were made in efforts to resolve agricultural problems have already led to major advances in biology and medicine. Findings from research with plant models, for example, will lead to advances in the understanding of basic genetics and gene expression. Over time, the research results and their application will significantly decrease both regulatory and environmental costs.

Adequate funding through the six proposed program areas must be available to support the best and brightest researchers currently working in agriculture and to attract top researchers in other disciplines who have not previously participated in USDA programs. Current funding cannot do either.

Researchers' proposals for scientific inquiry are currently funded at levels that are too low to meet the demands of high-quality science. The average annual grant size from USDA is $50,000, in contrast to average annual grant sizes of $71,300 from NSF and $154,900 from NIH. USDA grants average 2 years in contrast to 3 years or more for NSF and NIH. In addition to funding grants at a higher level, both NSF and NIH fund a much larger number of grants. In fiscal year 1988, USDA awarded approximately $40 million for competitive grants, in contrast to the $265 million awarded by the Directorate of Biological, Behavioral, and Social Sciences at NSF and the $632 million awarded by the National Institute for General Medical Sciences (NIGMS), which is only 1 of the 12 institutes of NIH. All of the institutes that make up the NIH together awarded $6.4 billion in competitive research grants in 1988. Research supported by NIGMS is broad, covering all areas of fundamental biomedical science that bridge the responsibilities of all the institutes within NIH. Research supported by the USDA's competitive grants program is narrow, covering only some of the six program areas recommended in this proposal.

The proposed increase of $500 million would expand the current competitive grants program level of $50 million to an annual total of at least $550 million. The overall $550 million program should support the following four types of grants:

1. About 800 principal investigator grants for an average duration of 3 years. Total annual expenditure: $250 million.
2. About 180 fundamental multidisciplinary team grants for an average duration of 4 years. Total annual expenditure: $150 million.
3. About 60 mission-linked multidisciplinary team grants for an average duration of 4 years. Total annual expenditure: $100 million.
4. Research-strengthening grants to institutions for programs and to individuals for fellowships. Total annual expenditure: $50 million.

The expansion of USDA's competitive grants program by $500 million from its current level of $50 million will enable USDA to significantly support the innovative science that is poised to proceed—as soon as funding can be obtained.

Support with New Money

Support of the competitive grants program with new money will reverse the consequences of no R&D growth in agriculture and sustain the state-federal partnership.

The publicly funded research system has not been able to investigate many scientific questions comprehensively because fiscal constraints have allowed little, if any, real growth in R&D expenditures. From 1955 through 1988, research funding for USDA remained virtually stable in constant dollars, corrected for inflation. The purchasing power actually decreased, and higher costs are associated with the potent but costly instruments and supplies required by today's researchers. In 1988 USDA's total annual R&D funding was only 4.6 percent of the total R&D funded by the federal government, exclusive of the Department of Defense. Unfortunately, the lack of growth in USDA's support for R&D from 1955 through 1988 did not allow sufficient advancement in scientific knowledge. The agricultural sector cannot progress under the current level of funding; it can only fall behind.

The lack of real growth in R&D expenditures during the past 30 years has slowed research within U.S. agriculture and other areas of science. Opportunities are missed, such as the relatively slow application of biotechnology to agricultural issues; problems have increased, such as the need for new uses for commodity crops and for improved new crops for better nutrient composition and postharvest quality. At the same time, however, science and technology in other countries are advancing rapidly. Without a new infusion of funds, there will be insufficient support for the talented researchers with new ideas that can refuel scientific advancement in U.S. agriculture. Furthermore, without new funding, prospective students and new Ph.D. graduates will not be attracted to careers in agriculture or retained in them.

Most states support research at land-grant universities and state agricultural experiment stations (SAESs) far in excess of the matching formula funds they receive from the federal government. A substantial portion of this state support goes to research on fundamental scientific problems of national importance. Increased federal support for competitive grants will ease that burden and allow more of the state funds to be used for problems specific to that state or region.

Redirection of funds from intramural or formula-based programs to competitive grants would be counter-productive. The delivery system—SAES scientists and extension specialists and advisers, in combination with government and the private sector—is already unduly stressed, and redirection would exacerbate staffing insufficiencies for ARS, CES, and SAESs.

The Central Role of USDA

USDA is the federal agency responsible for advancing the agricultural sciences and developing technology applicable to food, fiber, and forest product industries. It is the entity best suited to administer the agricultural, food, and environmental competitive grants program.

The competitive grants program will warrant status as an independent office within USDA's Office of Science and Education, setting its administrator on a par with the administrators of the Agricultural Research Service, Cooperative State Research Service, and Extension Service as the managers of USDA's science, education, and training activities. As the USDA competitive grants program grows from about $50 million to $550 million in annual awards, changes in administrative procedures and institutional relationships will be essential.

Competitive Grants

The competitive grant is the proven and appropriate mechanism to stimulate new research in high-priority areas of science and engineering. It is flexible, reaches a large pool of talented scientists, and pro vides a balance to the overall research program, thereby ensuring high-quality research.

Responsiveness and flexibility in altering the direction of exploratory research are critical to scientific excellence. A competitive grants program capitalizes on the skills and experiences of leading scientists in recognizing the need for new directions in science. Because funding commitments to any one project are for only 3 to 5 years, this mechanism is flexible and responsive to rapid advancements in science, thereby allowing resources to be targeted at the most promising areas of scientific research in each grant cycle.

Sufficient funding over an adequate period of time is the best way to attract talented scientists from a variety of disciplines. The expanded competitive grants program will more adequately support researchers within the agricultural research system and will also open the system to scientists from other disciplines who have not previously participated in the USDA grants program. These scientists should be, but are not now, applying their skills to agricultural research.

An expanded competitive grants program will provide the needed balance among the funding mechanisms that support USDA R&D: intramural programs, formula funding, special grants, and competitive grants. Competitive grants area significant source of funding within other federal agencies. At NIH and NSF, 83 and 90 percent of R&D support, respectively, is distributed through competitive research grants. At USDA, however, less than 6 percent of R&D support is so distributed. USDA should not attempt to mirror NIH and NSF in the proportion of funds it distributes on a competitive basis. Problems specific to certain crops, technologies, and regions are often best addressed through formula funds or special grants. Long-range research, such as the development of improved plant and animal germplasms, or tracking of the diets and nutritional status of a group of children as they grow, for example, are more effectively supported on a continuing basis through intramural funding. With full funding of this proposal, the annual investment in R&D by USDA would rise to $1.54 billion from $1.04 billion (Office of Management and Budget, 1989), and the $550 million in competitive grants would then account for approximately 35 percent of USDA's research expenditures.

FISCAL REALITIES

The recommendation for a major increase in funding of competitive research grants for agricultural, food, and environmental research comes at a time of overall fiscal constraint for the nation. Elected and public officials must reduce the national debt and at the same time set priorities among competing federal expenditures to enact programs that maintain the welfare, infrastructure, security, and continued economic growth of the United States. As a part of that they must also address public concerns for maintaining global competitiveness, the safety and nutritional quality of the food supply, and environmental resources. The goal of reducing expenditures while allocating funds for essential programs thus requires fiscal prudence.

Trade-Offs

Political leaders will need to consider the proposal for an increased commitment to agricultural, food, and environmental research against a background of potential trade-offs. What are these trade-offs?

- The additional $500 million could come from sacrificing other USDA research programs. Can some current research programs be discontinued in an effort to strengthen competitive grants research?
- The necessary funds could be directed to research from other USDA budget categories. Commodity price supports, for example, have decreased from $26 billion to $11 billion during the past 3 years, as U.S. agricultural export prices have improved. Should $500 million of those savings and future budgetary savings be redirected toward research, toward reducing the national debt, toward a combination of the two, or toward progress outside of agriculture?
- The funds could be shifted from other parts of the federal budget into USDA. Does the consistently high return on the agricultural research investment override the need for funds in other areas of national interest?
- The investment in agricultural, food, and environmental research can be deferred until deficit reduction has been achieved. But investing new funds now can hasten future economic and scientific benefits. What will be gained—or lost—by postponing the investment?

Redirection within the USDA Research Budget

For the past 25 years the USDA budget for research has not increased. Actual monetary increases have barely kept up with inflation. In 1965 the USDA research budget had the purchasing power of $788 million in 1982 dollars; the 1988 research budget was valued at $778 million in 1982 dollars. In reality, any past changes in agricultural research priorities had to come from the redirection of funds within the research budget. Further redirection by increasing the investment in competitively awarded grants does not address the problem of the continued federal underinvestment in research through USDA. It also raises the real risk of destroying some of the "muscle" of current high-quality research in intramural and formula-funded research in attempts to cut out any "fat."

Without some real growth in the USDA research budget, there can be no realistic opportunity to broaden the scope of science contributing to agricultural, food, and environmental research. Many of the new scientific opportunities that require costly supplies and instrumentation will have to remain unexplored, and few multidisciplinary research teams will be able to be formed to attack the multifaceted problems of competitiveness, food quality, and natural resources confronting agriculture.

The proposed increase in funding for competitive research grants is justified. This proposal stands strongly against reallocation within the USDA research budget for the reasons given above. If no growth in the USDA research budget is possible, then decisions to redirect funds are judgments that elected and other public officials may choose to consider.

Reinvesting Subsidy Savings

As U.S. agriculture gradually returns to a state of economic health and as commodity prices return to free-market conditions, the federal budget appropriations currently used for price support programs may be targeted for budgetary savings. Part of these savings should be reinvested in research programs to strengthen the knowledge that supports the nation's food and fiber industries.

Federal Investment

Investments in agricultural research in the United States have consistently shown high returns, as noted previously. Such data demonstrate that an increased investment in the agricultural, food, and environmental research system will be paid back rapidly in economic development and other public benefits.

The U.S. gross national product in 1987 was $4.5 trillion (Council of Economic Advisers, 1989). Of that, the agribusiness complex contributed approximately 18 percent, or roughly $815 billion (Harrington et al., 1986). The current annual federal investment in agricultural R&D is about $1.04 billion—less than 0.13 percent of agriculture's annual contribution to the gross national product.

Investing Now

A major increase in research funding of $500 million is needed at this time. The scientific opportunities exist today to use this increased funding wisely. The needed scientific talent is available now, primarily through the nation's existing scientists in the physical, biological, engineering, and social sciences, as well as those in agriculture and related disciplines, who are ready to compete for this new funding. In addition, as noted above, increased funding will also ensure the flow of young scientists into agriculture-related research areas.

To achieve the maximum effect, this substantial increase should be enacted in a single year as a reflection of the value of the broadened scope of agricultural, food, and environmental research and the importance of the sustained advancement of this system to the U.S. economy.

Given the overall fiscal problems facing the nation, the appropriation of the full $500 million increase may not be possible in a single year. Even so, a commitment of this magnitude is essential. Any stepwise. increase in funding should provide the full increase as soon as possible, preferably within 3 years, and be balanced to address the needs and opportunities in agriculture, food, and the environment.

CONCLUSION

Agriculture is the world's oldest and largest industry, and it has been a highly successful industry in the United States. The United States is endowed with perhaps the world's most extensive and abundant complement of soils, water, and climate favorable for agricultural production. Still, several other countries have tremendous natural assets to draw upon in developing productive agricultural industries. One dominant factor stands out in making possible the remarkable pace of development of agriculture in this country in contrast to that in other countries—the early and very strong support given to agriculture by the U.S. government. Agriculture was the first—and for a long time, the major—federally supported scientific effort. It is significant that early federal support was not directed primarily toward infrastructure investments that yielded only quick benefits. Rather, support was broad, and a large proportion was directed toward research and education.

The decision to provide federal support for a strong U.S. agricultural system was made by the Congress 127 years ago through the Morrill Act of 1862. Now is the time to make a renewed investment in U.S. agriculture, one that will ensure its worldwide leadership role in the coming decades.

As a leader, the United States calls upon its agricultural and food system to compete in a free-market world. But U.S. farmers cannot compete with the price of labor in many countries, where it is far lower than that in the United States. And, for the same reason, they cannot compete with the cost of fertile land in other countries. The single resource that U.S. farmers can draw upon to capture the leading edge is science and technology. The U.S. government must help to provide an environment where U.S. producers and processors can compete. The most effective way to ensure a strong U.S. agricultural system is to capitalize on science and technology by investing strongly in agricultural, food, and environmental research.

2

The Proposal

The agricultural and food system in the United States undoubtedly has proved its capacity for providing food and forestry products in large quantities and at low prices, for serving as the base for almost 20 percent of the nation's economy, and for capitalizing on research and development (R&D) to attain exceptional levels of productivity. Even as this level of performance continues, however, agriculture—and the associated food-related industries—is facing three major challenges:

1. Competitiveness and economic performance, both nationally and globally: U.S. agriculture needs to be able to sustain itself as a major global leader, thus contributing to national economic strength and deficit reduction.
2. Human health and well-being: Convenient and nutritious food needs to be available to individuals with a variety of dietary patterns, thus contributing comprehensively to disease reduction and good health.
3. Natural resources stewardship: Environmental quality needs to be enhanced and the high quality of U.S. natural resources needs to be sustained at reduced costs to producers and the public.

Meeting these challenges will require an effective national strategy, implemented with ingenuity and innovation. It will also require major advances in science and technology on a scale and of a scope not seen previously. These science and technology advances are needed throughout the entire agricultural, food, and environmental system (see the box "Defining Agriculture" for a definition of and perspective on this system). Achieving these advances will require a major additional investment in R&D and the securing of as much talent as possible for the agricultural, food, and environmental research system.

This proposal calls for an investment in research for the agricultural, food, and environmental system. The recommendations of this proposal will, when implemented, be a major new step for ensuring that sufficient new knowledge is generated to successfully address both the continuing national need for high-performance productivity and the three challenges identified above.

The recommendations and the specific actions these challenges call for are set forth in this chapter; the rationale for them is presented in Chapters 3 through 5. Chapter 6 discusses the institutional and administrative issues that will arise upon implementation of the recommendations.

This proposal would stimulate the broad array of the nation's science and technology expertise to conduct fundamental research on issues of national need and to use new ways of deriving innovative applications from the knowledge that is gained. The proposal does not—nor can any single proposal by itself—address all the important needs of the agricultural, food, and environmental research system. For example, the proposal is not intended to provide a significant new source of funds for state-specific applications of technology or for regional technology transfer and educational activities. Those and other needs will continue to be met principally by activities of the state agricultural experiment stations, the Agricultural Research Service, the Cooperative Extension Service, and other components of the agricultural research, extension, and educational systems. The goal of this proposal is to create fundamental new knowledge and tools that will help the entire agricultural, food, and environmental research system meet its central responsibilities to the nation.

Defining Agriculture

Agriculture, as the Board on Agriculture defines it, encompasses the entirety of the system that grows, processes, and provides food and fiber for the nation. Agriculture also includes the management of natural resources such as surface water and groundwater, forests and other lands for commercial or recreational uses, and wildlife; the social, physical, and biological environments; and the public policy issues that relate to the overall system. All the activities, practices, and processes of the public and private sectors involved in agriculture and forestry are contained within the system.

In this report, the term agriculture, food, and the environment is used to communicate the full meaning of agriculture in this broad sense. The term agricultural, food, and environmental research is used to designate all of the research relevant to the entire system. That research is the focus of this proposal.

AN EXPANDED PUBLIC INVESTMENT

Research support for agriculture, food, and the environment should be increased by $500 million annually. This increase should support competitive grants administered through the U.S. Department of Agriculture's Competitive Research Grants Office.

Tight budgets have limited the U.S. government's capacity to respond to national needs in the agricultural, food, and environmental research system. The potential to respond is available throughout the nation's research system: in state land-grant universities and agricultural experiment stations; in private universities and not-for-profit institutions; in federal science and mission-oriented agencies outside the U.S. Department of Agriculture (USDA); in USDA's Agricultural Research Service (ARS), Cooperative State Research Service, Extension Service, Economic Research Service, and U.S. Forest Service; and in other federal agencies.

The most effective way to enlist science and technology to more effectively address the agricultural, food, and environmental needs of the nation is with a competitive grants program that is open to all scientists and scholars. Under a competitive grants program, limited funds can be allocated to those institutions and individuals who, in the judgment of their peers, have come forward with the best ideas and who have the capability for advancing science and addressing the issues. As discussed in later chapters (see especially Chapter 3), current funding for competitive grants for agricultural, food, and environmental research is far too low to meet major national needs, cover all program areas, and advance new developments in science.

This proposal calls for an overall increase in funding for agricultural, food, and environmental research, but not for a redirection or reallocation of the funds now being used to support research and education programs. New funding is called for because, although attracting the much-needed new talent to this area of research will provide substantial benefits to the nation, it will not by itself respond to major national needs. Advances in knowledge need to be complemented by research, education, and delivery mechanisms that will enable farmers, consumers, managers, and administrators to develop, adopt, and use the new knowledge and technology in their day-to-day activities. The only way to give full and timely application to the scientific and engineering progress that will be made through the competitive grants program is by maintaining and strengthening the existing research and education programs, including formula-funded programs.

The current system[1] for putting research results into practice is effective, especially in light of the many complexities of adaptation that arise from regional differences.[2] With the demands on the system increasing while resources remain level, however, the system is under stress. Weakening it by diverting federal formula or ARS funds to other programs—even to an expanded competitive grants program—makes little sense; and politically, the attempt to do so would be destructive. The state and federal funds supporting the current system of technology development and transfer should be continued. Thus, new funds—not reallocated funds—are needed for the expanded competitive grants program proposed here.

PROGRAM AREAS AND SCIENTIFIC SCOPE

The expanded competitive grants program should encompass all the science and technology that are relevant to agriculture, food, and the environment. For this to be done, six program areas should be established: (1) plant systems; (2) animal systems; (3) nutrition, food quality, and health; (4) natural resources and the environment; (5) engineering, products, and processes; and (6) markets, trade, and policy.

The boundaries of agriculture now far transcend the activities of planting and harvesting crops and raising livestock. Agriculture includes all dimensions of the agricultural, food, and environmental system. Activities in agriculture and forestry can have a major influence on environmental quality, the biodiversity and stability of ecosystems, and water quality. These activities can also have long-term effects on global changes, such as those involving the greenhouse effect on climate, ultraviolet radiation, and acidic deposition.

Accordingly, the science and technology related to the agricultural, food, and environmental system now extend beyond plant and animal science to include, for example, ecology and environmental studies; engineering, management, and information systems; economics, sociology, and community development; biomedicine and human nutrition; and biotechnology, food technology and processing, and decomposition of wastes.

The existing USDA competitive grants program, which was established in 1978, has limited its grant awards to only three areas: (1) plant science, which includes molecular biology, genetics, plant physiology, and plant-pest and environmental stress interactions; (2) animal science, with a grant program that was introduced in fiscal year (FY) 1985 and is scheduled for a substantial increase in funding in the President's proposed FY 1990 budget;[3] and (3) human nutrition, with a few important areas of research, particularly nutrient availability, receiving modest support in some program years. There was also a short-lived and severely underfunded forestry grants program that, among other things, stimulated research with the potential to hasten progress in the genetic improvement of tree varieties for commercial forest plantings.[4]

The expanded competitive grants program should cover the entire agricultural, food, and environmental system and should therefore support work not only in the three areas currently receiving support but in all six program areas listed above. Similarly, the program should embrace all necessary science and technology disciplines needed for each of the six program areas. For example, engineering and economics are both necessary when new cropping systems and new products are considered; veterinary medicine, immunology, and epidemiology are integral to animal systems; the physics and chemistry involved in transport phenomena in porous media, as well as in soil science, are directly relevant to water quality, sustainable agricultural systems, and waste management; and operations research, applied mathematics, computer and information sciences, engineering systems, and robotics are relevant to environmental management and post-harvest processing. Furthermore, many of the problems are multifaceted and are properly addressed in integrated multidisciplinary studies (as proposed below).

By embracing all of the program areas and opening the competitive grants program to scientists and scholars in all relevant disciplines, the expanded competitive grants program will, for the first time, support the range of science relevant to agriculture and be available to the broad community of scientific researchers.

The six program areas proposed here cover not only the current program areas of the Competitive Research Grants Office but also the program priorities of the Joint Council for Food and Agricultural Sciences and the strategic plan of the ARS (see Chapter 5). Research topics within the six proposed areas would include (but are not limited to) the following:

1. *Plant Systems:*[5] Plant gene expression and genetic diversity; the genetic and biochemical basis of important crop plant traits and advanced plant breeding systems; crop plant use of energy and nutrients; plant-pest interactions and biocontrol systems; crop plant response to environmental stresses; the economics of cropping systems and practices; the biological basis of forest and range productivity; new food and industrial uses of plant products.
2. *Animal Systems:* Cellular and molecular basis of reproduction, growth, lactation, and disease; nutritional attributes of animal products; nutritional and environmental effects on livestock production systems; economics of animal production systems, nutrient sources, and animal health care practices; wildlife and fisheries management; identification of the genes

responsible for improved production traits or resistance to disease.

3. *Nutrition, Food Quality, and Health:* Chemical residues (natural and man-made), microbial contaminants, and foodborne illnesses; methods of identifying population subgroups that are genetically predisposed to diet-related diseases; links between diet and health; bioavailability of nutrients; dietary needs and sensitivities of specific subgroups of the population; methods of achieving quality control in food processing; improved packaging, preservation, transportation, and preparation of foods.
4. *Natural Resources and the Environment:* Fundamental structures and functions of ecosystems; biological basis of sustainable production systems; methods of minimizing the loss of soil resources and the negative environmental effects of agricultural and forestry practices; maintenance of biodiversity in forests and croplands; options to improve the energy and water use efficiencies of crop and forest production systems; global climatic effects on agriculture and forestry; development of a land stewardship and an environmental ethic within U.S. society.
5. *Engineering, Products, and Processes:* Novel uses of traditional crops, animals, forest trees, by-products, and natural resources; systems of planting, harvesting, processing, and marketing new crops; more cost-effective harvesting, manufacturing, and production and quality control procedures using sensors, biotechnological probes, robotics, expert systems, and diagnostic tools; new hazard and risk assessment and mitigation procedures; options to improve the energy efficiencies of farming and industrial activities and to produce energy from renewable biomass derived from agricultural and forestry activities; recycling of municipal and food processing wastes.
6. *Markets, Trade, and Policy:* Interactions of technology, policy, and economics; advanced systems and tools to manage investments and make decisions on choices and applications of technology; optimal strategies for entering new overseas markets; methods of adopting new technologies and agricultural systems; new approaches to economic development in rural areas of the United States and in developing countries.

TYPES OF GRANTS

In each of the six program areas, four types of competitive grants should be available: (1) principal investigator grants, (2) fundamental multidisciplinary team grants, (3) mission-linked multidisciplinary team grants, and (4) research-strengthening grants.

A crucial aspect of a competitive grants program is the types of grants it makes available. In the current USDA program, grants for principal investigators predominate. The expanded program would offer four types of grants, giving scientists a range of options for pursuing critical areas of fundamental research, problem-solving or mission-oriented research, and technology development and adaptation.

Two of the four types of grants—principal investigator grants and fundamental multidisciplinary team grants—are intended to advance science and can be thought of as science-driven. They will support individuals and teams carrying out fundamental research relevant to agriculture, food, and the environment. The other two types of grants—mission-linked multidisciplinary team grants and research-strengthening grants—are more applied or problem-driven. The four grant types are defined as follows:

1. Principal investigator grants will be awarded to individual scientists or to two or more principal investigators working collaboratively as co-principal investigators within the same discipline or in closely related disciplines. Grants for principal investigators are the foundation of the highly successful competitive grants programs in the United States and are the major way to attract talented scientists to research areas. Because of the inherently individualistic way in which research scientists work and the extraordinary success of comparable competitive grants programs, the principal investigator grant is to be the primary type of grant awarded.
2. Fundamental multidisciplinary team grants will support basic, i.e., fundamental, research conducted by a team of collaborating scientists from two or more distinct science or engineering disciplines integrated into a single plan of study. The research will focus on answering important basic scientific questions that are involved in understanding a biological phenomenon, such as disease resistance, or that are applicable to phenomena central to an overall agricultural, food, and environmental system, such as the biogeochemical principles of agricultural ecosystems.
3. Mission-linked multidisciplinary team grants will also support multidisciplinary work. The work will be conducted on major science and engineering questions of national import, basic to understanding the phenomena being studied, and will be linked to

more applied problems. Examples of mission-linked problems are agricultural production and harvesting systems, including issues of soil and water sustainability; food processing and the improvement of health through dietary modifications; and diversification of the economic base in rural areas by developing value-added industries, including new crops, new uses for crops, and recreational opportunities. A prerequisite for this type of grant will be links extending from basic research to applied research and technology development and transfer, forming a continuum of results and applications. Moreover, an important component of the proposal should be linkage to a state agricultural experiment station, a cooperative extension program, industry, or an ARS or other government laboratory, which should include matching grants or in-kind support.

4. Research-strengthening grants, too, will be mission-linked. Their purpose is to increase the research capacity of institutions, departments, and programs as well as that of individuals. They will address the need for a more competitive state and regional research infrastructure and the need for more qualified research scientists. Institutions that are both focused and committed but that lack a sufficient research capacity may receive program grants to develop research capabilities in areas of special need. Predoctoral students and postdoctoral research associates in program areas that need human resources will receive fellowships from institutions, enabling them to upgrade their ability to perform research related to agricultural, food, and environmental needs. However, under this expanded competitive grants program, these fellowships will not be the sole, and may not even be the major, source of support for higher education: Most individual and multidisciplinary competitive grants should routinely include funds to support graduate students and research fellows, and the USDA fellowship program should also be continued and expanded.

Research-strengthening grants should not be made or used for construction, renovation, or other major capital expenditures. Equipment to help improve the use of existing expertise and facilities would be an appropriate use of monies from these grants.

The expanded USDA competitive grants program should allow applicants to seek any one of the four grant types in each of the six major program areas. Goals for the distribution of funding by type of grant (see Chapter 3) should apply to the total program, not to each of the six program areas separately.

ATTENTION TO MULTIDISCIPLINARY RESEARCH

The expanded competitive grants program should put major emphasis on supporting both fundamental and mission-linked multidisciplinary research teams. Up to 50 percent of the funding awarded for USDA's competitive grants should support multidisciplinary research.

Fundamental research done by an individual scientist within one discipline or by a small group of scientists in closely related disciplines has always been, and will remain, a cornerstone of scientific advancement.[6] However, many fundamental scientific and technological questions in food and agriculture—and certainly the more applied problems—are multifaceted. Making steady progress to resolve these questions and problems requires that several scientific disciplines be integrated and managed to ensure collaboration and synergy. Thus, it is appropriate and necessary to establish multidisciplinary grants and award a significant portion—up to 50 percent—of the funding for the program through fundamental multidisciplinary team grants and mission-linked multidisciplinary team grants.

An expanded competitive grants program that targets funding and attention to multidisciplinary grants will encourage and stimulate research on problems that require the combined skills from several disciplines. This will help focus attention on issues that cross several disciplines. The emphasis on multidisciplinary research approaches may also modify some of the procedures and criteria for evaluating proposals and awarding grants. For example, the makeup of peer review panels can be modified or augmented so that people experienced in managing and working on multidisciplinary teams will be evaluating multidisciplinary grant proposals.

STRENGTHEN INSTITUTIONS AND HUMAN RESOURCES

Research-strengthening grants to institutions and individuals should be a key component of an expanded competitive grants program.

Academic institutions are not equally capable of pursuing research. Yet, an academic institution needs research strength if it is to participate in the national scientific agenda, as it surely should. Small to mid-sized academic institutions in rural areas warrant special consideration and investment through a program of research-strengthening grants.

The expanded competitive grants program can lessen the unevenness in the research capability among U.S. academic institutions by strategically investing in the infrastructure and by attracting more talented young scientists and engineers to pursue careers in the agricultural, food, and environmental sciences. Research-strengthening grants are intended to improve the research capability at academic institutions and in departments that aspire to, but have not attained, nationally recognized R&D capability. They are also intended to increase the training and experiences available to pre-and postdoctoral fellows in agricultural, food, and environmental research.

These research-strengthening institutional grants are conceived of as being comparable in purpose and value to those offered through the National Science Foundation's (NSF's) Experimental Program to Stimulate Competitive Research (EPSCoR) program, and they could be managed like the EPSCoR grants or like those offered through the training grant programs of the National Institutes of Health (NIH).

The fellowships are meant to complement existing USDA fellowship programs, which should be continued. Areas emphasized for fellowships should be those in which it is necessary to ensure future scientific talent and those in which fields of knowledge are rapidly expanding. A primary goal of the fellowship programs should be to attract and retain top-quality scientific talent for the agricultural, food, and environmental research system.

Providing opportunities within the agricultural, food, and environmental research system for women, minorities, and disabled individuals must be a goal for all programs, and certainly for the expanded grants program proposed here. Research-strengthening grants should be a major means to this end.

If as much as 10 percent of competitive grants program funding is allocated to research-strengthening grants, the program will significantly broaden the nation's scientific base by providing scientific capabilities that will likely pay significant dividends.

SIZE AND DURATION OF SUPPORT

The size and duration of USDA competitive grant awards should be substantially increased. The average size of a grant should be at least $100,000 per year per principal investigator; the duration of a grant should be at least 3 years and as many as 5 years.

The size and duration of the awards a program offers are critical to its ability to attract top-quality scientific and engineering talent. At present, too many leading scientists and institutions pass up the opportunity to compete for the limited, short-term funding available from the USDA competitive grants program. Those who do secure funding must cope with inadequate budgets and little assurance of continued support.

To rectify this situation, the USDA competitive grants program should award grants that enable effective conduct of research and that are more nearly comparable in size and duration to the grants awarded by NSF and NIH—the institutions with the largest and most successful grants programs in the United States. This change alone will do much to attract more top-quality and new scientific talent into the agricultural, food, and environmental system and to further stimulate and reinforce the talent already in the system.

Ideally, under an overall program of $550 million—$50 million from the current program, $500 million from the proposed increase—$250 million in grants averaging about $100,000 per year and lasting an average of 3 years would be allocated to principal investigators; $150 million in grants lasting an average of 4 years would be allocated to fundamental multidisciplinary teams; $100 million lasting an average of 4 years would be allocated to mission-linked multidisciplinary teams; and $50 million would be allocated to recipients of research-strengthening grants (to institutions for programs and to individuals for fellowships).

NOTES

1. The current system includes state, federal, and private scientists such as state agricultural experiment station scientists, cooperative extension service specialists and advisers, ARS scientists, and their counterparts in the private sector. The publicly funded components are supported by a mixture of state appropriations, federal formula funds to the states, the research budget of ARS, and funding from commodity groups and industry.

2. Examples of applications distinct to particular regions are the breeding of salt-tolerant cultivars for western soils with a high salt content; the development of soil erosion control systems that are effective in

regions experiencing potentially high rates of both wind and water erosion; and the identification of pest and plant disease control practices that are effective, safe, and profitable in regions with diverse indigenous pests, soils, and climates.

3. The $8.0 million increase proposed in FY 1990 in animal science competitive grants funding results in large part from the proposed inclusion under the competitive grants program of the Section 1433 program, which distributed about $5.0 million annually from 1984 to 1988. Congressional response to the proposal to transfer the funds is uncertain.

4. It should be noted that current plant and animal science competitive grants programs cover only portions of the proposed plant and animal systems program areas (for example, veterinary medical issues are not now included) and that the current biotechnology program applies to five of the six proposed program areas but only partially and partially to the sixth proposed program area (markets, trade, and policy) (see Chapter 5 for a discussion).

5. The term systems as used here has two meanings: (1) The crop plant or animal of interest is part of a larger biological system that includes relationships with other plants, animals, insects, or microbes—relationships that can be either beneficial or harmful. (2) The resolution of problems such as disease control or improved quality in crop plants and animals will require an integrated approach that combines expertise ranging from economics to biochemistry. (Placing organisms or phenomena in a systems context is particularly relevant to the new category of multidisciplinary grants; see later sections of the chapter).

6. This has been the case in all areas of science, including those closely related to agriculture, food, and the environment. For example, basic research has helped scientists to understand gene transfer mechanisms in plants, develop and refine analytical chemistry methods, understand the physiology of plant responses to stress, describe the mechanisms important to animal and human reproduction, and develop controls for human and animal viruses.

3

Rationale for the Proposal

The fundamental reason for this proposal is that major challenges with substantial implications for the well-being of the United States are confronting the U.S. agricultural, food, and environmental system. A greater research and development (R&D) capacity is needed to fuel the necessary advances in science and technology to address these challenges. These challenges are broad, and each relates to the entire agricultural and food enterprise and to the environmental and social quality of the nation. An overview of the challenges is contained in Chapter 4; a brief synopsis of each follows:

- Competitiveness and strong economic performance are crucial for the economic vitality of U.S. agriculture and for agriculture's capacity to provide low-cost, nutritious food to consumers: increasing the efficiency and profitability of the food, fiber, and processing industries; reducing the environmental costs of such actions as pesticide use and waste management; making available, and using, modern equipment and technology that have state-of-the-art control and management systems and sensors.
- Contributing to human health and well-being is the goal of the entire agricultural and food system: increasing the nutrient availability of all foods; making optimally nutritious foods conveniently available to all Americans even while social patterns are changing; and elucidating the full relationship between diet and health.
- Natural resources stewardship is necessary for maintaining the health of the environment: providing the basis for prudent long-term production systems and resource sustainability; minimizing direct costs to producers for maintaining environmental quality and indirect costs suffered by consumers when environmental quality is diminished; and ensuring high environmental quality, with its concomitant benefits for food, soil, and water.

One way to deal effectively with the challenges and with the myriad of specific research needs is to exploit current opportunities in science and technology by expanding the nation's R&D system.

This chapter presents the rationale for all aspects of the proposal except for that on program areas and scientific opportunities (which are discussed in Chapter 5):

- Support for fundamental science is mainly a federal responsibility.
- The agricultural, food, and environmental research system requires a substantial increase in funding to conduct the needed research programs and to cover the necessary program areas adequately.
- The money should be new funding, not redirected funding.
- Responsibility for administering the additional funds should lie with the U.S. Department of Agriculture (USDA).
- The increased funding should be for competitive grants, not for some other form of allocation.
- Competitive grants to principal investigators should be complemented by multidisciplinary and research-strengthening grants.

A FEDERAL INITIATIVE

Funding for research in science and technology comes from the state, private, and federal sectors. However, primary responsibility for supporting fundamental research that benefits the nation as a whole has traditionally been assumed by the federal government; and neither the states nor the private sector can be expected to underwrite a marked expansion in the overall science and technology effort in agriculture, food, and the environment.

State Sector

States are highly unlikely to provide additional funds for research, nor should they be asked to do so. First, state expenditures for agricultural research are already significant. Second, and even more important, the research to be funded by the program proposed here is of national importance rather than of directly local or state importance.

Mainly through their land-grant universities, the states already do more than half of all research related to the agricultural, food, and environmental system. Since 1972, only about 30 percent of the states' research funding has come from all federal sources (about two-thirds of that from USDA). In 1988, when total funding for state research was $1,674 million, the states themselves provided $822.8 million, the federal government $577.3 million, and industry $99 million; the remainder came from sales and other income. Of the federal funding, $383.5 million came from USDA through formula and other funds and $45.4 million came through USDA competitive grants (see Appendix A). Given the pressure on states to fund state responsibilities that are continuously increasing, they will almost certainly not be able to increase their proportion of research funding.

For program reasons, too, funding for this expanded research program is a federal, not a state, responsibility. The research to be funded by the expanded competitive grants program will not—even in mission-linked and research-strengthening grants—fund research that is narrowly focused on local, state, or regional needs. Rather, it will increase the fundamental understanding of basic biological and physical phenomena that relate to agriculture, food, and the environment, thus contributing substantially to the national base of knowledge for the agricultural system and strengthen the national infrastructure of that system.

Private Sector

Like the state sector, the private sector plays a vital role in ongoing agricultural, food, and forestry research activities. However, it, too, cannot be expected to underwrite a marked expansion in the nation's overall science and technology effort in agricultural, food, and environmental research. Indeed, private sector research investments may retrench somewhat in the years ahead. Even if private sector R&D were to increase, however, its priorities would not fully match or encompass national needs because of product development and proprietary considerations.

Level of Effort

The capacity of private firms to support R&D is a function of their gross sales, their profits, and the percentage of either gross sales or pretax profits that a company is willing to invest in R&D. The percentage of commitment of R&D funds ranges among companies. As one might expect, to remain competitive and profitable, industries that place relatively less emphasis on new technology tend to invest a smaller portion of their sales and profits in R&D; high-technology industries with higher returns in dynamic markets invest more heavily.

The food and the paper and forest products industries fall within a group of industries in which R&D investments are relatively low (see Table 3.1). These two industries spent 9.4 and 10.3 percent, respectively, of pretax profits on R&D in 1987. This represents the lowest level of R&D by all industries surveyed except for nonbank financial institutions. Not surprisingly, high-technology industries with patent protection and proprietary technologies were found to commit 30 to 50 percent or more of pretax profits to R&D (aerospace, 86.7 percent; chemicals, 31.8 percent; computers, 60.3 percent; health care, 52.6 percent).

Prospects for Growth

In the decade ahead, the following factors are likely to affect industrial R&D (see Appendix B):

- Public policies that affect cropping patterns, natural resource stewardship goals, and the manner in which food safety and environmental problems are addressed.
- Public sector R&D priorities and accomplishments.
- Tax and monetary policy, general economic conditions, and interest rates.
- Trade policies, both domestic and international.
- Policies affecting trade in technology and intellectual property.
- Government regulations, both domestic and international.

- Gross and net farm income, and export demand and performance.
- Corporate consolidations and methods of financing mergers.

Table 3.1 Private Sector Sales, Profits, and R&D for Selected Major Industries, 1987 (in millions of dollars)

Industrial Sector	Gross Sales	Net Profits	R&D Expense	Percent R&D of Pretax Profits
Aerospace	$88,435.1	$2,824.7	$3,865.4	86.7
Automotive	246,847.4	11,125.5	8,653.0	54.6
Chemicals	112,053.1	7,403.8	4,168.3	31.8
Computers	107,976.8	8,836.2	8,804.1	60.3
Consumer products	71,288.8	3,302.7	1,426.1	25.1
Personal care	35,879.9	1,450.5	968.7	38.2
Electrical and electronics	95,625.7	4,283.1	5,055.6	71.2
Food[a]	88,622.6	3,362.0	578.4	9.4
Fuel	285,216.3	5,493.7	1,906.2	12.2
Health care	70,252.7	6,404.1	5,554.9	52.6
Manufacturing	64,650.8	2,170.8	1,462.6	40.2
Metals and mining	26,028.1	583.8	306.3	31.7
Nonbank financial	9,698.3	767.6	57.4	6.4
Paper and forest products	42,071.2	2,456.6	429.3	10.3
Telecommunications	52,551.1	3,278.0	2,909.5	55.9

NOTE: Industry composites are from *Business Week* (see Source below).

[a] The food industry composite includes 25 companies with gross sales of $88.6 billion, including two seed companies (whose percent R&D of pretax profits are 50.9 and 86.8) and several major food processors and manufacturers representing all segments of the industry.

SOURCE: Business Week. June 20,1988. A perilous cutback in research spending. Pp. 139–162.

Various scenarios for the relationship between these policy and economic factors, on the one hand, and sales, profits, and private sector R&D, on the other, are presented in Appendix B. If a strong and sustained economic recovery in the farm sector in the 1990s were coupled with expanded crop production, private sector R&D might rise by as much as 9 to 13 percent. But such an eventuality, although possible, is not highly probable. Rather, a continued period of little or no increase in commodity prices is more likely, which may hold down increases in production levels. In addition, public policies and regulations may impose new costs related to food safety and natural resource stewardship. In this unfavorable scenario, private sector R&D might decline by 5 to 7 percent during the next decade.

Focus of Private Sector R&D

Private sector firms finance R&D from the sale of current products of from investment capital that seeks a return through future product sales. Thus, industrial R&D usually emphasizes areas of commercial or near-term interest and may give only modest attention to areas of research that—however important—are not related to a marketable product or service. Such areas will probably be addressed only by publicly funded R&D programs.

The following list of some research areas relevant to alternative agricultural practices illustrates the large number of research areas that are important to the long-term economic and environmental performance of U.S. agriculture and that need public funds:

- Interactions among cropping patterns, tillage, soil fertility, and nonchemical pest control methods and the effects of such practices and interactions on farm profitability, water quality, and the long-term productivity of soil and water resources.
- The development and testing of biologically and ecologically sustainable production practices, management support, and diagnostic tools that improve the options for managing soil nutrients, crop pests, or animal diseases.
- Effects of technological change on patterns of on-farm and rural employment as they relate to employment and worker health and safety in agricultural and forest product industries.
- Analysis and estimation of the costs of off-farm, nonpoint pollution efforts and policies and the effects of government programs and policies in shaping on-farm decisions that, in turn, significantly affect the attainment of goals for natural resource stewardship and environmental quality.
- Effects of technology and policy on the nutritional attributes of foods and on the health of the nation's population.
- Effects of alternative policies on the performance of a given sector or across sectors (crop producers and livestock producers, for example) in relation to such issues as profitability, environmental protection, food safety, and human health.

Diffusion of R&D Results

The private sector's focus on areas of commercial interest is related to another aspect of industrial R&D: the proprietary nature of some research results. When scientific and technological advances have prospective commercial applications, companies withhold publication of research advances as trade secrets or until they are assured of patent protection and application development.

The proprietary considerations that underlie such reticence are reasonable and likely to remain strong. Globally, food product and agricultural input industries have become more highly competitive; and a corporation's potential profitability—as well as the markets its products can realistically penetrate in the United States and abroad—will be determined by the corporation's ability to generate and use new information in product design, obtain strong patent positions in emerging areas of technology, and improve its manufacturing processes. These factors are reinforced by the trend toward greater corporate consolidation (see Appendix B).

Federal Sector

The federal government recognizes its responsibility as a major source of support for basic research. The President's budget request for fiscal year (FY) 1990 states, in the special analysis of the research components, that "even in an environment of continuing fiscal austerity, Federal support for basic research, especially at universities, is an important factor in generating new knowledge to ensure continued technological innovation. It is an essential investment in the Nation's future. The Federal government has traditionally assumed a key role in support of basic research because the private sector has insufficient incentives to invest in such research" (Office of Management and Budget, 1989, p. J-8).

As stated above, the substantial increase in support for competitive grants proposed here would apply to the entire agricultural, food, and environmental system, not to specific applications or geographic areas. That increase should therefore be funded by the federal government.

A $500 MILLION INCREASE

This proposal calls for a major expanded investment to accelerate the rate of discovery in the agricultural, food, and environmental sciences. The proposed increased investment of $500 million is justified on at least two counts: (1) agricultural research yields a high rate of return on investment, and (2) current funding for the agricultural research system cannot adequately support either the in-depth studies or the broad scope of science and technology necessary to maintain the competitiveness and sustainability of the overall agricultural, food, and environmental system.

Investing in Agriculture

Investment in agricultural research strengthens both agriculture and science because progress in agriculture and advances in science are reciprocal. Advances in science promote progress in agriculture; for ex ample, new discoveries in genetics continue to lead to crop and animal improvements through breeding. Conversely, research on agricultural problems frequently provides the model system for basic scientific discoveries; for example, work on potato diseases led to the discovery of viroids—previously unrecognized disease agents that attack humans, animals, and plants.

Public investments in agricultural, food, and environmental research are also warranted because they have a well-documented high rate of economic return. The minimum annual rate of return a private company expects from plant capacity, inventory, or other investments is 12 to 15 percent. In contrast, each public dollar (federal plus state) invested in agricultural research results in much higher returns to society through a net reduction in unit costs; for some investments, studies have shown that the returns can be as low as 45 percent and as high as 130 percent (Evenson, 1968; Evenson et al., 1979; Ruttan, 1982; Fox et al., 1987; Capalbo and Antle, 1988). Such studies derive the return to food and agricultural research by estimating the reduction in costs of consumer products made possible by efficiency gains following technological innovations. The benefits from most categories of food and agricultural technological innovations are estimated to span 20 to 30 years. Hence, annual returns compound to several multiples of the initial investment.

The public receives this return on investment in agricultural research not in the form of a dividend check but at the supermarket checkout counter and in a myriad of everyday products and activities that improve the U.S. standard of living and quality of life. In the United States, food claims a smaller share of personal consumption expenditures than it does in any other nation—just 17.4 percent in 1988 (Council of Economic Advisers, 1988, Table B-15, third-quarter estimate)—and the food is of high quality.

Public R&D investments have other benefits as well. For example, the resulting expansion of the knowledge base makes it possible to respond to consumer demands for varied and high-quality produce year-round, low-fat and low-cholesterol products, more nutritious snacks, and microwaveable products. Likewise, public R&D investment in research on resource conservation methods and food safety technologies can help accelerate the adoption of production practices that are not only sustainable and less likely to pollute the environment but that are also helpful in minimizing the chances that microbiological or chemical contaminants will create a food safety hazard.

In addition, food and agricultural research has a positive effect in terms of the distribution of wealth and quality of life among all members of society (White, 1987). Poorer families and individuals tend to spend a higher portion of their disposable income on food and pay a relatively smaller portion of income in taxes. Research and other public policies and programs lower the cost of food, and in this way they provide a proportionately greater benefit to citizens on the lower end of the income scale.

Adequacy of Funding

An annual increase of $500 million will enable the USDA's competitive grants program to meet two objectives: (1) attract new talent into agricultural, food, and environmental research and (2) expand the scope of agricultural, food, and environmental research. The size and duration of grants and the number of grants available need to be substantially increased, however, to achieve these objectives. The pool of talented scientists is large enough to put such an expanded program to good use.

Three factors determine the amount of support needed for an expanded competitive grants program: (1) the size of the average adequate grant for each grant type, (2) the average adequate duration for each grant type, and (3) the minimum funding level that is desirable for each program area and capable of allowing all six program areas to be covered. The number of grants thus derived is then evaluated for its reasonableness, given the needs of the program areas, the number of investigators funded in the current competitive grants program, and the availability of scientists to seek the grants. The analysis shows that the overall $550 million program should support the following:

- About 800 principal investigator grants for an average duration of 3 years. Total annual expenditure: $250 million.
- About 180 fundamental multidisciplinary team grants for an average duration of 4 years. Total annual expenditure: $150 million.
- About 60 mission-linked multidisciplinary team grants for an average duration of 4 years. Total annual expenditure: $100 million.
- Research-strengthening grants to institutions for programs and to individuals for fellowships. Total annual expenditure: $50 million.

Size and Duration of Grants

The grants awarded by USDA's competitive research grants program have always been characterized by inadequate size and duration. This is one reason that the full range of scientific and engineering talent in the United States has not been more involved in research on food and agricultural problems.

The average annual size of USDA competitive grant awards per principal investigator is now about $50,000—an amount too small in most instances to support research adequately. The cost of conducting food and agricultural research differs little from the cost of conducting research in other areas. In fact, expenses per investigator can be markedly higher in certain areas of food and agricultural research, in contrast to areas in which less equipment and less field experimentation are necessary. In agricultural, food, and environmental research today, as in research in other areas of science, relatively few types of studies can be adequately undertaken with a research budget of less than $100,000 per year per principal investigator. To do high-quality research on a grant of $50,000 per year, most researchers must secure additional support or in-kind contributions from other sources. Those funds are often difficult or impossible to get or may require compromises in the research plan.

Table 3.2 describes what a typical principal investigator's grant budget would be under $46,000 and $100,000 awards. Table 3.3 delineates the personnel costs under both award levels to show how limited the options are with the smaller grant: A principal investigator could afford, for example, the assistance of either a graduate student, a technician, or partial support of a postdoctoral fellow. In contrast, an award at the higher level would provide a principal investigator with sufficient funds to pay for research supplies and to support at least one graduate student, one postdoctoral research fellow, or both. This provides a key means of attracting young scientists to careers in agricultural and food science. These figures are particularly sobering since competitive grants are a major source of support for graduate students—the nation's future scientists.

A program's grants should not only be sufficient in size but they should also be large enough to compete for the attention of scientists currently working in other areas. The average size of current USDA grants—$50,000—compares unfavorably with the average sizes for National Science Foundation (NSF) and National Institutes of Health (NIH) grants, which are $69,600 and $154,900, respectively (see Table 3.4). The proposed average grant size for the expanded USDA program—$100,000 per year per investigator—makes the USDA grants not only sufficient but also competitive with NSF and NIH grants.

Table 3.2 What a USDA Competitive Grant Can Buy (in dollars per year)

Average Grant Size	Personnel	Equipment	Supplies	Travel	Publication	Miscellaneous[a]	Indirect Costs
46,000 (28,700–60,000)	23,000 (11,300–34,000)	4,600 (3,000–9,000)	5,800 (1,000–13,100)	1,100 (500–2,000)	500 (100– 600)	4,700 (1,000– 15,000)	13,200 (7,800–22,500)
100,000 (74,000–139,000)	46,000 (24,800–82,000)	11,300 (3,000–29,000)	17,000 (5,000–32,000)	1,600 (500–7,000)	800 (500– 1,200)	1,600 (500– 3,500)	27,800 (11,000–39,000)

NOTE: The sum of all budget categories adds up to more than the average size of a grant because each grant does not allocate monies to all the budget categories. Only the supplies and indirect costs categories are allocated in all grants. Values in parentheses are ranges.

[a] This category includes equipment maintenance contracts, animal care facility fees, subcontracts to outside services, etc.

SOURCE: Data are based on a review of 20 randomly selected grants and were compiled by the Competitive Research Grants Office, U.S. Department of Agriculture, Washington, D.C., 1989.

Table 3.3 Representative Personnel Expenditures under a USDA Competitive Grant (in dollars per year)

Average Grant Size	Total Personnel	Principal Investigator	Postdoctorate	Graduate Student	Undergraduate	Technician
46,000 (28,700–60,000)	23,000 (11,300–34,000)	7,800 (4,500–15,000)	23,000 (17,000–28,000)	13,000 (4,500–25,200)	3,000 (1,000– 5,000)	12,000 (2,900–21,000)
100,000 (74,000–139,000)	46,000 (24,800–82,000)	13,000 (6,000–30,000)	28,000 (20,000–61,000)	15,500 (8,000–31,000)	4,700 (1,500– 12,000)	20,800 (10,000–30,000)

NOTE: The sum of all personnel categories adds up to more than the total personnel category because each grant does not allocate monies to all the personnel categories. Values in parentheses are ranges.
SOURCE: Data are based on a review of 20 randomly selected grants and were compiled by the Competitive Research Grants Office, U.S. Department of Agriculture, Washington, D.C., 1989.

Table 3.4 Comparison of Competitive Grant Programs Administered by the U.S. Department of Agriculture, National Science Foundation, and National Institutes of Health, FY 1988

Parameter	USDA[a]	NSF[b]	NIH[c] Total	NIGMS
Number of proposals	1,466	3,586	19,205	2,709
Number of grants funded	339	683	6,212	1,044
Percentage of proposals resulting in grants	23.1%	19.0%	32.3%	38.5%
Amount requested (in millions of dollars)	$339.2	$1,096.7	$3,728.7	$461.5
Amount awarded in new grants (in millions of dollars)	$37.2	$61.5	$1,098.5	$167.4
Percentage of requested amount awarded	10.9%	5.6%	29.0%	36.0%
Average amount of new awards (in thousands of dollars/year)	$50.0	$69.6	$154.9	$156.2

[a] Data represent grants from the Competitive Research Grants Office of the Cooperative State Research Service. They do not include Forest and Rangeland Renewable Resources Program, Special Research Grants Program, or National Needs Graduate Fellowships.
[b] Data are for new awards excluding continuation payments for awards made in previous years. Combined data from three of the six divisions of the Directorate of Biological, Behavioral, and Social Sciences. Includes the Division of Biotic Systems and Resources, Division of Cellular Biosciences, and Division of Molecular Biosciences.
[c] Data represent grants to individual investigators, which are predominantly grants coded as ROI, and exclude continuation payments for awards made in previous years. Data from the National Institute of General Medical Sciences (NIGMS) are a subset in the total for all of NIH.
SOURCE: For USDA, adapted from data compiled by the Budget Office, Cooperative State Research Service. For NSF, adapted from data compiled by the Directorate of BiologicaL, Behavioral, and Social Sciences. For NIH, National Institutes of Health, Division of Research Grants. In press. NIH Data Book 1989. Washington, D.C.: National Institutes of Health.

The duration of grants is important, too, because only in a few selected areas of research can significant experimental results be attained within 1 or 2 years. Research in genetics and plant breeding that needs data from at least four or five growing seasons cannot rationally be proposed for completion within a 2-year grant period. Similarly, worthwhile projects that involve extensive field or clinical work require not only the support of skilled laboratory and field personnel but also sufficient time. Another example of research that requires a longer time frame is the effort to break through long-standing barriers to knowledge of basic plant or animal growth processes or barriers to knowledge of ecosystems for sustainable agriculture—breakthroughs that are prerequisites to developing more efficient systems of production. Still another example of research that requires a longer time frame is the pursuit of economically viable new uses of existing crops—a pursuit that may entail the application of genetic engineering techniques to develop new traits in plants, agronomic and production research and plant breeding to bring yields up to profitable levels, engineering and food processing research to develop efficient technologies for handling and converting materials, and changes in agricultural commodity and conservation policies to accommodate the needed adjustments in regional cropping patterns.

It is difficult to persuade talented scientists to invest time in preparing and conducting research programs when the time allowed for the research is too short for them to achieve meaningful results and when there is uncertainty about whether a grant will be renewed and the funding continued so that the work can be completed. It is also difficult to persuade new postdoctoral fellows to relocate if they can only be guaranteed partial support for 2 years. It is difficult, too, to conduct strong graduate-level research training programs if only short-term partial funding is available. These programs generally run at least 3—and often 4—years, but the average duration of USDA competitive grants has been 2 years (see Table 3.5). The difficulty and uncertainty connected with planning a graduate research program with only 2-year grants has discouraged many scientists and their students from applying for the short-term grants.

The best solution is the most direct one. Average

Table 3.5 Competitive Grant Funding per Principal Investigator in Agriculture, Biology, and Biomedicine, FY 1986

Sponsoring Agency	Average Grant Award (dollars)[a]	Average Award Duration (years)	Total Size of Agency Program (millions of dollars)
USDA Competitive Research Grants Office	46,200[b]	2	48.8
NSF Directorate for Biological, Behavioral, and Social Sciences	70,000[c]	2–3	248.9
DOE[d] Biological Energy Research Division	72,000	3–3.5	11.8
NIH	164,000	3–3.5	4,900.0

[a] Values given for FY 1986 awards include both direct and indirect costs.
[b] Average for all grants awarded, including forestry and small business innovation awards.
[c] Only plant biology-and biotechnology-related grants; the average grant size over the entire Directorate for Biological, Behavioral, and Social Sciences was $65,000.
[d] DOE, U.S. Department of Energy.
SOURCE: National Research Council. 1987a. Agricultural Biotechnology. Washington, D.C.: National Academy Press.

USDA competitive grants to principal investigators should be more nearly comparable in duration, as in size, to the grants made by NSF and NIH (2 to 3 and 3 to 3.5 years, respectively). This change alone will enable the USDA competitive grants program to go a long way toward attracting more top-notch, new scientific talent to the sciences basic to agriculture, food, and the environment. It is a necessary first step in meeting the research and educational challenges that lie ahead (National Research Council, 1988b).

Table 3.6 Goals for the Distribution of Funds with an Increase in the USDA Competitive Grants Program to $550 Million

Type of Grant	Goal Millions of Dollars	Percent	Average Length of Grant[a] (years)
Principal investigator	250	46	3
Fundamental multidisciplinary team	150	27	4
Mission-linked multidisciplinary team	100	18	4
Research-strengthening	50	9	3[b]

[a] Program administrators need maximum flexibility in determining the appropriate length of grants; the table shows overall averages.
[b] The size and duration of research-strengthening grants, depending on the need for fellowship or program support.

Number and Size of Grants by Type

Recent funding levels for the USDA competitive research grants program have ranged from $46.0 million in 1985 to $39.7 million in 1989 (see Table A.19), and the program has been able to award, on average, less than 400 grants each year. (See the box "Counting Grants," and for a comparison of USDA grants with those of NSF and NIH, see Table 3.4.) Each year, hundreds of technically meritorious proposals submitted to the USDA competitive grants program go unfunded, and if funding prospects were better, many more proposals would probably be submitted. Given the number of high-quality proposals, the number, size, and duration of grants in the current program for even the limited program scope are entirely too small.

Goals for the distribution of funding by type of grant should apply to the total program, not to each of the six major program areas. The awarding of funds should be governed by the creativity that scientists demonstrate in proposing to tackle problems and by the relevance of the proposals, not by a priori distributional goals. But the distribution of funds through the four types of grants would also depend, to some degree, upon the goals and priorities set for research. In a period when a major new area of science is first being explored—like plant molecular biology—principal investigator and fundamental multidisciplinary team grants will probably be the types most commonly sought and awarded. When new plant biotechnologies are being adapted and assessed for widespread commercial use, a different mix of grant types will be expected, including mission-linked multidisciplinary team grants.

The distribution of funds by grant type and across the six major program areas will also be influenced by the priorities of the executive and legislative branches of the federal government. Growing concern about both the protection of water quality and changes in global climate, for example, might lead to an increase in the funding appropriated to the natural resources and the environment program area.

Targets for the distribution of funds by type of grant are presented in Table 3.6. These are goals to strive for rather than binding rules, and they apply only to a fully funded program. The emphasis given to principal investigator grants is appropriate because scientists—indeed, scholars as a group—work particularly well in individual creative endeavors, pursuing their own interests to achieve maximum progress. In the NSF, NIH, and USDA competitive research grants programs, principal investigator grants have been, and continue to be, highly successful in advancing science, and they constitute the primary basis of research progress. They must be given a major emphasis in the expanded USDA competitive grants program.

Counting Grants

Within each fiscal year, funds are obligated to new grants, continuing grants, and supplemental funding. In counting and comparing the total number of proposals submitted, grants awarded, and grants funded, one runs the risk of mixing apples with oranges. Most grants cover a time period of more than 1 year, and a grant awarded for a 3-year period, for example, may appear in the statistics overtime either as one grant or as three grants, depending on whether it is a simple or a continuing grant. In the case of a simple grant, the full 3 years of funding are obligated in 1 fiscal year, so the grant appears only once in the statistics. But in the case of a continuing grant with incremental funding from different fiscal years, the grant counts over time as three grants, even though it went through only one competition (the first year). Supplemental funds are small additions to a grant to cover an unanticipated need to complete the research, such as the need to purchase a special instrument.

Thus, statistics on the success rate of grant applications can compare the number of proposals received and reviewed within a fiscal year with the number of new grants competitively awarded in that year, but not with the total number of grants funded during that same year. The USDA Competitive Research Grants Office makes simple grants and has few, if any, continuing grants. In contrast, both NSF and the institutes at NIH obligate roughly two-thirds of their funds to continuing grants in each fiscal year. The data presented in Table 3.4 include only proposals and grants that were competitively reviewed in FY 1988.

Assuming that a principal investigator grant represents funding for one senior scientist, a student, and a technician for 3 years; that a fundamental multidisciplinary team grant represents funding for at least two collaborating senior scientists and staff for 4 years; and that a mission-linked multidisciplinary team research grant represents funding for a team headed by four senior investigators for 4 years, then one can construct a table (see Table 3.7) showing the estimated number of grants and scientists that might be funded after the expanded competitive grants program reaches its fourth grant-cycle year. Since the size and duration of research-strengthening grants will vary depending on the need for fellowship or program support, their number is not included in the estimates in Table 3.7.

Thus, a $500 million increase added to the current appropriation of approximately $50 million would provide approximately 1,042 grants to be awarded each year, not counting research-strengthening grants. The expenditure per grant would vary from an average of $312,000 per 3-year grant for a principal investigator ($104,000 per year) to $1.6 million per 4-year mission-linked multidisciplinary team research grant ($100,000 per year per investigator). Still excluding research-strengthening grants, an estimated 4,832 principal investigators or senior scientists would be supported in any 1 year—more than five times the number under the current program (which supports about 850 scientists per year: about 425 scientists working in the first year of a 2-year grant and 425 in the second year). The more than doubling in the average annual size of grants of principal investigators would also allow the investigators to secure the help of several thousand more laboratory technicians, postdoctoral assistants, and graduate students (see Tables 3.2 and 3.3).

In comparison, NIH awards about 6,000 grants annually. These last an average of 3 years and provide about $160,000 annually per grant, generally to one principal investigator. About one-third of the proposals submitted each year to NIH result in grant awards. NSF awards about 2,200 biosciences grants each year—twice the number proposed for the expanded USDA program; about 20 percent of the proposals result in grant awards. (For comparative data for FY 1988, see Table 3.4.)

The estimates in Table 3.7 of the funding available for grants do not account for the administrative cost of the program. If the administrative cost is 3 percent, then $15.5 million must be subtracted from the award totals, removing funding equivalent to 150 investigators from the total of 4,832 researchers.

Availability of Scientists

The current pool of talented scientists is more than sufficient to ensure a strong response to the expanded program by top-quality scientists. This conclusion is based on the size of the pool of agricultural and biological scientists who are expected to be interested in the expanded program. This group is already interested in the current program, as indicated by the high proportion of proposals judged meritorious that go unfunded each year. The proposed expansion in program scope and the increased size and duration of grants should secure their interest even more. In addition, the proposed expansion will also provide for graduate assistantships and postdoctoral appointments that will maintain a continuing influx of high-quality young scientists. Comparable data for physical and social scientists and engineers cannot be examined because the scope and emphasis of the current program do not attract their attention, but it is wholly reasonable to expect them to be highly interested in the expanded program, as they are for comparable NSF and NIH programs.

As Table 3.7 shows, the estimated 1,042 grants awarded per year would support 4,832 scientists. This represents 56 percent of the 8,654 agricultural scientists working in traditional agricultural science fields, mainly at land-grant universities (Table 3.8). However, the grants will also go to scientists outside the traditional agricultural science fields, just as grants in biomedicine go to scientists both inside and outside biomedical fields. To illustrate the potential involvement of scientists outside traditional agricultural sciences, consider only the 40,416 biological scientists (see Table 3.8). If all 4,832 grants were awarded to these scientists, the USDA program would be supporting about 12 percent of them. But, of course, a mix of scientists will be supported. If the proposed program were to fund agricultural and biological scientists in the same proportions as at present (about 70 percent of the grants now go to scientists at land-grant universities), then about 3,382 agricultural scientists (about 39

Table 3.7 Estimated Number of Grants and Scientists Supported through a USDA Competitive Grants Program of $550 Million Per Year

Type of Grant	Total New Funding (in millions of dollars)	Total Award/ Grant[a] (in thousands of dollars)	Number of New Grants/ Year	Total Number of Active Grants[b]	Number of Researchers Receiving Support/Year
Principal investigator	$250	$312	800	2,400	2,400
Fundamental multidisciplinary team	150	833	180	720	1,440
Mission-linked multidisciplinary team	100	1,612	62	248	992
Research-strengthening[c]	50	NA	NA	NA	NA
Total	550		1,042	3,368	4,832

[a] Assumptions used in making calculations, in addition to the distribution of funding among grant types shown in Table 3.6, are as follows: (1) Principal investigator grants: one principal investigator per grant, $100,000 per year, average length of 3 years. (2) Fundamental multidisciplinary team grants: average of two principal investigators per grant, each at $100,000 per year; for this calculation average length is assumed to be 4 years. (3) Mission-linked multidisciplinary team grants: average of four principal investigators, each at $100,000 per year, average length of 4 years.

[b] Estimates based on the number of new grants awarded each year times the average length of grant.

[c] Research-strengthening grants would vary in size and number and are not estimated here (NA, not applicable).

percent of their total) and about 1,450 biological scientists (about 3.6 percent of their total) would be supported. In comparison, about 45 percent of the 40,416 biological scientists conducting research in 1987 received NIH grants. Therefore, the 1,042 grants awarded per year are still insufficient to fund agricultural scientists even to the level of NIH's funding of biological scientists and can involve biological scientists only to a very small extent. Thus, 1,042 grants per year should be seen, over the long term, as only a minimum number of grants for the USDA competitive grants program.

Table 3.8 Percentage of Scientists by Field at Four-Year Colleges and Universities Receiving Federal Science Agency Support, 1987

		Percent Receiving			
Field of Science[a] and Selected Disciplines within Fields	Number at Colleges/ Universities	USDA Funding	USDA Comp. Grants[b]	NSF Grants	NIH Grants
Agricultural scientists	8,654	63.3	3.2	4.8	1.6
Economics-related	1,838	68.1	NA	1.0	0
Plant biology-related	2,511	63.6	NA	6.0	1.5
Biological scientists[c]	40,416	9.5	<0.1	15.8	45.6
Agriculture-related biological	6,778	28.2	<0.2	17.6	19.2
Plant-related	1,098	48.0	NA	29.0	5.5
Environmental scientists	7,375	4.6	<0. 1	35.5	1.5
Hydrology and water resources	293	23.2	NA	27.3	0
All scientists	185,746	6.8	0.2	12.1	18.5

NOTE: NA, Not available; percentage cannot be estimated on the basis of available information.

[a] Fields of science are as defined and grouped by the 1987 Survey of Doctorate Recipients conducted for the National Science Foundation by the Office of Scientific and Engineering Personnel, National Research Council.

[b] Percentage of scientists receiving USDA competitive grants is estimated on the basis of the following assumptions: 70 percent of an average of 425 grants awarded annually are received by agricultural scientists; 30 percent of grants are awarded to agriculture-related biological scientists. These assumptions are consistent with data provided by the Competitive Research Grants Office on the distribution of USDA competitive grant awards.

[c] These are not part of the land-grant university agricultural experiment station system.

SOURCE: Compiled by Board on Agriculture, National Research Council, based on data from the National Science Foundation. 1988b. Table B-29 in Characteristics of Doctoral Scientists and Engineers in the United States. NSF Report No. 88-331. Washington, D.C.: National Science Foundation; data were also provided by the Office of Scientific and Engineering Personnel, National Research Council, derived from a special analysis of the Survey of Doctorate Recipients (1989).

SUPPORT WITH NEW MONEY

This proposal for new funding for an expanded grants program comes at a time of fiscal stringency for the United States. Yet, the needs and opportunities warrant the proposed action. This section presents three reasons for the need for new, not redirected, funding: (1) the consequences of the past 25 years of no real R&D growth for agriculture, (2) the need to retain the state-federal partnership, and (3) an evaluation of the trade-offs required by the fiscal realities.

Consequences of the Lack of R&D Growth

From 1955 through 1965, USDA research budgets grew in real terms, but from 1965 to the present, they have shown no real growth when corrected for inflation (see tables in Appendix A). Based on 1982 constant dollars, the purchasing power of USDA re search appropriations in 1965 was $788 million dollars; in 1988 it was $778 million.

Not only has funding for agricultural, food, and environmental research changed little in absolute terms during the past 25 years, but as a percentage of total federal appropriations for nondefense R&D it has also been unchanged—consistently 5 percent or less. Yet, the environment in which agriculture must operate has changed substantially. The macroeconomic conditions that affect the farmer and producer—global trade policy, the federal budget, and the value of U.S. currency—have changed a great deal. The regulatory climate is different and in flux, which increases the complexity and expense of doing business throughout the agricultural and food sector. And science and technology continue to evolve, altering farming practices, markets, the cost of inputs, and overall productivity.

The lack of real growth in the R&D sector of the agricultural, food, and environmental system has four major consequences.

First, without the prospect of a sufficient and accessible source of funds, the agricultural, food, and environmental research system will find it difficult to bring younger scientists into the system and induce them to establish research careers there. This takes on greater significance since the large cohort of highly productive scientists who have been in the system since the 1950s will soon be retiring.

Second, without growth, opportunities for graduate education and research experiences within the system cannot be maintained. Yet, graduate education is a major product of the U.S. research system. Some would even argue that it is its most important product. Educational opportunities emphasizing agricultural research are the source of the skilled talent on which agriculture depends.

Third, the no-growth condition of agricultural R&D funding has, in effect, decreased funding because simply "keeping up" requires spending more than normal inflation would suggest. This is partly because the entire character of science has changed, particularly science for agriculture and biology. Instruments, techniques, and supplies have become extremely sophisticated and accurate, as well as much more expensive, so it costs more to perform high-quality science today than it did 10 to 20 years ago. In addition, since many of the problems are now more multifaceted, more emphasis must be placed on multidisciplinary work, and this, too, has raised costs, particularly in the field-and clinic-based studies necessary to understand the complex phenomena involved in agriculture. Moreover, intensifying the consequences of no R&D growth, the price indices for research generally run ahead of normal inflation indicators, thus depressing even further the purchasing power of a grant.

Fourth, the lack of real growth in federal funding for R&D has meant that new scientific opportunities and necessary new programs have been funded through an internal redirection of federal funding, as is the case for intramural research programs within USDA. Redirection of state funds and the securing of new state funds have also occurred through interactions within the state-federal partnership in research. In a very real sense, the agricultural research sector has already been redirecting its funds.

However, new demands are being made on the research system. For example, new information and analysis are required within the regulatory environment. Much more caution and thoroughness are required in developing and using new technologies, such as biotechnology for plants and animals, than have been required for conventional plant and animal breeding in the past. And there are research questions connected to the relationship between agriculture and the environment—for example, when the environment is actually or potentially polluted by the continued use of pesticides and natural and chemical fertilizers, by agricultural and food processing wastes, and by leachates.

Thus, when viewed from a number of perspectives, the current no-growth policy in agricultural R&D is putting at risk the vitality of the entire U.S. agricultural and food enterprise.

State-Federal Partnership

The partnership between the states and the federal government in research, development, and application related to the agricultural and food sector involves both state and federal agencies and scientists. Through the state agricultural experiment stations (SAESs) and Cooperative Extension Service systems, it involves the land-grant universities, the colleges of 1890, and the Tuskegee Institute; through the Agricultural Research Service, Cooperative State Research Service, Extension Service, and, to some extent, the Economic Research Service and U.S. Forest Service, it involves USDA. The partnership is strong and well established, and one of its key elements is collaboration in research and application. This collaboration is helped by the fact that the federal government provides each state with formula funds that the state matches or exceeds. In 1988 the federal contribution of formula funds for research ($201.8 million) funded only 12 percent of the SAES research program of $1,674 million (see Tables A.14 and A.15).

States use a large portion of their total research funds to do research that is relevant to the entire nation. Although valuable, this research has been done at the expense of state responsibilities for technology development and application, for site-specific research, and for stronger linkages between research and extension. One recent example of nationally relevant research by states is biotechnology research, which many states have emphasized and which, in most instances, is fundamental research. The significance of an expanded USDA competitive grants program is that it would use federal funds to provide major necessary support for fundamental research of national value, thereby lessening some of the competition for state funds, which could then appropriately be applied, in part, to state and regional problems.

The state-federal partnership has been, and will continue to be, a key factor in converting research results, whether fundamental or applied, into technologies and knowledge that are usable by producers and processors and then, through the cooperative extension system, in getting them applied. There are no excess funds in this partnership for doing this essential job. As noted elsewhere in this proposal, if funds are taken away from the partnership or redirected to other activities—even to an expanded competitive grants program—the nation's capacity to keep research, development, and application flowing will be diminished.

Fiscal Realities

Finally, there is the matter of fiscal realities: Is funding available? Where would it come from? What are the implications of shifting funds from one program to another?

At this time of fiscal constraint, the executive and legislative branches of the federal government must reduce the national debt and at the same time set priorities among competing federal expenditures to enact programs that maintain the welfare, infrastructure, security, and continued economic growth of the United States. They must also address public concerns for maintaining global competitiveness, increasing the safety and nutritional quality of the food supply, and protecting environmental resources. The goal of simultaneously reducing expenditures and attending to essential national needs requires fiscal prudence.

Trade-Offs

Given the current era of fiscal constraints, this proposal for an increased investment in the agricultural, food, and environmental research system requires that several possible trade-offs be considered.

- The $500 million for competitive grants could come from sacrificing other USDA research programs. Can some current research programs be discontinued in an effort to strengthen competitively supported research?
- The necessary funds could be directed to research from other USDA budget categories. Commodity price supports, for example, have decreased from $26 billion to $11 billion during the past 3 years, as U.S. agricultural export prices have improved. Should $500 million of those savings and of future budgetary savings be redirected toward research, or should they be directed toward reducing the national debt, toward some combination of the two, or toward progress outside of agriculture?
- The funds could be shifted from other parts of the federal budget into USDA. Does the consistently high return on the agricultural research investment override the need for funds in other areas of national interest?
- The investment in agricultural, food, and environmental research could be deferred until deficit reduction has been achieved. But investing new funds now can hasten future economic growth and scientific benefits. What will be gained—or lost—by postponing the investment?

Redirection within the USDA Research Budget

As discussed above, the USDA research budget has not increased in real purchasing power for the past 25 years. Thus, agricultural research is already substantially underfunded, given the continuing needs and the many new needs. It follows that a redirection of funds within an appropriation that is already too small will not allow the agricultural, food, and environmental research system to address fully the challenges confronting it. However, some might argue that current funding is less than suitably used. At least three points should be made in response.

First, many observers believe that the political prospects for redirection are nil to modest.

Second, any funds derived from redirection within the USDA research budget would diminish the capacity of the research and delivery system itself. It is this very system that is responsible for capturing the results from competitively funded, formula-and state-funded, and other research, formulating them into technologies and applications and then delivering them to users. Redirection of funding would undermine not only the system's capacity for innovation but also continuing efforts to strengthen its research capabilities. Thus, taking funds from the research and delivery system would diminish it precisely when it needs to be more effective.

Third, redirection runs the risk of destroying some of the "muscle" of quality research in intramural and formula-funded research while attempting to cut out any "fat."

The proposed increase in funding for competitive research grants is justified. This proposal strongly recommends against the redirection of funds within the USDA research budget for the reasons given above. If no growth in the USDA research budget is possible, then decisions to redirect USDA's research funds are judgments that elected and other public officials may choose to evaluate.

Investment of Subsidy Savings

As U.S. agriculture gradually returns to economic health and as global commodity prices increase, the federal budget appropriations currently needed for price support programs may be released. If that occurs, part of this funding should be reinvested in research programs that can strengthen the knowledge that supports the production of agricultural commodities and the food and fiber industries of the country. Such redirection is appropriate because the research will directly benefit those commodities: the increased knowledge will be the basis on which profitability is increased and new uses for agricultural commodities are created.

Investment Using Non-USDA Funds

Beside reinvesting savings from the decreases in subsidy payments, another possibility is reinvestment from other nonresearch portions of the federal budget. This alternative may be possible, but it would require major budgetary decisions and analyses that are outside the scope of this proposal.

There is also the possibility of reinvesting other parts of the nondefense federal R&D budget into this expanded program. While possible, this would be a difficult and unreasonable thing to do at the time the nation as a whole is trying to reinvest in its research infrastructure and the federal government is committed both to doubling the NSF budget and to funding major research initiatives in relevant areas, such as the human genome project.

Investment Now

For three reasons, a $500 million increase in research funding is needed at this time. The first reason is economic, the second is scientific, and the third combines both.

First, agricultural research gives a high return on investment (see "Investing in Agriculture"' in the section "A $500 Million Increase" above), and the high return strongly confirms the economic value for the nation of investing in agricultural and related research. In addition, investment in the environmental component of the system will have a substantial direct monetary value as less expensive and more effective environmental management systems are used (involving more effective, less environmentally problematic fertilizers, insecticides, and herbicides and their integrated systems). Furthermore, money spent ensuring environmental quality for the agricultural and food system will keep problems from building and will thus save on future remedial costs.

A second reason for increasing research funding by $500 million now is the combination of existing program needs and scientific opportunities applicable to agriculture: Increased funding can be used to major advantage. The necessary scientific talent—in the physical, biological, engineering, and social sciences as well as in agriculture and related disciplines—is also available and ready to compete for this new funding. Moreover, USDA has shown that it can professionally administer and manage a competitive grants program.

The third reason that this substantial increase should be enacted in a single year is a reflection of the broadened scope of agricultural, food, and environmental research and of the importance of sustained agricultural advancement for the U.S. economy. The agribusiness complex contributes an estimated 18 percent of the gross national product (Harrington et al., 1986). Farming itself accounts for 2 percent; the "upstream" industries that supply farming equipment, feed, seed, fertilizers, and financing account for about 2 percent; and the "downstream" industries that retail, transport, process, and manufacture products from the commodities supplied by farms account for the remaining 14 percent. In addition, the ties between farming and its linked industries continue to increase because the value added to agricultural products beyond the farm continues to increase. For example, the activity in "downstream" industries, corrected for inflation, doubled from 1960 to 1980.

In 1987 the U.S. gross national product was $4.5 trillion (Council of Economic Advisers, 1989). The 18 percent contributed by the agribusiness complex would be roughly $815 billion. This means that the estimated $1.04 billion in 1990 federal obligations for agricultural R&D (Office of Management and Budget, 1989) represents a research investment of less than 0.13 percent of agriculture's annual contribution to the gross national product. In light of the value of the agricultural complex to the U.S. economy, a major investment in research seems appropriate. The increase will thus provide substantial economic benefits for the nation.

Given the overall fiscal problems facing the nation, the appropriation of the full $500 million increase may not be possible in 1 year. Even so, a commitment of this magnitude is essential, and any stepwise increase in funding should reach the full increased amount as soon as possible, preferably within 3 years. The actions taken by the federal government should also firmly state the goal of increasing the investment in research through competitive grants.

A CENTRAL ROLE FOR USDA

The competitive grants program proposed here should be the responsibility of USDA. The specific organizational environment for the proposed expanded program within USDA is analyzed in Chapter 6. This section discusses some of the reasons for locating the program in USDA and then surveys the kinds of links the expanded program could be expected to have with the Agricultural Research Service (ARS), the SAESs, the Cooperative Extension Service (CES) system, and other federal agencies.

First, the expanded program should be placed in USDA because the U.S. Congress has designated it as the federal agency responsible for advancing the agricultural sciences and developing technology applicable to food, fiber, and forest product industries and for responding to issues—such as environmental concerns—related to the production and processing sectors. The department has special responsibilities and expertise in agricultural production, food safety, environmental protection, and human nutrition. Its mission agencies and programs focus on conserving resources, tracking nutritional status, enforcing quality standards and grades for food and forest products, guarding against the spread of disease, managing forests and wildlife, and helping marketing systems work more efficiently. The department administers several programs that develop new knowledge and technology and other programs that help refine technology and transfer it into widespread use.

Second, USDA has responsibility for the national laboratories for agricultural research (ARS), for federal agricultural regulatory and economic analytical services, and—in cooperation with the states—for the network and capacity for transferring technology to productive use. That network includes the ARS, the SAESs, and CES. It also extends outward to other federal agencies.

Third, USDA has proved itself able to manage a competitive grants program characterized by high quality, timeliness, and professionalism.

Linkages with ARS

The mission of ARS is to develop, refine, and adapt science and technology to advance USDA's basic goals. Well over half of the federal government's current investment in food and agricultural R&D goes to support ARS research—basic, applied, and multidisciplinary. Ongoing ARS programs correspond closely to the proposed six major program areas.

ARS scientists can participate in the expanded competitive grants program by applying for grants, by identifying the mission-linked research needs and priorities of USDA and other federal agencies, and by serving on peer review panels. ARS scientists and engineers have experience in key engineering disciplines, instrumentation, new product and process development, natural resource stewardship, and other critical areas. Moreover, ARS scientists are among those most familiar with mission agency needs and with ongoing government regulatory, grading, and related program activities.

Linkages with State Agricultural Experiment Stations

SAESs encompass those faculty and scientists at land-grant and similarly chartered universities who are involved in the agricultural research system and who generally receive part of their support from state and federal funds appropriated to the SAESs. A major fraction of all public funding for research on agriculture and food is spent through the SAESs, and the combined state and federal support for the SAESs is approximately three times the federal support for ARS (see tables in Appendix A). The work of the SAESs involves basic research on fundamental biological processes, more applied work on the problems and issues confronting agricultural and food production systems, and technology development and application (aided by the CES and the private and federal sectors). Many SAES scientists have combined teaching, research, or extension appointments.

Strong collaborative relationships exist between SAES and ARS scientists throughout the country. Many ARS scientists are located at universities and may even have adjoining laboratories with their SAES colleagues.

The role of the SAESs and their participating scientists has become broader, not narrower, in recent years. They are involved not only in their traditional responsibilities in agricultural research but also in laboratory-based fundamental research such as molecular and cellular genetics, and they interact closely with non-SAES biological scientists. Concurrently, SAES scientists are also involved in the assessment and implementation of agricultural policy issues. For example, throughout the SAES, extensive work has been done to respond to issues on water quality, pesticide use, and the competitiveness of agriculture.

In addition to competing for grants from the expanded competitive grants programs, SAES scientists will have important roles to play in serving on competitive grants program advisory committees and peer review panels, defining program priorities, identifying mission-linked research issues, and reviewing multidisciplinary research proposals.

Important but sometimes ignored in the university-based agricultural research system are the scientists who are not operationally within the SAES system but who are interested in and contribute to research important to agriculture. This group includes scientists at the land-grant universities outside the colleges of agriculture, human ecology, and veterinary medicine and scientists at non-land-grant universities, both public and private. This group must be seen as potential collaborators with USDA in developing and applying new results and technologies to the agricultural, food, and environmental system.

Linkages with the Cooperative Extension Service

The CES, assisted by the Extension Service of the USDA, brings research applications and education to users and communicates users' special needs to the research community. The CES uses a network of extension specialists and county-based agents who are supported through combinations of federal formula funds, state funds, and county or regional funds. This confederation of extension agents is unique in providing the communication and education link between users and researchers.

In an expanded competitive grants program, the CES system would have a particularly critical role in mission-linked team research projects. These projects would be multidisciplinary, would range from basic laboratory research to applied laboratory and field work, and would include a knowledge and technology transfer component. Because many SAES scientists have partial extension responsibilities, they are also well positioned to help plan and carry out both the applied research and the technology transfer components of mission-linked multidisciplinary team research.

The CES has communications networks for fostering and using new knowledge, refined technologies, and improved production methods. Extension personnel can also help recognize and pursue opportunities for partnerships between the public and private sectors and for dialogue among state and federal agency personnel, interested citizens, private organizations, and industrial leaders.

Linkages with Other Federal Agencies

There is substantial cooperation and communication between USDA research agencies and most other federal research agencies. The Joint Council for Food and Agricultural Sciences, in particular, has been helpful in fostering interagency communication about overall scientific activities and priorities, and the Users Advisory Board provides helpful analyses. An expanded USDA competitive grants program will have a more important government-wide role in advancing the science and technology capability relative to the needs of several mission agencies (e.g., the U.S. Food and Drug Administration for food safety, the U.S. Environmental Protection Agency for environmentally safe methods of pest control, and the U.S. Department of Energy for biological energy sources and waste management.). As this occurs, USDA will have more opportunities to receive input from active scientists in other agencies and to coordinate research activities and exchange research information—particularly with NSF and NIH—in the day-to-day planning and administration of competitively awarded programs.

THE ROLE OF COMPETITIVE GRANTS

Competitive grants are not the only mechanism for distributing the new $500 million allocation for research, but they are best suited to stimulating new research activity in specific areas of science. This section discusses the federal R&D funding mechanisms and covers in detail the particular advantages of competitive grants.

Federal R&D Funding Mechanisms

The federal investment in agricultural, food, and environmental research is distributed by four different funding mechanisms: intramural research conducted by USDA staff, formula funds to the SAESs, grants for special R&D initiatives, and competitive grants.

Intramural Funding

Intramural funding is the principal form of support for ARS, the U.S. Forest Service, and the Economic Research Service and provides their long-term, mission-oriented research activities with the stability that is essential for continuity of effort.

Agricultural and food research activities that require a steady effort over many years to obtain significant results are often pursued most effectively through intramural and formula funding mechanisms. Examples include long-term breeding programs that select and breed plants and animals for desirable traits over several generations, soil and water conservation research that must focus on how to stabilize land or protect water quality, and nutrition research on the effects of dietary patterns on physiological development as children move into and through adolescence and in the aging population.

In addition to long-term research projects and research studies that require extended monitoring programs, intramural funding also maintains the research talent and infrastructure necessary to respond rapidly to national or regional emergencies, such as pest outbreaks.

Formula Funding

Formula funds are federal allocations to the SAES in each state and territory. These allocations require matching state support. The formula refers to the distribution of the federal payments to each of the states and territories. Congress last revised the formula in 1955. (See Appendix A for details of the formula.)

Formula funding provides a relatively stable resource base and is an important source of support for a variety of important activities, including long-term studies; for the more applied research that helps states meet their responsibilities for food safety, nutrition, pesticide safety, and animal care and disease prevention and for assisting states working on multistate, regional problems; as well as for graduate student training.

Special Grants

Special research grants are a flexible and adaptive funding mechanism to target new resources to particularly pressing problems that are often specific to a single state or region of the country. For example, agronomic or pest problems would demand in-depth knowledge of the local or regional production practices as well as knowledge of natural resource conditions and limitations, pest pressures, and economic and policy considerations. Such problems typically demand swift action and may be only periodic. These grants generally last for a finite period of time, sometimes only 1 year, and they are usually specifically identified in the appropriations bill for USDA research.

Competitive Grants

Competitive grants are the proven and most appropriate mechanism to attract and retain people from throughout the nation's scientific community to do top-quality fundamental research and the more applied research in promising areas of science and technology. Grants are awarded on the basis of quality and technical merit, as judged by experienced scientists serving on peer review panels. The peer review process is used to select research that is both relevant and of high scientific quality. The annual cycle of proposals and awards keeps the focus on research that is at the forefront of science and technology.

Research in genetics, chemistry, economics, and applied mathematics are examples of areas that are not location-specific and in which the pursuit of agriculturally related basic research can contribute to future advances in agriculture across the nation.

Competitive grants have been used with high effectiveness by NSF and NIH. The strengths of the competitive grants funding mechanism are elaborated in a subsequent section.

FY 1988 Distribution of Funds

In FY 1988, the combined research outlays for ARS and the Cooperative State Research Service (CSRS) totaled $911.5 million. Of these outlays, $559.5 million (61 percent) went to ARS and $352 million (39 percent) went to CSRS (see Table A.5). For CSRS, FY 1988 expenditures totaled $383.5 million (see Table A.14), slightly higher than the FY 1988 budget obligations (see the box "Appropriations, Obligations, and Expenditures" in Appendix A). Of these expenditures, formula funds accounted for $201.8 million (53 percent), competitive grants $45. A million (12 percent), and special grants $51.8 million (14 percent) (see Table A.14).

The Advantages of Competitive Grants

The competitive grants mechanism is advocated in this proposal because it has three major strengths:

- Responsiveness and flexibility
- Talent and openness
- Balance among funding mechanisms

Before discussing the strengths, one should note the reservations some people have about the competitive grants mechanism. Some believe that an inordinate amount of time is required to prepare applications for competitive grants and their renewals; this burden can be particularly onerous when the duration of grants is too short, as is now the case with the USDA competitive grants program. There is also some uncertainty and anxiety about the continuity of funding, particularly at the time of renewal; some institutions try to handle this uncertainty by providing bridging support in the event that the renewal is late, insufficiently funded, or not awarded. Funding for lengthy research, such as that for long-term plant, animal, social, and ecological studies, is sometimes more difficult to secure through competitive research grants; this is usually dealt with through a combination of renewal grants and institutional support. Securing support for multidisciplinary work through competitive grants is allegedly difficult because the evaluation paradigms often come from single disciplines and the scientists on peer review panels may from single disciplines and the scientists on peer review panels may not be equally knowledgeable in all the disciplines covered by the proposal.

Some people are also concerned that competitive grant research programs avoid applied research. That concern is understandable and was unavoidable in the past because competitive grants from NSF are intended for research at the forefront of a discipline and not for mission-oriented research; and the mission of NIH competitive grants is biomedical, not agricultural, problems. In an expanded competitive grants program in USDA, the mission will be agriculture, and the distinction between basic and applied research should not be of concern. The distinction should be between high-quality and relevant research, on the one hand, and pedestrian and inappropriate research, on the other. In agricultural, food, and environmental research, many of the more interesting problems are in settings that have an applied character (such as ecosystem studies in relation to sustainable agriculture); these kinds of studies are intended to be funded under the proposed competitive grants program within USDA.

Some of the conditions noted above, such as the time required to prepare competitive grant proposals and the risk of losing continuing support, are necessary to ensure the highest quality of science. Other conditions, such as those dealing with multidisciplinary and applied research, can be suitably dealt with by new approaches like those presented in this proposal.

Notwithstanding the reservations, competitive grants are the preferred way to award the funds for the research envisioned by this proposal.

Responsiveness and Flexibility

A key strength of the competitive grants funding mechanism is responsiveness and flexibility. Responsiveness and flexibility jointly are the ability to identify and support potentially important areas of research—areas that are emerging but that have not yet been designated significant. Responsiveness means being hospitable to—and strongly encouraging—work at the forefront of an area of science.

The basis of the competitive research grants system is doing a definable piece of work within the bounds set by the grant's funds and duration. Virtually by definition, competitive grants programs have the capacity to be responsive. Future funding can be redirected without unduly disrupting previously funded research studies. Over relatively short periods the program can significantly and systematically change the emphasis on the area of research to be funded. Its commitments are for finite lengths of time and for relatively small amounts of money. Thus, such a program is less likely to get locked into supporting research whose relevance to significant problems might become marginal as advances are made elsewhere in science or as social needs or economic opportunities change. It can afford to support risky but potentially promising work and to make awards to promising but not yet fully established younger scientists.

A competitive grants program can also be responsive to changing USDA mission agency needs by making additional or new grant support available in particular program areas. Such needs can be highlighted in annual program announcements, and efforts can be made to notify the science and engineering communities of the new program areas. Notwithstanding the desire to respond to new opportunities and to change as needs dictate, frequent and extensive shifts in priorities should be avoided because continuity and stability are hallmarks of high-quality science.

A further aspect of responsiveness is the capacity to promote communication and links across scientific disciplines and between program sectors. Such communication and links are built into the administrative processes of the program at every stage. People from various disciplines and from all segments of the scientific community—academia, industry, and government—are necessarily brought together to discuss and refine program priorities, establish proposal review criteria, and serve on peer review panels. Scientists who submit grant proposals receive constructive critiques on their proposals from peer review panels and administrative staff. Even the process of developing proposals—particularly those involving multidisciplinary team research—requires considerable dialogue.

Talent and Openness

In addition to its responsiveness and flexibility, an expanded USDA competitive grants program will have the advantage of being able to attract additional scientists to the agricultural, food, and environmental system and to retain them. It will do so by expanding opportunities for scientists who are currently involved in agricultural research; by drawing productive, Proven scientists from other areas into agricultural research; by attracting and retaining new, younger scientists into agricultural research at the beginning of their careers; by removing financial and other barriers impeding women, underrepresented minorities, and disabled individuals and providing them with greater opportunities for research; and by encouraging and supporting work across all the program areas—areas in which many scientists both inside and outside agriculture are strongly interested.

An expanded competitive grants program offers an important new opportunity for top-quality scientists currently involved or interested in agricultural research to be significantly more involved. This is particularly important for—

- scientists who are involved with USDA's current program: the grants are too limited in funds and time;
- scientists working in plant biology: funding from both USDA and NSF is altogether too limited;
- scientists involved in animal-oriented studies: the biomedical programs of NIH are not applicable to their research unless the animal biology they are studying is congruent with the human and medical focus of NIH; and
- scientists wishing to study environmental, engineering, markets and trade, or social and policy issues: normal funding sources from USDA are not available for those scientists outside the ARS-CSRS research system, and for those who are already part of that system, funding is limited.

New talent will be attracted to research important to agriculture because people throughout the science and engineering communities—both new, younger scientists and established scientists—will, perhaps for the first time, seriously consider how they could participate in agricultural research and, reciprocally, how their research activities could advance the science and technology interests relevant to U.S. agriculture, food, and the environment. An illustration of this kind of successful involvement is NIH's use of competitive grants to attract and retain researchers for biomedical science. NIH grants are one of the main reasons for the exceptional advances recently made in understanding molecular and cellular genetics and in elucidating the biology of growth and development—advances that lie behind the development of the entire biotechnology industry.

The competitive grants approach is successful for biomedicine and should be equally so for agriculture. For that to occur, however, it will be necessary to make the size and length of the grants competitive with other grant forms and thereby secure the interest and commitment of researchers.

As important as attracting and retaining new talent is the need to encourage and support members of groups that have not traditionally been part of the agricultural, food, and environmental system: women, underrepresented minorities, and disabled individuals. Relative to their proportion of the general, university, or research community populations, these groups have been significantly underrepresented in the scientific disciplines involved in agriculture.

Evidence suggests that many women, members of other underrepresented groups, disabled individuals, and young scientists trained in basic science departments outside colleges of agriculture are discouraged from pursuing careers in food and agricultural scientific disciplines because of the lack of financial support in the system and, in some cases, because of their sense that greater professional challenges can be found elsewhere (National Research Council, 1988b). This proposed grants program would help significantly in addressing this need.

Thus, a competitive grants mechanism gives scientists and scholars in public and private universities, government laboratories, and not-for-profit research locations a fair and equitable chance to obtain additional support. The benefits of increased funding would be distributed widely. The openness of the competitive grants mechanisms is important for attracting top-quality scientists to agricultural research.

Balance among Funding Mechanisms

Each of the four funding mechanisms now supporting agricultural, food, and environmental research has a valuable role to play in ensuring that the vital basic (or fundamental), applied, technology development and transfer, crisis driven, and long-term forms of research are being met. Different needs are best met by different funding mechanisms. The most immediate ways of doing this are to (1) attract new talent into the research system and (2) help active scientists take greater advantage of the developments rapidly occurring across all fields of science. Both of these can best be done with competitive grants, yet the present USDA competitive grants program now awards far too few grants to fully perform the task. Moreover, at present there is marked imbalance across federal funding mechanisms (see the section "Federal R&D Funding Mechanisms" above).

In terms of total public and private support for all components of the agricultural, food, and environmental research system, competitive grants play an even more modest role. Total support for agricultural, food, and environmental R&D within ARS, CSRS, and the SAESs was about $2.2 billion in 1988, but only 2.5 percent of that was awarded competitively. (The $2.2 billion includes about $900 million from USDA and about $1.3 billion from state governments, commodity organizations, and product sales and other private sources.)

Other agencies with a strong record in advancing science and meeting national needs allocate a much larger portion of their R&D expenditures through the competitive grants mechanism: NIH allocates 83 percent and NSF allocates 90 percent (see Table 3.9). The applied, regional, and site-specific nature of many agricultural, food, and environmental research and engineering issues makes it appropriate for a considerable portion of total agricultural research funding—perhaps one-third to two-thirds, depending on the area of science—to continue moving into the system through federal and state formula funds and other noncompetitive mechanisms. The $1.2 billion in state government and private support to SAESs is outside the pool of funds that might be allocated competitively and nationally.[1]

One way to redress the imbalance is to secure more competitively awarded support for agriculture from other agencies (principally NSF and NIH). Although support from these sources has been crucially important in advancing basic science in fields key to agriculture, food, and environmental research, it is generally directed at priorities and applications other than those most critically needed to advance the agricultural and food sector. In addition, competition for these funds

Table 3.9 Research Funding by Federal Agencies Based on Type of Program Funded, FY 1987 (in thousands of dollars)

	Competetitive Research Grants		Intramural Research		Formula Research Funding		Other Noncompetitive Funding		Total
Agency	Dollars	Percent	Dollars	Percent	Dollars	Percent	Dollars	Percent	
U.S. Department of Agriculture	$55,968	55	$662,854	64	$203,210	20	$116,799	11	$1,038,831
Cooperative State Research Service	49,968[a]	15	—	—	203,210	60	83,895[b]	25	337,073
Economic Research Service	—	—	43,300	97	—	—	1,500	—	44,800
Agricultural Research Service	—	—	501,442[c]	97	—	—	16,795[d]	3	518,237
U.S. Forest Service	6,000[e]	4	118,112	85	—	—	14,609[c]	11	138,721
Department of Defense (life sciences)	165,701	55	136,44	45	—	—	—	—	302,145
U.S. Department of Energy (life sciences)	54,582	28	100,691	52	—	—	37,402	19	192,675
Department of Health and Human Services									
National Institutes of Health	4,820,822	83	888,750	15	—	—	77,007	1	5,786,579
National Science Foundation	1,247,158[f]	90	131,171[f]	10	—	—	—	—	1,378,329
Biological, Behavioral and Social Sciences	259,313[g]	100	—	—	—	—	—	—	259,313

[a] Includes higher education fellowship grants of $2,852,000.
[b] Site-specific contracts and grants for research or buildings.
[c] Includes a nutrition center operated at Tufts University (Medford, Mass.) under a $10,355,000 contract.
[d] Extramural grants and contracts.
[e] The forestry grants program is run by the Competitive Research Grants Office, Cooperative State Research Service, U.S. Department. of Agriculture.
[f] Data from National Science Foundation. 1987. Federal funds for research and development, detailed historical tables: Fiscal years 1986, 1987, and 1988. In Federal Obligations for Total Research and Development by Major Agency and Performer: Fiscal Years 1986, 1987, and 1988, Vol. 36. NSF Report 87-314. Washington, D.C.: National Science Foundation.
[g] Totals for each directorate include administrative costs. Data from National Science Foundation. 1988a. Budget Summary FY 1989. Washington, D.C.: National Science Foundation.

is increasing. Much of the knowledge and techniques discovered by scientists who received NSF and NIH grants can be applied to agricultural research. An expanded USDA grants program will increase the application of this new knowledge to address the needs of the agricultural, food, and environmental system. Reciprocally, scientific developments brought about by USDA-supported work will advance fundamental knowledge, for example, by increasing the understanding of genetic, physiological, and ecological processes.

A second way to obtain a better balance among funding mechanisms is to redirect funding currently in the intramural, formula fund, or special grants programs to competitive grants. But such redirection, as noted earlier, would likely damage the agricultural research system as a whole. Furthermore, as problems become more complex and as more rapid responses are needed to keep up with global competition, it will be essential to keep the ARS, SAES, and CES sectors as fully funded as possible, lest their ability to accept and use new knowledge, develop new technologies, and help with technology application decreases even further.

It has been suggested, for example, that USDA might allocate all its research support through a national competitive grants program. If that were done, just under one-half of total state and federal agricultural research support would be competitively awarded. But doing that would require the ARS to close and would completely eliminate formula funds and special grants. That would be a mistake. Competitive grant program expenditures should grow relative to those of the intramural, formula, and special grant funding mechanisms but should neither replace nor dwarf them.

Given the needs and opportunities, at least 35 percent of the total USDA investment in R&D should be awarded nationally through competitive grants. Although 35 percent for competitive grants is considerably lower than the percentages in NSF and NIH, it is more than seven times USDA's current level of 5 percent.

ATTENTION TO MULTIDISCIPLINARY RESEARCH

Multidisciplinary research is the term used in this proposal to describe research that combines expertise from two or more disciplines into a shared focus on a common research problem and that has an integrated plan of study. A multidisciplinary project requires research "in" the disciplines and at the same time draws research and results "from" the disciplines to form a study that integrates the disciplines and results to examine systematically the various facets as well as the totality of the problem. As used here, multidisciplinary research designates both cross-disciplinary and interdisciplinary research, even though the three terms have somewhat different meanings.

The attention given to multidisciplinary research in the proposed expanded program for agricultural, food, and environmental research is based on the premise that many of the most significant, interesting, and difficult problems—be they fundamental or mission-linked—are inherently multifaceted. Four examples illustrate the point:

- Understanding the dietary patterns appropriate for good health requires research in biochemistry, physiology, genetics, nutrition, psychology, and sociology.
- Understanding plant pathogenesis requires research in plant pathology, biochemistry, plant biology, cell biology, ecology, and population biology.
- Developing sustainable animal agricultural systems requires research in agronomy and soil science, ecology and ecosystems analysis, animal nutrition, population and community biology, economics, and other disciplines.
- Controlling the postharvest losses of crops involves a combination of the ability to resolve engineering problems in the harvesting, sorting, and refrigerating equipment and an understanding of certain aspects of plant breeding, genetics, pathology, nutrition, toxicology, and plant science; only such a combination can address crop quality, control of postharvest diseases, nutrient loss during storage, and control and detection of mycotoxins.

To realize the full potential of science and technology in agricultural, food, and environmental research, the USDA competitive grants program should direct up to 50 percent of its support to multidisciplinary research (through multidisciplinary team grants, both fundamental and mission-linked). This emphasis is meant to stimulate more multidisciplinary team research and to strongly encourage it among senior scientists.

The word team in multidisciplinary team research implies that there is more than one senior scientist or principal investigator. As described earlier in this chapter, fundamental multidisciplinary team grants are conceived of as the involvement of, on average, at least two senior scientists as principal investigators; and multidisciplinary mission-linked teams would involve about four senior scientists (see Table 3.7). But the terms team and multidisciplinary may also suggest the concept of a research center. That association is incorrect, however, because center implies a larger research group, a more permanent or long-term association, and a physical facility, whereas the multidisciplinary team grants proposed for the USDA competitive grants program are intended to go to small teams of probably two to four scientists and to extend for no longer than one grant cycle, with the possibility of one renewal. The association of multidisciplinary team with center should be avoided.

Both types of multidisciplinary grants proposed for the competitive grants program will involve multidisciplinary team research and will address fundamental science and engineering questions. The difference between them is that fundamental multidisciplinary grants should be for pioneering research at the forefront of science and engineering disciplines. Mission-linked projects should address major science and engineering questions and perform basic research on understanding the phenomena being studied. They are also to link the work with more applied problems. Examples of mission-linked projects might be research that addresses both the source of the commodity and the market for a new product by studying the enzymatic, microbiological, or genetic basis for new uses of commodity materials or by combining agronomic, economic, and ecosystem research to determine the optimum balance of components for a more sustainable and profitable crop and animal agricultural system.

The key aspect of mission-linked multidisciplinary grants—their direct connection to the more applied problems—can be facilitated, and in some cases ensured, if teams applying for grants of this type are required to include people from the applications sector. Such people could be from private industry (e.g., from a food processing company), from government (e.g., a department of agriculture or health), or from a land-grant university (e.g., from cooperative extension).

In multidisciplinary team research, the proposed research can be carried out only with the full interaction and integration of the combined expertise and talents of the members of the team. If the proposed research can be conducted by the team members separately, it does not qualify as multidisciplinary team research.

Multidisciplinary team research presents a number of conceptual and practical difficulties. Chief among them are issues of leadership, management, coordination, rewards, and satisfaction. Scientific problems—and their relation to new research findings—evolve continuously, sometimes rapidly, and keeping up requires good coordination and the ability to change research plans expeditiously, as necessary. In addition, integrating the work of several researchers, even those with a common plan of study, constitutes a personal, managerial, and leadership challenge to principal investigators; when there are several principal investigators, coordination, discussion, and agreement usually take more care and time than when the research is directed by a single principal investigator. Then, too, rewards, advancement, and satisfaction within the profession and within the university environment, and sometimes within the industrial or governmental environment, have traditionally been based on work done individually, not that done as part of a team. All of these difficulties together constitute a management and leadership challenge for an institution, and resolving the difficulties is essential for the long-term success of multidisciplinary team research.

Granting agencies have customarily awarded grants to single investigators within one scientific discipline; thus, the reviewing mechanisms are generally set up on a disciplinary basis. Involving reviewers from several rather different disciplines is considerably more difficult. Reviewers must give careful consideration to the composition of the research team; the quality and creativity of the scientific approaches being proposed; the extent of direct working involvement by the appropriate individuals, agencies, and institutions; and the ability to manage the project effectively. For the granting agency, managing the review of multidisciplinary team grants is exceptionally important. Some of the management issues are discussed in Chapter 6.

Notwithstanding the difficulties, multidisciplinary research is clearly worth doing because of the multifaceted nature of the problems—both the fundamental and the more applied problems that are common in the agricultural, food, and environmental system. It is also worthwhile because of the unexpected synergism and creativity that good collaboration may generate.

STRENGTHEN INSTITUTIONS AND HUMAN RESOURCES

The proposed research-strengthening grants have two goals: (1) to help institutions and academic departments develop competitive research programs in areas of research important to their regions and (2) to attract more talented young scientists and engineers into careers in high-priority areas of national need in the agricultural, food, and environmental sciences. Thus, two types of research-strengthening grants would be offered:

1. grants to institutions and academic departments and programs to strengthen the capacity and competitiveness of their research in areas significant to their region; and
2. fellowships to broaden and strengthen the human resources in the agricultural, food, and environmental system.

Grants to institutions, departments, and programs would be for research program development, retraining, and instrumentation (but not for buildings and capital expenditures). These grants would be targeted at institutions that aspire —but are currently unable—to develop nationally competitive proposals to submit to federal funding agencies. Many agricultural, food, and environmental issues are unique to certain regions; so the whole system—land-grant universities, state colleges, and private universities—will become stronger and more responsive as a broader array of institutions attain the capacity to compete for grants on a national basis. These grants would thus help overcome the geographic and institutional unevenness in the nation's ability to pursue research and technology development. NSF's Experimental Program to Stimulate Competitive Research initiative could serve as a good model.

In some cases, the need for a research-strengthening grant will be revealed when reviewers identify specific weaknesses or constraints in a grant proposal. A proposal may go unfunded, for example, because investigators either lack access to a certain instrument or research method or have inadequate experience in using it. Or an investigator or research team may not display enough familiarity with related scientific developments or with multidisciplinary research. In such cases, a research-strengthening grant could prove to be appropriate and constructive support.

Fellowship support would be for both graduate and postdoctoral research studies. These fellowship opportunities would supplement, not replace, USDA's successful and nationally competitive higher education fellowship programs (National Research Council, 1989c).

NOTE

1. In virtually all of the states there are systems of peer review for allocating state and industrial support. Further, some of the SAES use internal competitive grants programs to allocate portions of their state and industrial support.

4

Challenges Facing the Research System

As U.S. agriculture continues its impressive record of production and productivity, it also confronts a number of troubling issues. Chief among them are competitiveness in the United States and abroad and the overall economic performance of the agricultural and food sector, human health and well-being, and natural resources stewardship. In particular, competitive and other pressures must be met or the agricultural sector will contribute less than its full potential to the nation's economic performance. Consumers in the marketplace and the public, through the political process, demand that the U.S. food system provides increasingly nutritious and convenient foods without raising prices. And public concern about the environment—water quality; preservation of forest and wildlife habitats; and the sustainability of current agricultural, rangeland, and forestland production practices—is leading to new conservation and regulatory policies.

Although the issues of competitiveness and economic performance, human health and well-being, and natural resources stewardship have always been on agriculture's agenda, their growing magnitude, coupled with the public's increasing concern about them, gives each one a new urgency. This chapter surveys these three issues. It is based on assessments of research and development (R&D) needs and priorities that have been undertaken by the Board on Agriculture of the National Research Council, by institutional components of the research system (see Appendix D), and by professional societies.

COMPETITIVENESS AND ECONOMIC PERFORMANCE

Competitiveness is the need to progressively reduce costs per unit of production while improving the consistency, quality, and value of products; to expand markets; and to add value to increase profitability (see the box "Productivity"). Although economic policy plays a role in helping the nation's agricultural and food sector be competitive, the key determinant of national agricultural competitiveness is science and technology through R&D.

In the United States, competitiveness is intensified by three major trends:

1. Many countries, including some developed and most developing nations, are gaining the capacity to expand production or lower per-unit costs for agricultural products.
2. Channels of trade are becoming progressively more open, so that competitive prices and quality are becoming more important.
3. To the extent that U.S. agriculture is coupled with sufficient R&D, it has the continuing capacity to strengthen the United States economically—both to reduce the budget and trade deficits, and to improve the U.S. balance of trade.

The competitiveness and the economic performance of the U.S. agricultural and food sector are discussed in this chapter in two broad contexts, each of which is of major importance: (1) sustaining and expanding international agricultural trade and markets, and (2) ensuring strong national economic performance from agriculture.

International Agricultural Trade and Markets

The 1970s were characterized by explosive growth in agricultural trade. The United States was a major participant in and beneficiary of that growth. The 1980s have been characterized by stagnant or declining trade, and U.S. agriculture has suffered. The experience of the last two decades underlies three major trends that have and will continue to provide the context within which U.S. agriculture operates: (1) the U.S. agricultural economy is becoming internationalized. and integrated into the world agricultural economy; (2) the U.S. agricultural sector and other sectors of the national and international economies are increasingly interdependent; and (3) domestic and international markets are increasingly unstable.

Productivity

Productivity, as defined by economists, differs significantly from production, as defined by physical scientists or economists. The harvested yield of corn from an acre of land, for example, is a measure of the production from that acre (whether measured in dollars [output times price] or in physical units [bushels, pounds, kilograms]). Production, as a measure of the output harvested or obtained from a unit area (or geographic region) or from a single animal or a given herd, is relatively one-dimensional. In contrast, the productivity of a certain unit area of land or of certain animals is a multidimensional measure, expressed as a ratio. It measures the combined monetary value of all outputs from a production activity (grain, stover, meat, manure) in relation to the total monetary costs of conducting the activities (all cash production costs, land rental, depreciation, interest, etc.).

In the short term, there can be too much production, but there can never be too much productivity. When production exceeds demand, surplus stocks tend to build, crop prices fall (lowering measures of productivity), and the cost of government farm programs tends to grow. But increased productivity, after correction for confounding factors like policy changes, generally results from real reductions in the cost of producing food and fiber products. Gains in productivity benefit society by making products available at lower costs to the consumer than would otherwise be the case, at a higher profit to the producer or processor, or both.

In the 1980s U.S. agriculture suffered from too much production, largely because global demand declined (in response to macroeconomic adjustments and a worldwide recession). As a result, crop and land values fell and farmers tried to cut production costs in a variety of ways. Many farmers succeeded in reducing costs and are now operating more efficiently, i.e., more productively. Over the long term, their productivity will also rise, and higher profits should result.

Increased internationalization, interdependence, and instability have had major effects on the economic performance of U.S. producers and processors and on the nation's economic condition. They are closely linked and require joint treatment if U.S. agriculture is to adjust and thrive in the global economy (Experiment Station Committee on Organization and Policy, 1984, U.S. General Accounting Office, 1987).

Policy Context

U.S. agriculture became irreversibly internationalized in the 1970s as the sector expanded its exports to world markets at unprecedented rates. The foreign exchange earned by the agricultural trade surplus paid for imports of petroleum, raw materials, and consumer goods. In the 1980s, this was reversed. Agricultural exports and farm prices declined substantially, causing serious problems and loss of income for U.S. agriculture. Falling prices, rising stocks, and bankruptcies caused government expenditures for farm programs to increase sharply. Concurrently, imports of various commodities and foods have significantly increased in recent years, and much imported produce is now competing with domestic produce.

Integration into the global economy means that foreign markets are now centrally important to U.S. agriculture and that its economic health depends on continued strong export demand.

Changes in international demand for U.S. agricultural products result from many variables: growth in income and demand in developing countries, lagging production in many areas of Africa and Asia, changes in policy in centrally planned economies, changes in currency values, and policies of major foreign competitors. As more countries compete in agricultural trade and as the volumes of trade have risen, international markets have become more complex. Thus, understanding the international dimensions of agricultural development and trade are essential if U.S. agriculture is to thrive. For example, detailed knowledge of future growth in demand and of its implications for agricultural imports and exports is key to establishing a national strategy for agricultural exports.

Integration of the agricultural sector into the international economy and the sector's greater reliance on the nonagricultural sector for inputs and markets mean that agriculture (and policies specific to it) is less in control of its own destiny than at any time in the past. This interdependence between the agricultural sector and other sectors of the U.S. economy is illustrated by the export of major commodities, such as wheat, corn, and soybeans, that make strongly positive contributions to the U.S. balance of trade. Conversely, for livestock products—lamb, pork, beef, and dairy products—the United States is a net importer. Reversing this negative balance for livestock products should be a major target of innovation and technology development, which is dependent on strong R&D investment.

Agriculture is becoming more dependent on other sectors of the economy at the same time it is becoming (as a percentage) a decreasing—albeit still very important—part of the overall U.S. economy. This increased interdependence makes it important to conduct research that gives a clearer understanding of the broader environment of U.S. agriculture: its long-term comparative advantage, the variables influencing its competitiveness, and the effects of macroeconomic policies.

Domestic and international markets are also increasingly unstable. This derives from normal biological or physical events and from policy instability that, in turn, results from domestic interventions. This instability is illustrated by the changes in U.S. agricultural exports from the 1970s to the 1980s, as described above. There are several important causes for this: the global recession in the 1980s following growth in the 1970s, entry into the international market of countries previously not involved in it (such as the Soviet Union in 1972 and 1973), creation of trade barriers to insulate domestic economies from international conditions, and monetary instability. Responding to instability within the context of internationalization and interdependency requires, at a minimum, a better understanding of the agricultural conditions inside other countries so that U.S. agricultural policy can adjust to those conditions. This ensures that economic policies—such as tariffs, trade barriers, support mechanisms, and money supply and value—can be evaluated in relation to the desired vitality of the agricultural sector.

Thus, policies cannot be pursued in isolation but must be seen in context. International negotiations under the General Agreement on Tariffs and Trade (GATT), for example, require that domestic policies be discussed in an international forum. On the domestic front, expenditures to stabilize farm income, which are valuable in the short term, may have a major effect on the long-term performance of agriculture because, with a fixed budget, as at present, such expenses preclude long-term investments in R&D that have traditionally ensured a strong economic future. (The rise of support and stabilization payments from $3.5 billion in 1980 to $29.6 billion in 1986 left little room for real increases in the U.S. Department of Agriculture's [USDA's] R&D budget.)

Therefore, considering the three trends toward internationalization, interdependence, and instability, it is important to address competitiveness and economic performance in a much broader international and national economic context than has traditionally been the case for individual commodity programs.

Issues

Some have argued that U.S. agriculture has lost its inherent competitiveness. The more optimistic, and probably more realistic, view is that U.S. agriculture is, inherently, still highly competitive globally but that monetary policy and the continuously changing value of the dollar are masking that competitiveness and that inward-looking domestic policies in other countries are distorting international markets.

Three issues are central to sustained competitiveness and economic performance: (1) evaluating the competitive position of U.S. agriculture in terms of long-term comparative advantage; (2) recognizing that adding value to commodities and products is a key to competitiveness, as rising incomes shift patterns of domestic and international demand (the need to add value puts a premium on success in technological innovation and application); and (3) understanding that macroeconomic policies, probably well outside the agricultural sector, have a major effect on the vitality of agriculture.

First, international competitiveness needs to be viewed as a matter of comparative advantage over the long term, not just as a short-term issue based on current prices and short-term policies. For example, the traditional advantage of the United States has been its bounteous endowment of high-quality farmland, coupled with early advantages from the use of petroleum for power and as a base for agrichemicals, early technological innovativeness, and a highly effective R&D system for agriculture and food. Now, however, much of that advantage has disappeared or is disappearing: petroleum-powered equipment and agrichemicals are used throughout the world, energy prices are no longer advantageously low in the United States, technological innovation is now international, and although the U.S. agricultural sector has been effective at exploiting technologies that use the land, it has not been nearly so good at adding value to agricultural products. But innovation and technological development can continue to give the United States major advantages for the major crops it produces efficiently as well as for crops that are more specialized. In fact, investment in agricultural and food R&D is especially important for U.S. competitiveness because other nations are continuing to expand their national commitments to agricultural R&D, whereas the United States and some other countries are not. (Global trends in research expenditures have been assessed in a speech by William R. Furtick, Director for Food and Agriculture, U.S. Agency for International Development, entitled "International Dimension for the U.S. Agricultural Research Agenda" [Furtick, 1989]. A comprehensive data set on research investments around the world has been prepared by Pardey and Roseboom [1989].)

Second, in some countries value-added exports are as high as 74 percent of total agricultural exports, whereas in the United States they are only about 30 percent. For comparative advantage in adding value, research and technology development and application are essential. The United States has been deficient in these areas in recent years, however. Will agriculture continue to be deficient relative to the innovation-oriented advances other countries are making?

For research to be used as a tool to strengthen international competitiveness and help make U.S. agriculture successful in the global market, two divergent trends must be reconciled, or at least understood. First, a global information network is now coupled with an increasing technological and innovative capacity throughout the world, and it is less possible than it once was to establish a market niche simply through production efficiency. Furthermore, market advantages resulting from superior technology are more difficult to establish because the innovation derived from knowledge that is available to all is now within the reach of all countries. The second trend is the private sector's increased investment in proprietary research, which attempts to keep results out of the public domain. This privatization now makes technology a private good that one purchases as an input, rather than a public good available as knowledge usable by all.

The third issue central to competitiveness and economic performance is that a variety of macroeconomic policy issues affect agricultural trade: monetary policy, the value of national currencies, monetary instability, and trade and tariff agreements.

In research terms, competitiveness in international agricultural trade faces some of the following challenges:

- narrowing the nation's trade deficit by improving export competitiveness and expanding export demand;
- stimulating global economic and trade growth, including a reduction in trade barriers;
- reconciling national agricultural policies with the international mix of agricultural policies, thereby establishing the strategy of flexibility in setting policies;
- assessing the effect that changes in economic and technical factors and in resource endowments have on import demand, availability of export supplies, and comparative advantage in agricultural production;
- identifying and analyzing monetary linkages among countries; assessing the implications of monetary phenomena for trade flows; and understanding the functioning of financial, commodity, and international capital markets;
- understanding the trade-offs and linkages between domestic agricultural and trade policies and removing distorting policies;
- assessing and evaluating trade and the implications of restrictive trade policies and practices in terms of who gains and who loses;
- identifying the characteristics of international markets that discourage or encourage U.S. entry into them;
- identifying economic and technological strategies for entering and staying in international markets; and
- developing cost-effective technological and management strategies for allaying potentially detrimental trade effects resulting from the quality of U.S. Exports.

National Economic Performance

Inasmuch as agriculture has become internationalized and is dependent on other sectors, it does not stand alone as a sector of the national economy. It is a demand-driven industry, both in its sales through international trade and in the types and amounts of value-added products it supplies domestic consumers. The future vitality of U.S. agriculture will depend partly on its international competitiveness and performance and partly on domestic performance and demands.

Domestically, both increasing household income and changing demographic patterns—such as the increasing proportion of two-employee households, the increasing use of convenience foods, and changing ethnic food preferences (National Research Council, 1988a)—will affect purchases in major ways. In addition, social and environmental constraints, such as concerns for food safety and environmental quality, will affect the economic performance of agriculture.

There are four areas that affect national economic performance, that are the responsibility of the U.S. agricultural industry itself, and that have immediate implications for agricultural R&D: (1) the effects of policy, (2) developing new uses and markets, (3) developing value-added products, and (4) reducing producer and processor costs.

Needing and Using Policy

Government programs and policies are a major influence on the performance of the agricultural, food, and environmental system. As noted above in the discussion on international markets and trade, major changes in monetary, trade, and technology policies have complicated U.S. agriculture; these policy issues apply domestically as well. For example, in the 1980s the direct annual cost of government farm programs and policies to the U.S. Treasury and the indirect costs to producers and the private sector of the economy reached unprecedented proportions. The need for policy reform was recognized in the early 1980s, and several major policy changes were incorporated into the 1985 omnibus 5-year farm bill (the Food Security Act of 1985). A consensus is growing that additional policy reform will be needed to allow U.S. agriculture to take greater advantage of its inherent strengths in natural resources, human talent, technology, and marketing.

Developing New Uses and Markets for Agricultural and Forest Products

The production capacity of U.S. agriculture and forestry is strong. It is therefore reasonable to look to that capacity to produce more goods for the country. Such a strategy would use a national resource—agriculture and its land base—as national assets. But doing so requires the development of new products and markets, which requires R&D of a type and amount that has not been done in the past. For example, biotechnology promises to produce more disease-resistant plants, and computer systems and biosensors promise to bring about greater production efficiency to the food processing industry and a higher quality of food. More specifically, biodegradable plastics should be developed more readily, and the use of ethanol as a viable oxygenated fuel should be brought closer to economic reality. This would be of major economic value for agriculture (additional profit centers and reduction in surplus commodities) and would meet major environmental objectives (less solid waste and cleaner air).

Another approach would be to shift to new or different crops that could be of value. A recent example is the use of oil from rapeseed. Rapeseed oil has major health and nutrient advantages because of its high proportion of unsaturated fatty acids, permitting it to be substituted for the traditional, more highly hydrogenated oils. Development of varieties of rape-seed that can be produced on large acreages in the United States will provide a new production opportunity to U.S. producers and be a boon to consumers seeking healthier dietary patterns.

Developing Value-Added Products

The value of the entire agricultural and food enterprise is about 18 percent of the nation's gross national product (GNP) (Harrington et al., 1986). Thus, adding value to agricultural products can have a significant effect on a major sector of the economy. Although the production sector is only about 2 percent of GNP, adding value would have a major positive effect on producers because the value-added component would expand the demand for high-quality agricultural products. Adding value would likely have major benefits for the consumer as well.

Product diversification, new processes, and convenience packaging are all value-added activities that respond to changing consumer demands in a society that, domestically and internationally, is increasingly affluent. For example, the California almond industry has recently focused on adding value to its crop through new products and has gained major new markets, bringing economic success for all parts of the almond industry.

The changing patterns of public and private technology development present complications for deciding the best approach to take. Addressing the problem seems straightforward: capitalize on the large reservoir of U.S. scientific and engineering talent and knowledge and then develop innovative technologies before others do. Selecting the most advantageous products and processes is more difficult, however. One illustrative possibility is the packaging of seeds in a fundamentally new way: Use breakthroughs in molecular and cellular genetics and tissue culture to create new plants; package the seeds or viable tissues from them with nutrients and selective pesticides into discrete, stable, and transportable biological systems; and then plant them in the usual manner. The science and technologies are becoming available for such a project, and it would give growers a major technological advantage.

Reducing Producer and Processor Costs

In addition to changes in policies for international trade and new uses, new crops, and value-added products, other changes must also be made if new R&D for the agricultural, food, and environmental sector is to be of maximum value for economic performance. New ways of doing business have the potential to reduce costs and make production systems more efficient. Specifically, better use must be made of information, resistance to change must be overcome, development should pass expeditiously into application, and societal and environmental constraints must be addressed.

Making better use of information will be especially important as the agricultural and food production systems become more dependent on more detailed and sophisticated knowledge and as the requirements of production systems increase. The use of expert decisionmaking systems for insect and disease management is one example, since pest control is based on a multifaceted integrated system. Another example is on-farm systems for making investment and expenditure decisions based on economic trends. In the political arena, information will be increasingly important in making rational resource allocation decisions that balance farmland preservation, urban expansion, amenity values, and public infrastructure investments in the face of inexorable population pressures in metropolitan areas.

Information is crucial for simultaneously maintaining farm profitability and meeting environmental conservation goals, such as preservation and stewardship of natural resources and sustaining the quality of soil and water systems for agriculture. Also needed are new analytical tools for monitoring plant and animal growth and health, determining cost-effective inputs for optimum growth, determining cost-effective agrichemical inputs, and minimizing plant and animal disease.

Overcoming resistance to change, like making better use of information, is likely to become more, not less, important. Change will permit producers and processors to be competitive with change-oriented foreign competitors. Willingness to change will be particularly important for the public—given the public's wariness of technological effects and its ambivalence toward new technologies—as R&D develops more production systems based on the results of the newer biological and technological advances. Examples include recombinant DNA technologies for improved plants and animals and automation and technological systems that make it possible to replace more labor with equipment. Willingness to change will be important for government, as permits, product approvals, and regulatory guidelines are developed and applied to new products and uses. Overcoming resistance to change, or at least dealing with it in an informed way, will be essential for U.S. agricultural competitiveness and economic performance.

Economic advantage also depends on being able to pass expeditiously from development into application with new products and processes. Much economic advantage is associated with securing market position rapidly; indeed, some businesses believe that product development and market position are substantially more important than patent protection. A recent report of the National Academy of Engineering (1989) highlighted this need:

> Recent U.S. industrial performance in global competition demonstrates clearly that other nations often do a better job of using both product and process technology for competitive advantage. The United States may be the world's greatest inventor nation, but other nations are now often better at applying technology, better at product and process engineering.

Dealing with societal and environmental constraints as part of the normal production process is also essential for optimal performance. For example, polluting production practices—such as the use of natural and chemical fertilizers that leach into groundwater supplies and pesticides that contaminate environments and produce—are increasingly identified for regulatory or remedial action. Eliminating such practices, for example, by using sustainable agricultural systems, reduces direct costs to producers and indirect costs and concern to consumers. Such changes will come about, however, only when physical, biological, and social R&D is sufficient so that the form and effects of the optimal systems can be known with precision and farmers can make informed judgments.

Challenges

The economic performance of the nation's agricultural and food sectors depends on overcoming a variety of challenges:

- determining the optimal strategies for securing comparative advantage through value-added approaches using science and technology;
- understanding the biological and physical properties of plants and animals that are most advantageously manipulated, so that economically useful new uses of major crops can be developed and additional nutrient qualities can be designed into foods;
- establishing a national strategy for proceeding from a commodity-based to a value-added agricultural and food sector;
- raising per-capita income among farmers and lessening their reliance on government payments;
- creating jobs, particularly in export-oriented, value-added industries;
- understanding personal and societal resistance to change so that a more efficacious system can be established for utilizing new information and technology;
- developing management skills and practices for reducing costs in both the producing and the processing sectors;
- developing effective R&D systems that accelerate the conversion of science and engineering results into practicable use; and
- ensuring an optimal delivery system for applying knowledge and technologies.

HUMAN HEALTH AND WELL-BEING

The health of U.S. citizens depends on the quality and quantity of the U.S. food supply and on the food choices people make. In turn, the ability to create more nutritious food largely depends on R&D in nutrition, food science and technology, and related health disciplines. Scientists must also find ways of inculcating optimal dietary habits.

Given the strong relationship between nutrition and health, improving the diet of Americans is clearly a top priority for producers, food processors, and consumers. For example, a January 1989 survey of more than 1,000 shoppers revealed that 94 percent were "somewhat concerned" or "very concerned" about the nutritional content of the foods they eat (Food Marketing Institute, 1989). The top concerns were about fat, salt, cholesterol, vitamins, minerals, and sugar. Given this concern about nutrition by so many people, it is ironic that poor health and disease in millions of Americans can often be traced to inappropriate dietary patterns, including excessive or inadequate consumption of particular macronutrients, minerals, vitamins, or dietary fiber (see Table 4.1). For example, increased energy intake, decreased energy expenditure leading to obesity, or both can be a severe problem, especially among certain segments of the population. Moreover, although the overall quality of the U.S. food supply is high, pesticide and microbiological contamination may occasionally pose risks to some consumers.

Designing Food Products for Improved Health

The nutritional and food sciences have made great strides in identifying some dietary risk factors for certain diseases (see Table 4.1) and in developing nutritionally improved food products. Still, the complex interplay among life-styles, human behavior, and changing patterns of food consumption makes it difficult to engineer adequate nutritional levels for all Americans into the food supply. Few people now consume too little protein or vitamin C, yet many continue to consume too many calories and too many saturated fats.

In certain respects, however, diets have improved somewhat during the 1980s. Table 4.2 shows the percentage of selected population groups that met nutritional targets in 1985. Among adult women, between 1977–1978 and 1985, the percentage of calories in the diet from fat declined from about 41 percent, on average, to 37 percent (see Tables 3-4 and 3-5 in National Research Council, 1988a). The percentage of people consuming less than 30 percent of their calories in the form of fat—the maximum level of fat consumption recommended by government agencies and private medical associations—increased from between 5 and 10 percent to between 12 and 15 percent in most age groups (see Tables 3-3 and 3-4 in National Research Council, 1988a).

Table 4.1 Ten Leading Causes of Death in the United States, 1987

Rank	Cause of Death	Number	Percentage of Total Death
1[a]	Heart disease	759,400	35.7
	Coronary	511,700	24.1
	Other	247,700	11.6
2[a]	Cancer	76,700	22.4
3[a]	Stroke	148,700	7.0
4[b]	Unintentional injury	92,500	4.4
	Motor vehicle	46,800	2.2
	All others	45,700	2.2
5	Chronic obstructive lung disease	78,000	3.7
6	Pneumonia and influenza	68,600	3.2
7[a]	Diabetes mellitus	37,800	1.8
8[b]	Suicide	29,600	1.4
9[b]	Chronic liver disease and cirrhosis	26,000	1.2
10[a]	Atherosclerosis	23,100	1.1
	All causes	2,125,100	100.0

[a] Cause of death in which diet plays a part.

[b] Cause of death in which excessive alcohol consumption plays a part.

SOURCE: Estimates adapted from the National Center for Health Statistics. 1988. Monthly Vital Statistics Report, VoL 37, No. 1, April 25. Washington, D.C.: National Center for Health Statistics.

Other dietary challenges remain, however, as illustrated by the problems of calcium and iron deficiencies. Calcium is important for normal body metabolism and is particularly important in the bone development of children; it is also important for the achievement of peak bone mass in adults to decrease die risk of osteoporosis. Currently, however, 25 percent of children aged 1 to 8, 58 percent of adult women, and 32 percent of adult males consume 70 percent or less of their 1980 recommended dietary allowance (RDA) of calcium (see Table 3.12 in National Research Council, 1988a).

Iron deficiency can reduce a person's energy, impair the immune response, and in children, reduce intellectual performance and development (Federation of American Societies for Experimental Biology, Life Sciences Research Office, 1984). Currently, however, 44 percent of children aged 1 to 8 and 56 percent of adult women consume 70 percent or less of the 1980 RDA for iron (see Table 3-17 in National Research Council, 1988a).

The examples of calcium and iron demonstrate the dual problem facing those who seek to modify the diet of the average American: Consumption of fat, cholesterol, and sodium should fall, whereas consumption of iron, calcium, and certain other vitamins and minerals often need to increase. Trade-offs would seem necessary because many animal food products are both part of the problem (high in fat and cholesterol) and part of the solution (high in calcium and available iron). However, in recent years the emergence of leaner cuts of meat and of many low-and nonfat dairy products has given consumers valuable new options for reducing their intake of fat and cholesterol while still getting and adequate daily allowance of essential vitamins and minerals (for a thorough discussion of the subject, see National Research Council, 1988a, 1989b).

Table 4.2 Percentage of Population Groups Meeting Nutritional Goals, Based on the 1984 1985 USDA Continuing Survey of Food Intakes by Individuals[a]

	Percent Making Goal for:			
Population Group and Age	Fat (Goal, 30% of caloxies)	Cholesterol (Goal, 300 mg/day)	Calcium (Goal, RDAs by age group)	Iron (Goal, RDAs by age group)
Children (ages 1–5)	15[b]	77[b]	48	38
Women				
19–34	13	62	NA	NA
35–50	12	62	NA	NA
All (ages 19–50)	12	62	19[c]	18[c]

NOTE: NA, Data not available.

[a] Calculations are based on 1980 RDAs. The figure for women meeting 70 percent of the 1989 RDA for iron will be slightly greater because of the decrease in that RDA.

[b] To ensure good growth in the early years of life, some authorities consider it inadvisable for children less than 2 years of age to limit fat intake to less than or equal to 30 percent of total calories. Furthermore, the desirable cholesterol intake for children less than 2 years of age has not yet been established.

[c] Calcium and iron data reported for children aged 1 to 8 and for women aged 19 to 64.

SOURCE: Calorie data are from Table 3-3, cholesterol data are from Table 3-11, calcium data am from Table 3-12, and iron data are from Table 3-17 in National Research Council. 1988a. Designing Foods: Animal Product Options in the Marketplace. Washington, D.C.: National Academy Press.

Challenges

While Americans are still advised to consume a variety of wholesome foods in moderation, there are also significant research challenges:

- determining the optimal period of time during which diets should be balanced with respect to individual nutrients;
- developing ways to identify and quantify dietary patterns over long periods as a basis for epidemiological understanding of the connection between cancer and other diseases and diet;
- developing technologies to improve foods and incentives to improve dietary patterns so they are adequate for long-term maintenance of good health;
- continuing to expand the nutrient data base of food composition and nutrient bioavailability for the food supply;
- continuing nutrition monitoring, with renewed emphasis on populations for whom little data are available (e.g., the elderly); and
- establishing agency authority for ensuring the quality of the food supply.

Food Safety

Product safety is considered a "very important" or "somewhat important" factor in food selection, as indicated by 90 percent of the respondents in a 1989 survey of 1,000 shoppers referred to above (Food Marketing Institute, 1989). Although this concern is appropriate, it is difficult for the public to evaluate risks. In some cases, even when risks are exceptionally low, public concern, is difficult to allay once it is aroused. Private industry is challenged to develop improved quality control processes; and government inspectors and regulators need more convenient, sen sitive, and timely tools and methods for monitoring and protecting the safety of the food supply.

The food safety agenda is dynamic, pushing hard at the borders of scientific detection, risk assessment, and risk management. Decisionmakers and regulatory scientists must call upon a wide range of scientific skills in defining safe, acceptable levels of pathogenic organisms, toxins, and chemical residues in food products and in determining how best to keep risks at or below safe levels. Fortunately, rapid scientific advances are making the task more manageable. For example, it is now more frequently possible to detect, trace, and avoid circumstances that lead to potentially hazardous levels of pesticide and drug residues in food or water. In addition, a powerful new biotechnology technique—the genetic fingerprinting of strains of bacteria and viruses—gives scientists a major new tool to use in foodborne disease outbreaks. With that tool, the sources of illnesses increasingly can be traced to a particular food manufacturing plant or even to a particular producer. Epidemiologists then have a much more realistic opportunity to recognize where and how to intervene to improve food safety.

Three issues are of major concern: pesticide residues, microbiological contamination, and risk assessment and management.

Pestecide Residues

Even though nonchemical methods of pest control (through expansion of sustainable agriculture and integrated pest management systems) will be use increasingly, residues of chemical pesticides will continue to be a major concern for the indefinite future.

These challenges are growing more urgent and complex for several reasons. First, new toxicological data on several dozen older pesticides are emerging and, in some cases, are raising the estimates and perceptions of risk. Second, as analytical methods of detection improve and as government agencies and the private sector monitor pesticides more intensively, pesticide residues are being detected with an increasing frequency in food and water, usually at very low levels. Third, risk assessment methods are beginning to take into account unique risk factors in certain population groups that may be more heavily exposed or susceptible to toxic agents—pregnant women, the young, the elderly, members of certain ethnic groups, farm workers, and people who have impaired immune responses or who are undergoing chemotherapy.

Challenges

- improving methods for estimating dietary risk from pesticide residues and pathogens;
- developing further incentives throughout the food system—from growers to marketers—for ensuring that pesticide residues and microbiological contamination are eliminated from the food supply;
- developing institutions and mechanisms that will provide a good understanding of the risks pertaining to the food supply;
- accelerating and intensifying the search for and development of nonchemical pest control methods, including the use of endogenous pesticides produced by the plants themselves, with the necessary genes obtained through classical breeding or recombinant DNA methods; and
- being able to communicate the concept of relative risk effectively to government officials and consumers so that informed choices can be made.

Microbiological Contamination

More than 50 percent of the 2,666 outbreaks of foodborne disease reported to the Centers for Disease Control in Atlanta, Georgia, from 1968 to 1977 were attributed to meat and poultry contamination alone (Bryan, 1980). However, the reported data are likely to represent only a small fraction of the true incidence of foodborne disease in the United States (Hauschild and Bryan, 1980; National Research Council, 1969). When a contaminated food product is widely distributed and eaten at different times and places, outbreaks may be difficult to detect. This is particularly true of diseases for which there is no epidemiological marker, so that strains recovered from infected individuals and from foods cannot be compared.

Pasteurized foods may still harbor spores that can germinate and multiply if pasteurization is insufficient. Certain pathogens, such as *Salmonella* species, *Campylobacter jejuni*, and *Clostridium perfringens,* are spread to carcasses and cuts of meat or to parts of poultry from infected tissues or contaminated surfaces of animals during slaughtering and processing. The microorganisms are then conveyed through additionally processed raw meat and poultry into food-service establishments and homes. Cross-contamination may continue and other foods may become contaminated during food preparation in home kitchens. The inappropriate use of newer methods of food preparation (i.e., microwave cooking) may also create problems;

for example, cooking times may be insufficient to deactivate foodborne pathogens.

With additional research, new technologies (some derived from biotechnology) can be applied to meat and poultry inspections and to surveillance of the food supply in general. These approaches give a means of identifying infectious agents with a high specificity that was not possible 5 to 10 years ago. Areas of investigation and application in biotechnology include recombinant DNA technology, monoclonal antibody technologies, and enzyme-linked immunosorbent assays.

Challenges

- improving the epidemiological and monitoring programs so that foodborne diseases and outbreaks can be traced;
- improving the detection systems for microbially contaminated foods, particularly meat and poultry products; and
- increasing the quality and performance of the analytical methods for risk assessment and policies for risk management.

Risk Assessment and Management

During the past two to three decades, the concerns of the public health and environmental communities have shifted dramatically, as have the public's perception and understanding of the relative importance of various types of threats to its health and safety. The political reaction to research results and to the public's heightened awareness has led to legislation on food and drugs, occupational safety and health, and the environment.

Regulatory actions are based on two processes: risk assessment and risk management. In risk assessment, the probability of potentially adverse health effects from exposure to hazards is assessed. In risk management, alternative regulatory and other actions are evaluated and a selection is made from among them, guided by risk assessment information and other considerations (National Research Council, 1983b).

A variety of scientific questions must be answered in risk assessments: Does the agent have an adverse effect? What is the relationship between dose and response? What exposures are currently experienced or expected under different conditions? What is the estimated incidence of the adverse effect in a given population?

Because of the current state of knowledge, risks projected by regulatory agencies may be derived by methods for which there is a limited means of validation. In addition, current methods of collecting information about harmful effects often rely upon postulated levels of exposure, sometimes under conditions that do not match and may be far in excess of actual environmental exposures (International Life Sciences Institute, 1987).

Challenges

- developing additional and more exact methods for evaluating risks; examples include methods to test for mutagenicity and teratogenicity using model organisms and enzymatic models and methods when the modes of action of an agent are specifically known;
- examining every facet of the agricultural, food, and environmental system to determine the most effective points of intervention to remove risks from the system;
- developing ways of removing the risk from the presence of harmful chemicals in food; and
- developing substantially more effective and timely systems for communicating actual and relative risks to those in government and industry and to the public.

NATURAL RESOURCES STEWARDSHIP

Natural resources include the living as well as nonliving components of the environment. Natural resources stewardship is the responsible and prudent caring for natural resources by the people and agencies, public and private, whose actions affect those resources directly or indirectly. Implicit in natural resources stewardship is the belief that the resources must be sustained and enhanced for the benefit of future generations.

Environmental protection by responsibly caring for natural resources is an increasingly critical economic and cultural consideration in agriculture, forestry, and other land management systems and practices. The ways in which farmers, ranchers, foresters, and other public and private landowners use and manage soil, water, wildlife, croplands, forestlands, rangelands, wetlands, parks, wildlife, and landscapes increasingly affect natural resources stewardship.

The effects of agriculture and forestry on steward-ship vary enormously across the landscapes of the United States. On much of the nation's agricultural lands, rangelands, foresdands, and parklands, effec tive resource conservation systems are commonly used. These systems sustain site productivity, control soil erosion, conserve water, improve recreational potential, and enhance wildlife habitats. In many areas of the country, however, intensity of use is greater than the carrying capacity of the land; the same land, water, wildlife, and recreational resources are claimed for competing uses; long-term sustainability conflicts with short-term profitability; and external effects such as those of farming practices on water quality, amenity values, or wildlife populations are not always adequately considered. Identifying and understanding these effects and conflicts and developing improved natural resource conservation and management systems and technologies to deal with them are key goals of natural resources stewardship. Some of the scientific and management challenges in natural resources stewardship are discussed below.

Water Quality and Quantity

Water is becoming a top resource management priority, likely taking precedence over soil erosion in the decades ahead.

The agricultural sector is the largest user of the water resources of the nation, using 104 million acre-feet per year for irrigated agriculture and 2.5 million acre-feet per year for livestock production, or 77 and 1.9 percent, respectively, of the total of approximately 135 million acre-feet used in the United States annually. In 17 western states, irrigated agriculture accounts for almost 86 percent of water consumption. Water is also an important output in the management of forestlands, parklands, and rangelands, affecting both water quality and quantity for downstream users. Thus, farmers, foresters, ranchers, and park managers all share an important responsibility for protecting water quality and conserving water quantity.

Contaminants from a variety of agricultural and forest practices negatively affect water quality, including pesticide contamination of groundwaters; accumulation of nitrates from both manure and chemical fertilizers in groundwater and surface waters; accumulation of salts in frequently irrigated lands; accumulation of toxic metals—especially selenium, cadmium, molybdenum, arsenic, and boron—in runoff and drainage waters from some irrigated lands; and sediments from soil erosion.

In addition to the specific effects of the pollutants themselves on the bodies of water into which they travel and on downstream users, there are also four management considerations. First, much of the surface water contamination results largely, if not exclusively, from nonpoint source pollution. Controlling such sources of pollution is difficult, and such pollution from agricultural and forestry practices has generally been exempt from regulation, but this may not continue. Second, groundwater contamination results from both point and nonpoint sources. Given the difficulty of controlling nonpoint sources of contamination, the long-term quality of some groundwater systems may be in doubt. Third, cross-media contamination of water sources can result from attempts to deal with pollution in other media, such as land and air. For example, leachates from solid and hazardous waste facilities can pollute groundwater, effluents into the atmosphere from urban and industrial facilities (e.g., acidic deposition and ozone) affect both watersheds and crops, and aerial deposition of toxic halogenated hydrocarbons from landfills and other sources can toxify surface waters. Fourth, to the extent that pollution worsens the quality of surface or groundwater resources, the usable quantity of water decreases.

Challenges

- developing cost-effective agricultural and forest management systems that minimize or, preferably, eliminate surface and groundwater pollution from both point and nonpoint sources;
- devising land management practices that reduce or eliminate the transport of pollutants through surface and subsurface flows and assessing the quantitative effects of such practices;
- developing methods for increasing water yields and availability while minimizing water quality degradation;
- using irrigation waters more efficiently;
- designing innovative systems for restoring water quality and preventing contamination from nonpoint sources;
- developing cost-effective remediation systems; and
- understanding the economic and social effects of possible abatement, remediation, and agricultural production strategies.

Water quantity has become a difficult issue for the agricultural sector in more and more parts of the country. The agricultural sector needs water, but so do the growing urban populations. Competition for water throughout the 48 contiguous states is increasing, and the agricultural sector is not always well positioned to compete against rapidly increasing urban pressures and demands for environmental quality.

Contamination of water supplies, including ground-water reserves, reduces the quantity of usable water. Some regions, particularly the western states, have water quantity problems because of overdrafting of aquifers. Even more seriously for some parts of the country, such as the high plains overlying the nonrechargeable Ogallala aquifer, increased pumping lifts, the associated increased pumping costs, and the longterm prospects of far less water are forcing a transition away from intensively irrigated crops. Finally, the competition between the agricultural and urban sectors for available water is becoming increasingly strong in the western states. If more of the available water continues to be shifted to the urban and industrial sectors and if users—including agricultural users—continue to be charged more of the full costs for delivering water, new crop production and water management practices must be developed to maintain profitability in the face of reduced and more costly water supplies.

Challenges

Challenges for ensuring adequate water supplies for both agricultural and urban sectors include the following:

- devising more effective and flexible institutions (e.g., laws, policies, rules, and organizations) for managing scarce water resources;
- understanding legal principles and market mechanisms and their usefulness for allocating water resources;
- devising systems of rights and entitlements that allow for adequate responses to droughts and long-term climatic changes so that both agricultural and urban sectors are sustained; and
- understanding the potential of water conservation in the agricultural and municipal sectors and developing systems and incentives for conservation.

Soil Resources

In past decades, agriculture's main goal in the area of natural resource stewardship was to control soil erosion. In the 1980s, that was USDA's main resource management priority (U.S. Department of Agriculture, 1989b). The Food Security Act of 1985 included provisions for a major new conservation program, the Conservation Reserve Program (CRP), and sodbuster and conservation compliance policies that promised to greatly reduce erosion on croplands identified as highly erodible. The 10-year CRP was estimated to entail expenditures of about $25 billion and is indicative of the nation's willingness to invest new funds in resource stewardship, even in an era of fiscal restraint.

Productive soils are lost to agriculture and forestry in the United States at an alarming rate. Four factors are involved: (1) erosion by water and wind; (2) contamination with toxic metals and persistent pesticides; (3) salinization after prolonged irrigation of croplands; (4) and permanent conversion to residential and commercial development, transportation and electricity transmission corridors, and impoundments. Soil productivity can also be lost by farming practices that compact soils, harm soil tilth, and exhaust soil fertility.

Challenges

- developing erosion prediction models that account for all forms of water and wind erosion and thus give realistic estimates of soil losses for individual events and total annual losses;
- developing realistic methods for assessing off-site effects of agricultural land use and management practices and construction, urban, and industrial operations;
- developing improved economic analyses of the costs and benefits of soil and water conservation practices;
- improving methods for reclaiming heavily disturbed lands;
- understanding the ecology of soil macro-and microorganisms, how agricultural and forestry practices modify their populations, and how beneficial consortia of organisms can be maintained;
- developing alternative cropping systems and management practices to minimize the loss and degradation of soil resources;
- increasing the use of education, regulation, and public awareness programs in altering local, state, regional, and federal policies that may favor poor land use decisions in the planning of residential expansion, transportation corridors, and reservoirs; and
- determining the societal costs of alternative land use patterns (e.g., costs for public transportation and public services).

Global Atmospheric Change

Various human activities are changing the chemical and physical climate of the earth. The combustion of fossil fuels to generate electricity, propel vehicles, and provide power to industries and residences is the largest single source of airborne pollutant chemicals that affect crops and forests. Chemicals that pollute the air include toxic gases, such as ozone, sulfur and nitrogen oxides, and fluoride. These substances are known to have negative effects on crops and forests. Other airborne chemicals include the so-called greenhouse gases, such as carbon dioxide, nitrous oxide, methane, and chlorofluorocarbons. These substances are changing the chemical climate of the earth and are said to be inducing a general warming of the earth's climate and the increasingly severe extreme weather events, such as droughts and floods.

Certain agricultural and forest practices contribute to the release of greenhouse gases. Use of paddy systems for the cultivation of rice leads to the release of nitrous oxides. Ruminant animal populations release large amounts of methane. Slash and burn techniques or the harvesting of forest trees leads to the increased accumulation of carbon dioxide in the atmosphere, which may lead to changes in photosynthesis and in the water use efficiency of crop plants and forest trees. Thus, agricultural and forestry scientists have a major contribution to make in understanding both the effects of global climatic change on agriculture and forestry and the effects of agriculture and forestry on the chemical and physical climate of the earth.

Challenges

Challenges for minimizing the effects of agriculture and forestry on climate and vice versa include the following:

- understanding more fully how forest and agricultural crops respond to changes in precipitation patterns and climatic warming;
- determining how air pollutants affect soils, plants, and microorganisms and understanding their response mechanisms to such stress factors;
- determining the role of natural emissions from vegetation in the formation of ozone and other photo-chemical oxidants; and
- determining how projected increases in carbon dioxide in the atmosphere may compensate for climate-induced losses in crop productivity and species diversity.

Biological and Genetic Diversity

Managing resources and activities to ensure biological and genetic diversity is easy to mandate but hard to do. Maintaining genetic diversity in agricultural crops is desirable in principle but hard to achieve in the face of market demands for uniformity in product quality and farmers' demands for convenient methods of raising crops. Before the goals of maintaining biological and genetic diversity can be met, many scientific questions need to be answered. What constitutes diversity? How much of it is needed? Over what areas should biological diversity be maintained? What is the role of genetics research in maintaining biological diversity? How will specific management practices affect ecosystem diversity? What are the implications for and uses of the principles of biotechnology in maintaining, expanding, and changing genetic diversity?

Challenges

- conserving and using natural genetic diversity so that new species can be found and used for beneficial purposes, such as new biocontrol systems;
- identifying genes and creating new genetic diversity by traditional and molecular genetic means;
- transferring genes to susceptible plant and animal species to create new properties, such as host resistance for biocontrol systems;
- developing methods to measure biodiversity in forest and agricultural ecosystems;
- developing methods by which indices of diversity can be included in ecosystem inventory procedures;
- expanding existing research on ecologically based systems for classification of forest sites;
- developing genetically engineered crops and forest trees that are tolerant of stress, parasites, and pathogens; and
- integrating the conservation of biodiversity, especially endangered species, with sustainable agricultural and forest production practices.

Ecosystem Structure and Function

Detailed knowledge of an ecosystem's structure and function is essential for optimum management of that ecosystem. When choosing among alternative systems, it is essential to understand the transfer and cycling of energy and nutrients through the various living and nonliving components of these systems. Empirical studies have provided data bases for various specific agricultural and forest production systems, but these information resources often are not adequate for the quantitative assessment of alternative management systems that are designed not to maximize yields per unit area of land but, rather, to achieve maximum efficiency of production over time or to meet long-term, external social and environmental objectives.

Further synthesis and integration of existing information and the synthesis of such information with the results of new, more mathematically and conceptually sound studies of ecosystem processes will help ensure that future crop and forest management systems can be economically profitable, environmentally sound, and socially acceptable.

Challenges

- developing integrated understanding of the biogeochemical cycles and nutrient cycling in agricultural and other managed ecosystems similar to the understanding of more natural systems;
- developing management systems that optimize the use of energy, water, and nutrients in agricultural and forest production ecosystems;
- developing strategies to achieve a sustainable production capacity and species diversity within ecosystems, while supporting mixtures of market and nonmarket values acceptable to society;
- understanding the mechanisms that act to limit ecosystem degradation after disturbances; and
- characterizing relationships between ecosystems—particularly terrestrial and aquatic ecosystems—so that they can be managed to meet societal goals.

Pests and Pesticides

Pests and diseases claim a large portion of global and U.S. agricultural production. To keep that percentage from going even higher, farmers now apply pesticides on most cultivated cropland in the United States. Crops in hot, humid regions of the country—particularly fresh fruits and vegetables, which must meet strict cosmetic standards—may be sprayed a dozen or more times with a variety of different crop protection chemicals.

During the past two decades, chemical control strategies have become steadily more costly in terms of economics, food safety, the environment, and public confidence. In some instances, these strategies are no longer socially sustainable.

Challenges

- understanding plant-pest interactions and natural defense mechanisms so that biological control alternatives can be developed;
- developing new technologies to reduce pesticide use and residue levels in foods;
- finding innovative ways to control pests using cultural practices—crop rotation, alternative tillage systems, mechanical cultivation, and integrated pest management; and
- developing improved applications technologies.

Progress in meeting these challenges will markedly decrease the use of pesticides, lessen the severity of water quality problems, lower the costs of pest control, and serve as a foundation for sustainable production systems.

Waste Management

A national crisis is developing over the carelessness with which waste materials are produced, handled, and disposed. As more landfills reach capacity, pressures grow for some of the waste materials—including plant and animal residues, food processing wastes, sewage and industrial sludges, and municipal solid wastes—to be applied to agricultural and forestlands.

Challenges

- developing ways to minimize and eliminate the production of wastes;
- developing technologies to increase the recycling of waste materials;
- developing better systems by which the wastes that are produced can be handled safely and disposed of by means that are economical and both ecologically and socially acceptable; and
- understanding the long-term implications for soil sustainability from the application of wastes to the land.

5

Program Areas and Scientific Opportunities

Research has played a major role in the success of U.S. and world agriculture. Advances in genetics and applied mathematics have stimulated major progress in plant breeding. Advances in microbiology have accelerated the study and control of plant diseases. Advances in endocrinology and reproductive biology have led to healthier and more productive livestock. Advances in electronics and materials science have yielded developments in agricultural engineering and food processing. Advances in computer science have transformed record-keeping and decisionmaking on many farms and throughout the agribusiness sector.

The pace of development of new scientific tools dictates a renewal and expansion of the research effort the nation commits to agriculture. The opportunities to develop and deploy new knowledge in agriculture are impressive and compelling. In particular, new multidisciplinary research will have a major impact on the future of agriculture. For example, neurobiology and insect physiology will be combined to address problems in pest control. Knowledge of photosynthesis and protein chemistry will create more efficient and environmentally safe herbicides to protect crops from aggressive weeds. Economics and management skills will be transformed by supercomputer technologies to allow farmers and merchants to make projections and shape trade decisions to meet specific needs.

Through the expanded program outlined in this proposal, the agricultural, food, and environmental research system can address the new problems confronting the United States, including international competitiveness, human health and well-being, and natural resources and the environment.

PROGRAM AREAS

The U.S. Department of Agriculture's (USDA's) Competitive Research Grants Office (CRGO) currently awards grants in three areas: (1) plant science, (2) animal science, and (3) human nutrition. These cover only a fraction of the broad program areas relevant to agriculture. Program areas are needed that would

- encompass all research challenges in the agricultural, food, and environmental system;
- encourage participation by scientists in the full range of disciplines that must be enlisted to meet the challenges within each program area;
- reflect the programmatic challenges (and the related economic, social, and environmental issues) facing state and federal government agencies; farmers and foresters; and food, fiber, and forest products industries; and
- advance scientific and problem-solving capabilities.

To bring this about, this proposal has identified the need for six major program areas: (1) plant systems; (2) animal systems; (3) nutrition, food quality, and health; (4) natural resources and the environment; (5) engineering, products, and processes; and (6) markets, trade, and policy.

Descriptions of some of the scientific opportunities that fall under the six program areas follow.

PLANT SYSTEMS

Research across the broad range of plant sciences from biochemistry to ecosystem studies will contribute to improvements in plant productivity for the 1990s and beyond. Table 5.1 lists some of the specialized research areas in plant science and gives examples of how they relate to practical and potential applications. Subsequent sections identify some examples of the research needs and opportunities for improving plant productivity.

Genetics and Diversity

The ability of plant breeders to breed crop plants and forest trees with specific desirable traits is enhanced by knowing the behavior of plant genes. Molecular biology has expanded the range and power of methods available to plant breeders. Researchers are beginning to work out detailed genetic maps for some plant species, which will be valuable for many applications. Equally important is the ability to identify specific genes as molecules—a sequence of DNA. When genes can be identified and isolated as a molecule of DNA, they can be transferred into plants by recombinant DNA techniques. In other instances, the gene might be used as a probe to find neighboring genes and to study how the plant's expression of genes is regulated.

The development of restriction fragment length polymorphisms (RFLP) and transposon tagging systems are two examples of how the technology of working with genetic traits at the molecular level has rapidly advanced. High-resolution mapping of plant genomes can now be done with RFLPs, which exploit subtle differences in the DNA sequences that can be correlated with the presence of specific genetic traits. With RFLP technology, a breeder can verify the inheritance of a trait in DNA taken from a small piece of tissue, such as a seed or seedling. This technology aids in decisionmaking, for example, by decreasing the size of a population that must be grown to maturity to test whether a trait will be expressed in mature plants. RFLP mapping is possible for any crop plant. Further refinements of this technique will do much to improve speed and accuracy in plant breeding. RFLPs can also be used to evaluate and monitor the parentage and diversity of crop varieties.

Another advance is the use of transposon tagging systems. A transposon is an easily identified sequence of DNA that is capable of infrequently "jumping" or relocating its position within the genome. In one application, if a transposon relocates by inserting itself within another gene, the insertion disrupts the expression of that gene. When expression of a trait is affected by a transposon insertion, the gene controlling that trait can be isolated, because the transposon identifies the gene. Naturally occurring transposons have been characterized in a few plant species, but recent work has demonstrated that functional transposons can be introduced into other crop plants using recombinant DNA technology. Transposons can be used in conjunction with RFLP technology to mark nearby genetic traits without disrupting gene expression.

Plant Developmental Biology

The regulation of plant development affects plant yield and plant quality. Modelers, geneticists, ecologists, and other plant scientists can identify many aspects of plant growth and structure that contribute to yield and quality. Despite this knowledge, the regulation of plant development remains poorly understood. Little is known about the genes that regulate development, the factors that control gene expression, or the specific sites in plant tissues where the genes are expressed. The regulation of plant developmental features such as branching patterns, formation of tubers or roots, the onset and termination of dormancy, induction of flowering, reproductive incompatibility, fruit development, ripening, and senescence remains to be characterized. Advances in these areas are now possible and can contribute to more powerful manipulations to improve plant performance in ways heretofore not possible.

The environmental regulation of endogenous plant hormones is an undeveloped area in terms of plant productivity and quality, despite the many empirical studies of the effects of exogenous hormones on a variety of processes associated with plant productivity. An increased understanding of hormone action could lead to the ability to grow crops and forest trees profitably under unfavorable soil or climatic conditions, or to raise the maximum economic yield. An understanding of hormone action will necessitate further research on receptors, metabolism, the mechanisms hormones use to regulate plant processes, and the mechanisms that allow the environment to influence the activity of plant hormones.

Table 5.1 Relationship between Science Areas and Practical Developments that Contribute to Plant Productivity

Scientific Areas	Areas of Practical or Potential Application
Molecular and cellular	
Gene structure	Plant breeding systems, control of plant protein synthesis
Gene expression	Nutritional quality, crop yield, pest and disease resistance
Complex genetic systems	Grafting scion and rootstock
Primary metabolism	Quality, industrial products, yield, nutritional value
Secondary metabolism	Drugs, disease resistance, pest resistance
Photosynthesis	Weed control, crop yield
Cell division	Plant architecture
Cell wall deposition	Fiber production, food texture
Signal transduction	Breeding systems, disease resistance, reproduction
Organismal	
Reproduction	Advanced breeding systems, harvest index
Florigenesis	Yield, agronomic performance, harvest index
Fruit and seed development	Yield, postharvest, seed quality
Embryogenesis (zygotic, somatic)	Seed quality, gene transfer techniques
Regulation of growth	Vigor, harvest index, yield
Germination and vigor	Stand establishment
Senescence	Postharvest quality
Heterosis	Yield
Environmental	
Stress-environmental physiology	Yield, crop loss reduction, environmental synchrony and genetic improvement
Water relations	Drought tolerance, costs of production, tolerance of wet soils and humid conditions
Soil chemistry-fertility	Yield, crop quality, environmental quality
Microbe-plant interactions	Biological nitrogen fixation, yield, more efficient use of chemical pesticides, disease resistance
Invertebrate-plant interactions	Crop management, disease prevention, pest control
Population genetics	Insect pest and pathogen control, genetic diversity
Ecology, plant-plant interactions	Weed control, disease and pest control
Systems analysis	
Operations research	Modeling of farming systems, stochastic optimization for use in decision-making aids
Resource economics	Assessment of environmental externalities, matching land use to soil and climate
Production economics	Economically optimum rates of input use

Energy, Carbon Metabolism, and Minerals

Plants are the source of many complex organic molecules used in commerce and industry. Their leaves and roots have large surface areas that absorb and accumulate resources, including solar energy, water, and minerals. Plants concentrate energy reserves and nutrients and form the foundation of the food chain for almost all life on earth. Photosynthesis converts solar energy to chemical energy, feeding the plant's metabolic machinery to produce an extensive variety of organic molecules. Energy is also used to take up mineral elements selectively and concentrate them in amounts necessary for life processes.

Studies on photosynthetic energy conversion yield insights on how to improve the effectiveness of plants in harvesting solar energy. For example, differences in carbon metabolism between C_3 plants (such as wheat and soybeans) and C_4 plants (such as corn and sugarcane) are responsible for the large differences in photosynthetic efficiency when the availability of water and carbon dioxide is limiting. Studies in plant biochemistry and carbon metabolism disclose the diversity of harvestable products that plants can produce and the pathways that regulate the partitioning of photosynthate between edible and nonedible parts of the plant.

Plant and Pest Interactions

Continued heavy dependence on chemical control of insect pests, plant pathogens, and weeds will lead to environmental and health problems as well as future pest control problems because of the establishment of pesticide-resistant pest populations and secondary pests.

Research on host-pest relationships provides the basis for more efficient, long-lasting pest control strategies. Such strategies include the use of biological control agents to attack pest populations, methods for assessing and predicting when pest damage will reach an economic threshold and when pesticide use would be most effective, and approaches for providing host plants with pest-resistant traits that can reduce the selection pressure favoring resistance.

Plants possess a broad range of genetic, structural, and chemical defenses that protect them from attack by plant pathogens and predators. Despite considerable research on plant responses to pathogens and pests, the specific mechanisms of the plant defense response are still not clear. In some cases, plant defenses appear to be analogous to general responses to many biotic, environmental, and chemical stresses, including the amount of water, the level of salinity, and the presence of heavy metals. Others are highly specific to a particular interaction. In most cases, a better understanding of the biological and genetic basis of plant resistance to pathogens will enhance scientists' abilities to control diseases without negative environmental consequences.

Ecology and Plant Populations

Farming, rangeland, and forestry practices impose major forces of change upon natural ecosystems. A better understanding and characterization of the components of different ecosystems and the factors important in stabilizing them will lead to more effective management of farmlands, rangelands, and forestlands. Study of the similarities and differences between natural and managed ecosystems will reveal the relative importances of genetic diversity; the role of beneficial and pest organisms in plant productivity; and the long-term stability of farm, range, and forest ecosystems.

Tropical ecosystems are of global concern. The enormous biological diversity that is characteristic of tropical ecosystems includes genetic traits for the synthesis of many novel compounds with biological activity for antibiotic, antiviral, pesticidal, and other chemical defense mechanisms. Those gene pools could be lost forever if tropical ecosystems are destroyed. Tropical ecosystems also play a major role in modulating global weather patterns and atmospheric conditions. As understanding evolves of the factors contributing to the so-called greenhouse effect, it is likely that tropical regions will become critical management zones.

Waste Management

The soil rhizosphere (soil near root surfaces) is a region of complex decomposition and nutrient recycling processes. It is in this zone that the activity of microorganisms and the release of minerals and nutrients play key roles in plant health and nutrition. The microbial population in the rhizosphere is large, diverse, and active. Microbes are important in the breakdown of organic matter and the release of minerals and nutrients for uptake by roots. Toxic wastes can be deactivated or decomposed by these microorganisms.

Some soil microbes are plant pathogens; some are biocontrol agents that protect plant roots from pathogens and pests. Others, such as the mycorrhizal fungi, play an important role in nutrient mobilization for plants. The potential exists for manipulation of natural soil microorganisms by genetic engineering to enhance their ability to remove toxic wastes, to use organic matter, to fix atmospheric nitrogen, and to increase disease suppression.

Plant Production Economics

New developments in plant genetics, pest control, and agronomic practices are widely implemented and accepted only if they provide farmers a clear-cut economic advantage. Economic factors are a significant component of plant productivity as global markets become more competitive and open. Research in plant production economics is needed to determine both economically optimum levels of input use and the productivity and profitability of various farming systems. Input use, productivity, and profitability are particularly important under marginal growing conditions. Economic analyses can also help identify problem areas in farming systems, for example, by evaluating the economic threshold of pesticide application to control pests. Economic analyses can be a useful step in targeting research in other areas. Research on the benefits of alternative farming and forestry systems and on the economic advantages and disadvantages of specialization or diversification of crops under different conditions is also important in formulating efficient and effective farm, conservation, and regulatory policies.

ANIMAL SYSTEMS

Research across a broad range of animal science areas from biotechnology to animal farming systems will contribute to future developments in animal productivity. Table 5.2 lists some of the specialized research areas in animal science and how they relate to practical and potential applications. The sections that follow discuss more specific examples of research needs and opportunities.

Cellular Growth and Development

Because early growth in animals often determines subsequent performance, a better understanding is needed of the developmental biology of productive tissues, including mammary glands, muscle, and fat. Research will involve studies of the biological control of homeostasis and of the state of equilibrium of the body's processes when other factors override the body's tendency to maintain a steady state (during lactation, for example).

Research on the mechanisms controlling energy and resource allocation in animal growth are also important. Future research will include genetic and nongenetic approaches to the partitioning of nutrients into various productive functions such as fetal development, muscle growth, fattening, and milk and egg production. As scientists gain a better understanding of those mechanisms, there will be new techniques to partition nutrients toward more desirable functions, such as increasing the proportion of lean to fat tissue or altering the saturated fatty acid profile of certain animal products.

A challenge to scientists working on the production and processing of animal food products is reducing the level of cholesterol or cholesterol-forming components in animal products. In the case of meat and milk, decreasing the amount of fat is clearly helpful in reducing cholesterol levels in humans.

Genetics and Reproduction

The new embryo biotechnologies of gene transfer, in vitro production, cloning, and determination of the sex of embryos have been developed and are being refined for practical use in animals. Development of efficient in vitro systems for maturing oocytes and sperm and for fertilizing and developing embryos has resulted in the commercial in vitro production of embryos. Cloning of embryos by nuclear transfer has been accomplished for sheep, cattle, pigs, and rabbits. The ability to select for males or females in sperm or embryos by using a specific antibody or other techniques could greatly improve the efficiency of many animal production systems.

Before transgenic animals of value can be developed, researchers must know which genes to introduce. Transgenic embryos or offspring have been produced from mice, rats, rabbits, chickens, fish, sheep, swine, and cattle. Genes can be targeted for expression in specific tissues, but more efficient methods and a better understanding of the genes to be transferred are needed. Researchers need to gain an understanding of the genes influencing animal growth; efficiency of growth; environmental adaptation; meat, milk, or egg composition; and animal disease resistance.

Table 5.2 Relationship between Animal Science Research Areas and Practical Developments That Contribute to Animal Production[a]

Scientific Areas	Areas of Practical or Potential Application
Molecular and cellular	
Gene expression	Production, quality, efficiency
Heterosis	Efficiency, production
Biochemistry	Efficiency, disease control
Physiology	Production, quality, efficiency
Metabolism	Efficiency, quality
Virology	Disease prevention
Immunology	Efficiency, disease control
Pharmacology	Disease control
Organizational	
Reproduction	Germplasm selection, production, efficiency
Embryology	Gene transfer and selection
Growth	Quality, efficiency
Microbiology	Disease control, forage utilization, product safety
Pathology	Disease prevention, control
Lactation physiology	Milk production, efficiency
Meat sciences	Quality, further processing, marketing
Biometry	Efficiency, selection
Environmental	
Population genetics	Breeding stock, efficiency, quality, production
Parisitology	Parasite control, efficiency
Nutrition	Disease control, production, efficiency, quality
Behavior	Animal care, efficiency, disease control
Systems analysis	
Facilities	Production, efficiency, disease control
Engineering	Sanitation, animal care, feed processing
Management	Production, efficiency, disease control
Profitability	Economic impacts of management systems, new technology

[a] Production refers to the yield of animal products such as milk, meat, eggs, and wool.

Molecular Basis of Disease

Many of the disease problems in food-producing animals do not cause premature death but do reduce productivity and efficiency. The incidence of subclinical disease (such as mastitis in dairy cows, viral pneumonia in swine, and leukosis in poultry), respiratory diseases, immune derangements (such as arthritis), and nutritional and metabolic imbalances in all classes of animals needs to be better understood and documented. Their effects on production characteristics, behavior, and genetics should be assessed.

Along with the traditional disciplines, new technologies such as those that use recombinant DNA and monoclonal antibodies now afford an opportunity to understand, detect, identify, and control many animal diseases. Diseases can be controlled by a combination of procedures, including vaccination, enhancement of the immune response, vector control, diagnosis, and therapy. New generations of antibiotics and pharmaceutical agents to increase animal productivity are on the immediate horizon. Study and characterization of infectious agents at the molecular level can lead to improvements in all these approaches to disease control. Research will likely focus on the genetics of the immune system in different animal species, the genes controlling virulence traits of diseases and parasites, and the use of hybridoma technology to develop highly specific monoclonal antibodies for use in disease treatment and diagnostic procedures.

Uses of Animal Wastes

A major area of new research will undoubtedly be in the science of waste management. Water and soil contamination from waste resulting from intensive animal production systems is the major environmental problem faced by some producers. Research directed toward the more efficient use of these wastes is critical. The nutritional value of some wastes may make them useful as animal feed, as has been done experimentally for over 25 years; other wastes should be utilized as plant nutrients. However, the safety aspects of these technologies are poorly understood, and more practical methods are needed for handling and processing wastes. Innovative methods that reduce nutrient losses when animal wastes are applied to the land will help improve the economics of waste-based nutrient sources and will emerge as key components of many future low-input, sustainable agricultural systems. Other uses of waste should be developed, including use for fermentation products and for energy-based products such as ethanol and methane. Animal wastes also have potential value for use in hydroponics and aquaculture systems.

Animal Production Systems and Economics

In animal production systems, complex interactions arise from breed selection, housing systems, the selection of feed, and disease prevention programs. These interactions greatly influence animal health and performance, the economics of production systems, and in some cases, the safety of food products. A systems approach to research is vital to take into account these interactions and to recognize their full impact on profitability following selection of technologies and other management decisions.

Two factors suggest that there is increased reliance on grass-and forage-based production systems in the beef industry. To meet nutritional goals, consumers are seeking leaner animal products. This will mean that leaner animals will be marketed at lower weights and producers will limit the time that animals spend in feedlots consuming high-energy, grain-based rations to gain weight and fat.

Emphasis in recent farm legislation on soil erosion control and cropping pattern diversification might increase the supply of available forages and thus lower the cost of feeding beef animals grass-based rations in contrast to more costly feedstuffs.

Sorting out these factors and determining how to respond to them at all stages in the industry are complicated tasks. Much improved production economics models, data, and analytical methods will be essential, as will the ability to estimate the effects of changes in government policies.

NUTRITION, FOOD QUALITY, AND HEALTH

This program area encompasses all of the topics relating to human nutrition, food quality, and human health. The relationships between nutrition and human health and among nutrition, food science, and food technology are not always clear; indeed, the research needs and opportunities are often multidisciplinary in their coverage and complexity. Nonetheless, relatively clear delineations are used in this section for purposes of illustration. Table 5.3 lists several of the scientific areas that contribute to nutrition and food science and technology and gives examples of how they relate to some practical and potential applications. All the research activities discussed in the following sections are being undertaken in rapidly changing areas of science. Interaction across disciplines is essential to ensure that scientists incorporate the latest findings and techniques from fields such as molecular biology, genetics, physiology, microbiology, biochemistry, medicine, immunology, chemical engineering, analytical chemistry, electrical engineering, agricultural engineering, economics, psychology, and other social sciences.

New Dimensions of Nutritional and Food Sciences

The "new" nutritional and food sciences continue to adhere to traditional roles as the interdisciplinary link between the composition and quality of the food supply and the effects of the food supply on the health

Table 5.3 Relationship between Scientific Areas and Practical Developments That Contribute to Optimal Nutrition, Safety, and Quality in Foods

Scientific Areas	Areas of Practical or Potential Application
Microbial genetics	Biotechnology of starter cultures and food ingredients, DNA probes
Microbial physiology and metabolism	Pathogen resistance, food fermentations, microbial control or inactivation, mechanisms of pathogenicity, food spoilage mechanisms
Immunology	DNA probes and antibody assays for pathogen or toxin detection, food constituent analyses, food allergies
Toxicology	Control of microbial pathogens and toxins; detection, removal, or neutralization of chemical and microbial contaminants
Analytical biochemistry	Rapid and automated analyses, food constituent interactions, physical and chemical properties of foods
Protein, carbohydrate, and lipid chemistry	Structure-function mechanisms related to texture, flavor and color; changes due to microbial and chemical actions; influence of physical-chemical processes on primary structure-function
Flavor chemistry	Constituents influencing normal and abnormal flavor, human responses to flavor compounds, differentiation between natural and artificial flavors, flavor stability
Physical chemistry	Interface phenomena in gels and emulsions, kinetics of food component reactions, description of primary structure of food constituents
Nutritional biochemistry	Nutrient bioavailability, nutrient stability in food processes, mechanisms of nutrient utilization at the molecular and cellular levels
Clinical nutrition	Diet-related disorders, nutritional requirements in disease, eating disorders
Epidemiology	Disease-nutrient relationships in different populations, dietary practice and changing food habits
Human physiology and metabolism	Nutrient form-efficacy, nutrition and disease interactions, diet and exercise, maternal nutrition, malnutrition, food allergies, sensory perception in normal and disease states
Pediatrics and geriatrics	Lifelong, age-related nutrient needs, lactating women and their infants, nutrition and immune response
Process engineering and control	Simulation and optimization of unit operations, processes and plants, fluid flow, particulate transfer, extrusion
Package design	Robot technology, biodegradable packaging materials, tamper-proof packaging, quality maintenance
Mass and heat transfer	Simulation of steady-and unsteady-state, semicontinuous, and continuous unit operations; ultra-high-temperature-preserved or semipreserved products
Equipment and instrumentation design	Sensors and monitoring systems, real-time sensing of quality attributes, nondestructive on-line measurements
Psychology	Analysis and development of diet-relevant behaviors

and well-being of the U.S. population. However, a revolution in the nutritional and food sciences is under way because there have never been greater opportunities for the nutritional and food sciences to take advantage of recent advances in modern biology and to contribute to the well-being of the nation's population. Mechanisms are being elucidated to identify how individual nutrients and combinations of nutrients influence genomic expression in humans, plants, and animals and how these principles are transferable between species. New connections between basic science and production agriculture are being forged. For example, the isolation and characterization of the regulation of genes that are known to limit rates of macronutrient metabolic pathways, such as the phosphoenolpyruvate carboxykinase or liproprotein lipase pathways, enable strategies and rationales to be established for preparing transgenic plants and animals with enhanced production capabilities or with more desirable nutrient compositions.

This combination of the nutritional and food sciences with advances in biology and medicine permits the establishment of multidisciplinary research teams to address the entire spectrum of needs and opportunities, ranging from long-term fundamental research (such as the molecular biology of fat metabolism and deposition) to more applied studies (such as the effects of food processing operations on nutrient availability and food digestibility in the gut) and to studies of the psychological and social factors influencing food and choice of diet.

Food Contaminants and Microbial Hazards

The Centers for Disease Control in Atlanta, Georgia, estimates that 6.5 million acute episodes of food-borne disease occur annually in the United States and that each year, more than 9,000 fatalities can be associated with foodborne diseases. Table 5.4 lists some of the causes of foodborne illness.

Although the United States enjoys perhaps the safest, most abundant food supply in the world, the potential for microbial, viral, and chemical contaminants in foods is ever present. Many genera of bacteria have been implicated as causes of foodborne disease, either as toxicants or as infectious agents. Toxins from naturally occurring fungi and molds and from other sources are well recognized. A host of viruses can be transmitted by food. As a result, there continues to be concern over potential contaminants in the food supply. This concern influences both private behavior and public policy. Part of this concern stems from the dramatically improved analytical methodologies available to regulatory agencies and the scientific community.

There is both a pressing need and a number of attractive, affordable opportunities to provide consumers with even greater margins of safety in terms of possible chemical or microbiological contamination. Improved analytical methods can be used quickly and inexpensively to identify and trace the source of microorganisms and contaminants in the food supply. DNA probes and immunoassays are two technologies that can be developed to detect viral or pathogenic microorganisms or their toxic constituents or by-products. Similarly, specific and highly sensitive analytical techniques and tools (gas and liquid chromatographies and mass spectrometry) are needed to determine more precisely the presence and fate of chemical contaminants and toxicants in raw materials and processed foods.

Basic scientific information and real-world data would enable researchers to identify factors that influence the growth and survival of microorganisms within ecological niches of food environments. For example, research could focus on how plant and animal genetic traits or management systems affect the presence of microorganisms, viruses, or molds that can pose risks to human health. Similarly, research could examine the influence of chemical residues and drug-induced metabolites in animals and animal products as they relate to food safety.

Fundamental knowledge for controlling the growth of microorganisms in foods will allow the development of food processing and preservation strategies. Such strategies might include combinations of processing methods (e.g., pasteurization, reporting, drying, and freezing), manipulation of ingredient composition, packaging modifications, and enhancing populations of competitive microbial flora.

Part of the difficulty in identifying food-related illnesses is that some diseases may require chronic exposure and many years to manifest themselves (such as aflatoxin-induced cancer). Thus, further study is needed on issues relating food to specific aspects of human health. This includes assessment of new developments linking foodborne microorganisms with chronic nervous system, circulatory, and skeletal diseases not previously associated with gastrointestinal disorders, as well as examination of the effects of malnutrition on the development and performance of the human immune system. Overall,

Table 5.4 Causes of Foodborne Illnesses

			Nonallergic Food Intolerances Caused by:	
Foodborne Infections Caused by:	Food Origin Toxemias Caused by:	Food Allergies Caused by:	Natural Products	Chemicals
Bacteria	Botulinum toxins	Milk	Lactose	Sulfites
Salmonella spp.	*Staphylococcus*	Eggs	Sucrose	Nitrites
Shigella spp.	enterotoxins	Wheat	Galactose	Nitrates
Campylobacter spp.	*Escherichia coli*	Wheat	Gluten	Monosodium glutamate
Escherichia soli	enterotoxins	Peanuts	Broad Beans (favism)	Tartrazine dyes
Vibrio parahaemolyticus	Verocytotoxins	Soybean	Laythyrus peas	Benzoic acid
Listeria monocytogenes	*Clostridium perfringens*	products	(laythyrism)	Organophosphates
Yersinia spp.	toxins	Nuts	Caffeine	Oxalates
Parasites	*Clostridium difficile*	Fish	Theobromine	Heavy metals
Trichinella	toxins	Shellfish	Histamine	Mercury
Toxoplasma	*Bacillus cereus*	Other foods	Tyramine	Lead Arsenic
Amoeba	enterotoxins		Tryptamine	Copper
Giardia	Mushroom toxins		Serotonin	Aspartame
Isosporia (Coccidia)	Fungal toxins		Phenylethylamine	Butylated
Cryptosporidia	Ergot, mycotoxins		Solamine	Hydroxytoluene
Viruses	Trichothecenes			Hydroxyanisole
Hepatitis A virus	Aflatoxins			
Norwalk agent	Puffer fish			
Other Norwalklike viruses	Tetrodotoxin			
Rotaviruses	Ciguatoxins			
Adenoviruses[a]	Scromobroid fish toxin			
	Shellfish saxitoxin			
Astroviruses[a]				
Echoviruses				
Snow mountain agent				
Cockle agent				
Coxsackie B viruses				
Caliciviruses[a]				

[a] Viruses that cause gastroenteritis and that may be foodborne.

SOURCE: From U.S. Department of Health and Human Services, U.S. Public Health Service. 1988. The Surgeon General's Report on Nutrition and Health. U.S. Public Health Service, U.S. Department of Health and Human Services Publication No. 88-50210. Washington, D. C.: U.S. Government Printing Office.

research should focus on methods to identify and evaluate food-associated risks.

Food Biotechnology

Biotechnology is not a new field in the food sector, since humans have been adapting living systems for the production of food for centuries. The use of more recent biotechnology techniques, such as recombinant DNA technology, enzyme and protein engineering, plant and animal cell tissue culture, and biosensor applications, will contribute to the increased efficiency of production of special food and food ingredients, reduced production costs, enhanced nutritional value, improved processing characteristics, and safer and more convenient food products.

A fundamental understanding of the structure, function, and regulation of genetic information at the molecular level is needed for plants, animals, and microorganisms important to the food supply in order to harness the potential benefits of biotechnology. Such information can be used to custom design foods with improved nutritional, functional, and processing characteristics: cereal with improved protein, amino acid, and fiber components; oilseeds with more desirable saturated fatty acid profiles; and fresh produce with improved flavor and storage qualities.

Other goals of food biotechnology research are food starter cultures that produce natural preservatives to extend shelf-life and ensure safety, modify fat and reduce cholesterol or caloric content, enhance digestibility of food components such as lactose in fermented dairy products, and improve the efficiency of fermentation used in food manufacturing. Cost-effective alternatives to chemical additives in processed foods might be developed from natural ingredients through microorganism and tissue culture systems.

Food biotechnology research is also leading to diagnostic tools (DNA probe and immunoassay tests) and biosensors (enzyme-, cell-, or antibody-based detection systems) that will more effectively ensure the safety of raw ingredients and finished products and that will improve the efficiency and economics of food processing systems.

Research in food biotechnology can be directed toward developing systems for the more efficient use of food processing waste streams and toward converting the waste streams to value-added or nonfood products. This is increasingly important to help cover the operational costs of food safety systems while, at the same time, meeting environmental and water quality protection goals.

Notwithstanding the major potential value of recombinant DNA technologies and other modern technologies such as irradiation for the food sector, it is essential that development of the processes and products that use them be undertaken as carefully and thoughtfully as possible. This is necessary for the health and safety of both people and the environment. Just as important is public acceptance of these technologies in light of some people's wariness of, even aversion to, such technologies. The need for public acceptance puts additional and interesting challenges before the public and private research and development (R&D) sectors to present and explain the research and technologies lucidly before misapprehension occurs.

Designing Foods for Optimal Nutrition and Safety

As the *The Surgeon General's Report on Nutrition and Health* states, "Good health does not always come easy" (U.S. Department of Health and Human Services, U.S. Public Health Service, 1988). It also indicates that diet plays a part in 5 of the 10 leading causes of death (1,445,700, or 68 percent of the deaths in 1987). About 34 million Americans are obese. Between 15 and 20 percent of older people are affected by osteoporosis.

For the first time in many decades, a clear consensus is emerging that the pattern in which the U.S. population is voluntarily selecting and ingesting food is significantly affecting the U.S. population's risk for chronic disease. Two major reports on the relationship of diet to health—Diet and Health (National Research Council, 1989b) and *The Surgeon General's Report on Nutrition and Health* (U.S. Department of Health and Human Services, U.S. Public Health Service, 1988)—have stressed the importance of instituting changes in diet both by altering the composition of the available diet and by promoting health-relevant behaviors. Although the exact nature of the interaction between the average U.S. diet and chronic disease is still poorly understood, both of these reports have deemed the scientific evidence sufficiently strong to recommend reductions in the amount and the type of fat in the diet, to stress the importance of complex carbohydrates and fruits and vegetables, and to increase the consumption of foods that can supply sufficient calcium and iron.

As the evidence linking patterns of nutrient intake to disease becomes more specific and as methods of dietary intervention become more effective, the delivery of reasonably priced, convenient, nutritionally balanced, highly palatable, safe, and stable foods to the consumer will remain the food system's major challenge.

Research on the bioavailability of certain essential nutrients is increasingly important. This includes rapid and accurate measurement (e.g., by nuclear magnetic resonance and gas chromatography-mass spectrometry) of the level of available nutrients, coupled with monitoring of their metabolic activities with biochemical markers such as enzyme-and activity-specific metabolites. Raw ingredients and processing variables may also affect the biological availability of critical nutrients. More specific information is needed on the role of individual dietary components and their interactions in relation to disease and aging.

Rapid, nondestructive methods such as biosensors would enable monitoring of the level of nutritional components during food processing, storage, and cooking. Similarly, development of processes such as supercritical extraction or fermentation could remove or modify fats and adjust the relative nutrient compositions in foods. Understanding the effects of processing and storage on fat, protein, and carbohydrate and fiber fractions of food products would allow for the prediction of the safety of foods, minimize the formation of undesirable substances such as oxidized lipids in foods, and optimize the amount and type of fiber added to some foods.

Research advances on alternative methods of preservation may permit reduction of certain food constituents such as salt (sodium), sugar, sulfite, and nitrite, which are used for food preservation and are typically consumed far in excess of need.

Quality Specifications, Processing, and Health

The essence of quality is to fulfill consumer needs and expectations. Quality attributes range from nutrition to taste, convenience, appearance, and product safety. Research on food quality emphasizes an understanding of fundamental physical and chemical properties of food constituents that affect food flavor, texture, appearance, nutritional value, and other essential attributes. Quality specifications of foods and food constituents are the basis for designing food production control processes that are fully responsive to safety and nutrient needs, that are economical, and that minimize postprocessing deterioration. Research should focus on the development of rapid methods to audit the effectiveness of quality control measures at critical control points and to examine alternative means of preserving quality and wholesomeness.

The role of changing food habits (grazing, increased reliance on both fresh and prepared foods, greater consumption of ethnic foods) on the diets of specific population groups should be studied, as should their subsequent effects on health. A fundamental understanding of why different groups of consumers respond in different ways to food quality attributes is important. This knowledge and recognition of the unique dietary needs of individuals in various age groups and with different physical conditions must serve as the foundation for future attempts to improve health through dietary modifications. This knowledge is also critical in assessing how traditional plant and animal products should be modified through genetics or management.

These challenges highlight the need for appropriate models to assess health risk and for improved dietary patterns. Essential components of such models will evolve from data bases on physiological mechanisms in food production and processing and on the effects of different processing, distribution, and preparation methods on food quality.

Automation has brought a major change in food processing methods. It has generated new control needs in processing, while reducing many sources of potential problems. Other changes arise from the acceptance of new processes such as ultra-high-temperature sterilization of foods and aseptic packaging methods. Hazard Analysis Critical Control Point procedures, under development by the U.S. Department of Agriculture in partnership with food manufacturing firms, utilize on-line monitoring techniques to ensure the safety of food products. These and other innovative processes increase the need for more understanding of the fundamental properties of specific foods and methods of preservation.

The influence of various processing operations on the molecular and structural properties of food and how conversion, processing, distribution, and storage affect food quality must be assessed. To get the highest food quality, it is first necessary to identify the effects of processing operations on the molecular and cellular mechanisms that control, inhibit, or inactivate biologically active constituents in food. Innovative processes will allow the creation of foods that fit into specific diets and health promotion plans. Models that describe and predict the outcomes of microwave processing and heating of foods, especially as they relate to safety and health, will increase the available food options. Traditional processes, such as caffeine removal, fat modification, or thermal processing, may work on new food products but must be assessed for their efficacy. The effects of processing on complex whole food systems must be evaluated at the molecular level. The influence of processing on incorporation and stability of nonnutrient ingredients that have been incorporated to address dietary needs remains a significant research need.

Postharvest handling and preservation is a key ingredient in successful food processing. Too little research is now done on disease control in stored foods and on the effects of storage and preservation techniques on food safety (effects both of synthetic chemicals used to control mold and insect infestations and of natural mycotoxins and other food safety hazards that can become worse under certain storage conditions).

Packaging and Distribution Methods

Consumer expectations for food delivery systems have changed dramatically. Effortless, quick, safe, and economical meals are sought from both supermarkets and restaurants. Consumers expect to be able to use a variety of cooking and storage techniques, purchase food in several portion sizes, and often prefer to consume or serve food directly from the package. These changes have brought on increasing concerns over excessive nonbiodegradable wastes from food packaging. In April 1989, Minneapolis and St. Paul, Minnesota, passed ordinances banning nonbiodegradable packaging. The extent of packaging waste generated by the food service industry has reached crisis proportions in many urban areas and requires immediate attention.

The visibility of the food industry places food and food products at the forefront of the solid waste debate. Immediate research is needed to develop packaging—and then to implement new packaging approaches—that will be responsive to the growing solid waste crisis, yet that will preserve the convenience, quality, economy, and safety that consumers have come to expect from their food products.

Developing improved storage and packaging technologies will require evaluation of the extent and consequences of the migration of packaging materials (toxicants, flavors, odors, etc.) into food and evaluation of the migration of food components (nutrients, flavors, fluids, etc.) into or onto packaging materials. Predictive models should be developed to determine the stability of packaging materials during processing, storage, distribution, and handling by consumers; technology for nondestructive methods to quickly and continuously test the integrity of packages and seals should also be developed.

Exciting research has begun on packaging systems with built-in, self-contained indicators of product safety and wholesomeness. Systems have been designed to ensure safe handling, proper storage, appropriate consumer cooking, and other actions that can influence product safety and quality. Some recently developed packaging materials actively and independently modify the atmosphere and environment in which food is kept, thereby ensuring that it stays fresh and free of contaminants.

NATURAL RESOURCES AND THE ENVIRONMENT

Research on natural resources and environmental quality, drawing on dozens of disciplines, will provide the technical foundation for decisions about new products, processes, services, and methods to manage natural resources. New discoveries in engineering, economics, sociology, and public affairs will provide the foundation for new means to utilize raw material, human resources, machinery, and market systems. Each must play a role in producing and delivering high-quality and competitively priced products, processes, services, and management systems to society. Table 5.5 contains a summary of relationships between scientific areas in natural resources stewardship and the environment and practical or potential applications, and the box "Natural Resources" describes the diversity of natural resources in the United States.

Water Quality and Water Management

Water quality can be impaired by a variety of agricultural and forestry practices. Although water quality problems are highly variable, the most commonly encountered problems include pesticide and nitrate contamination of surface and groundwaters, improper disposal of animal and food processing wastes, and accumulation of salts and metals—especially selenium, cadmium, molybdenum, and boron—at toxic levels in frequently irrigated land. Both water impoundments designed to control floods in urban areas and large-scale drainage of wetlands are drasti

Table 5.5 Relationship between Scientific Areas and Practical Applications in National Resources and the Environment

Scientific Areas	Areas of Practical or Potential Application
Ecosystem structure and function	Forest, range, and farm productivity and efficiency, water yield and quality, ecosystem responses to stress
Soil science	Erosion control, groundwater contamination, plant water nutrient use, irrigation, tillage practices, salinization, nutrient use efficiency
Hydrology	Water yield and quality, erosion control, waste disposal on forest and agricultural land
Plant physiology and biochemistry	Nutrient, water and energy use efficiency, air pollution impacts on crops and forests
Botany, zoology, and wildlife management	Quantification and maintenance of biodiversity habitat improvement for wildlife
Agricultural engineering	Waste disposal, irrigation practices, energy use, appropriate machinery, agricultural drainage
Landscape design	Management of rural and small town communities, management of energy use
Wood science and technology	Use of biomass as chemical and energy feed stocks
Meteorology and climatology	Pesticide drift, dispersal of pollutants, forest fire management, drought management, irrigation practices, climatic change impacts on forests and rangelands
Forest, agricultural, and resource economics	Optimization of plant locations, analysis of cost of alternative management practices, labor and market analyses, assessment of environmental and social externalities
Rural sociology	Revitalization of rural and small town communities, recreation and tourism, maintaining aesthetic quality
Urban planning	Maintaining parks and green ways, waste disposal and handling, land use planning, residential landscapes
Range science	Carrying capacity, habitat quality, reproductive biology
Population biology	Weed control; biological diversity; coevolution of hosts, pathogens, predators, and weeds; biotechnical improvement of forest and range plants
Social ethics	Land and environmental ethics, social impacts of technological innovations, social services in rural communities
Measuration and biometry	Monitoring change in forest and other ecosystems, geographical information systems for national resources, remote sensing, computer mapping
Atmospheric and climatic changes	
Methane cycle	Control of agricultural methane production
Pesticide volatilization	Integrated pest management
Air pollutants and atmospheric depositions	Quality of natural and agricultural ecosystems

Scientific Areas	Areas of Practical or Potential Application
CO_2 warming	Impact on agricultural and natural ecosystems
Global carbon and nitrogen budgets	Remote sensing
Modeling link of biosphere, lithosphere, and atmosphere	Perturbations by agricultural practices
Regional climate modeling	Regional water management
Quality and productivity of soils and land use	
Soil physical properties and quality	Land use, agricultural management
Efficiency of nutrient utilization by plants and trees	Optimization of fertilizer application practices
Pesticide fate in the environment	Groundwater quality transport in soils
Soil erosion	Soil and water conservation
Water quality and water management	
Hydrological cycle	Quality of surface and groundwaters
Lake and river fisheries	Surface water management practices
Wetlands and wetland wildlife	Drainage management refuges
Transport and transformations	Groundwater quality of water pollutants in soil sediment-water continuum
Salinity and toxic trace minerals	Irrigation and drainage management in soils
Irrigation systems	Agricultural water conservation and scheduling control of nonpoint source water pollutants
Regional water budgets	Regional-scale water management
Forest, range, wildlife, and biological diversity	
Genetics and ecology	Management of forests, rangelands, and biological diversity of wildlife habitats
Plant biomass production	Alternative energy source
Urbanization	
Urban ecology	Land use management of agricultural lands
Urban wastes and disposal	Land and water quality

cally altering the hydrological regime and sometimes even the survival of bottomland forests and shellfish populations in many parts of the United States. These impoundments and drainage practices have increased the land area available for agriculture and flood control, but have also altered freshwater and nutrient flows, sometimes with negative consequences for water quality and fisheries in lakes and rivers, coastal sounds, estuaries, and other inland waterways. Little is known about the relative costs and benefits from these water management practices or about the long-term trends and effects of changes in water quality and availability.

Natural Resources

The natural resources of the United States are made up of some of the following land, water, vegetation, wildlife, and recreation resources:

- Croplands and pasturelands cover about 25 percent (550 million acres) of the nation's land area. These lands provide most of the food that the nation grows or raises, including forage and feedgrains for domestic livestock, and most natural fibers (cotton and wool).
- Commercial forests cover about 35 percent (700 million acres) of the nation's land area. They provide lumber, plywood, and other timber products for residential and commercial buildings; wooden furniture and implements; and paper in prodigious amounts—more than 600 pounds annually for every man, woman, and child in the United States. They are the source of cellulose and other wood-based chemicals. Trees also provide protective cover for shallow mountain soils and regulate stream flows in watersheds. Forests provide habitat for wildlife and are places of beauty and recreation.
- Rangelands cover another 20 percent (400 million acres) of the nation's land area. They provide food for livestock and habitat for diverse populations of birds, fish, and game animals.

The agricultural, forest, and rangelands described above supply raw materials for industries that provide more than 25 million jobs in the growing, harvesting, manufacturing, and marketing of human food, animal feed, fiber, wood, paper, and chemical products.

- Surface and groundwaters sustain human life and make possible the productivity of industries and agriculture.
- Commercial and sport fisheries provide both employment for thousands of people in seafood industries and outdoor recreation for the millions more who enjoy fishing in the nation's streams, ponds, lakes, estuaries, and coastal waters.
- Abundant and diverse wildlife populations are a source of enjoyment to the millions who seek to photograph deer, bears, antelopes, mountain goats, beavers, foxes, coyotes, ducks, geese, eagles, squirrels, rabbits, and other birds and animals in the nation's fields, forests, grasslands, mountains, and deserts, as well as the millions of sportsmen who fish and hunt abundant wild species.
- The system of national, state, county, municipal, and community parks provides places of beauty and recreation where families gather and people can seek refuge from everyday life.

Regional water management practices can have a profound influence on agriculture, environmental quality, and water uses. For example, the diversion of the Truckee River in California for irrigation has heavily affected the depth and quality of Pyramid Lake in Nevada. Conflict is growing over the need to sustain irrigated agriculture in the region and the need to protect the quality of the water resources and in-stream flows.

Large-scale irrigation agriculture on the west side of California's San Joaquin Valley, an area with fertile soils but a shallow water table, led to rising concentrations of certain elements, particularly selenium, in the drainage waters. Selenium has reached concentrations that are toxic to fish and waterfowl in the Kesterson National Wildlife Refuge. Its environmental effect is the consequence of selenium and irrigation water transport through the soil profile. It then accumulated in drainage waters that were collected and transported in a drainage canal to the Kesterson National Wildlife Refuge reservoir.

A water management disaster outside the United States of catastrophic dimensions is the desiccation of the Aral Sea in the Soviet Union. Between 1960 and 1987 the level of the Aral Sea dropped nearly 13 meters, and the average salinity rose from 10 to 27 grams/liter. It has dropped from fourth to sixth in area among the world's largest lakes and is predicted to shrink to a residual brine lake by the end of the century if desiccation remains unchecked. Desiccation of the Aral Sea is the result of reduced river inflows caused primarily by diversion of river water for irrigation and by unchecked pollutant contaminations from industries along the inland sea and rivers flowing into it. As a result, the Aral Sea's severe desiccation has had widespread ecological consequences.

Water management challenges vary greatly across the United States, reflecting the great diversity in soil types and hydrogeological conditions across the country. Several water management problems are unique to arid, western regions—salinity and selenium buildup in soils, for example. Other problems are encountered more commonly in humid regions and include drainage, surface water runoff, flooding, and water management during periods of drought. Some problems are manageable and readily reversible; others are more severe and could take decades or centuries to reverse or may be essentially permanent. There is a pressing need for more research and data to help develop improved methods to distinguish between manageable problems and those with severe, long-term consequences.

Agricultural runoff problems also vary greatly across the country. Runoff from rain, snowmelt, or excessive irrigation can cause losses of nitrogen fertilizers, manure, and pesticides, followed in parts of the landscape by leaching to groundwater. More research on optimum irrigation management and reduced fertilizer and pesticide applications would alleviate the damaging effects of agricultural runoff on land and water resources. Discharge of animal manures, secondary treated municipal wastes, or food processing plant effluents into surface waters is of environmental concern and warrants renewed efforts in research and treatment technology, as does the effect of solid waste in landfills on surface and groundwater quality.

The ability to predict long-term trends in ground-water quality and ways in which land use and agricultural practices affect water quality is a critical area of hydrological research. Soil chemists and physicists, hydrogeologists, and environmental toxicologists face many challenges unraveling the transport and transformation of potential chemical pollutants in the soil-water continuum. The role of sediments and erosion control systems in protecting water quality also deserves special attention.

Quality and Productivity of Soils and Land Use

Maintenance of soil quality is one of the prerequisites for sustaining the productivity of agricultural and forest ecosystems and is central to the success of sustainable agriculture. Productive soils are lost to agriculture and forestry in the United States through four primary processes: water and wind erosion, contamination with toxic metals and persistent pesticides, salinization after improper irrigation and drainage of cropland, and permanent conversion to non-farm uses (impoundments, transportation and electricity transmission corridors, and commercial and residential development).

The incorporation into soil of greater quantities of crop residues and other nontoxic wastes, coupled with reduced tillage planting systems, has helped to sustain and often improve soil productivity. Common farm management practices can, however, otherwise adversely affect soil productivity through compaction; waterlogging; and excessive buildup of salt, other minerals, and toxicants. Soil maintenance in forests and other exploited wild systems is much less well understood, in part because the time scale over which effects are likely to occur is longer.

Fertilizer application practices in agriculture and forestry must be optimized to sustain soil productivity and at the same time satisfy the goals of sustainable natural resources management. A necessary step toward this goal is increasing the utilization efficiency by plants of available nutrients in the soil. Research in a number of disciplines is needed to determine more precisely crop nutrient needs, the amount of available nutrients in the soil, and how and when fertilizer can be applied to maximize the portion taken up by plants.

Research undertaken since the Dust Bowl era has identified some of the physical features of soils accounting for their productive potential and susceptibility to erosion. This knowledge has been useful in advancing science and is generally adequate for the administration of current conservation policies and in the design of affordable soil and water conservation systems for many types of land and farm operations. Gaps remain in understanding how farmers and foresters can best sustain soil productivity, and the record of on-farm adoption of soil conservation systems is spotty.

But certain types of problems are concentrated heavily in just a few areas. For example, about 15 percent of cultivated cropland accounts for some 80 percent of excessive erosion, selenium problems affect distinct hydrogeological regions in the western United States, and groundwater contamination is most severe in regions with sandy soils and shallow aquifers.

A final concern about soil quality and land use is the behavior of pesticides and nutrients in soils, their potential transport through the soil profile, and the resultant contamination of groundwater. Excessive application of mobile fertilizers, particularly nitrates, can cause leaching of nutrients into the groundwater. Pesticides with a long half-lives in soils are a threat to soil and groundwater quality. Intensive research into the transport behavior of agrichermicals in soils would allow more accurate predictions of the fates of pesticides and fertilizers in the environment.

Effect of Environment on Agricultural Productivity

The environment has a large effect on plant and animal productivity. Plants grown in nature normally cannot realize their full genetic potential. Boyer (1982) has estimated that average yields of eight major food crops are depressed by about 70 percent below their yield potential because of adverse soil and climatic constraints. Advances in the 1980s in irrigation technology and scheduling, expansion of the amount of irrigated acreage, aggressive federal acreage reduction programs targeted to highly erodible cropland, and steady progress in drainage methods have helped farmers overcome somewhat the yield-depressing consequences of adverse soil and climatic constraints. Furthermore, improved tillage methods, crop rotations selected for disease control, genetic improvement, and other agronomic practices are being developed and utilized by farmers for overcoming environmental constraints. While such practices and new technologies are usually successful to some degree, and often highly successful, they generally raise production costs over those in regions without such soil and climatic constraints; and when the natural constraints prove to be more limiting than thought previously, efforts to overcome them set the stage for sometimes serious adverse soil and water resource environmental consequences, both on and off the farm.

Table 5.6 shows that only about 12 percent of U.S. soils are ideally suited for plant production, whereas about 88 percent of the nation's cropland is affected by some unfavorable environmental limitation on plant productivity, primarily because of drought, soil shallowness, cold, and wet conditions. Moreover, these soil and environmental limitations can be made worse, or overcome, by human actions. Drainage can alleviate excessive wetness, erosion control systems can limit soil loss, and new crop varieties that are less susceptible to heat or cold can help overcome climatic limitations. Pesticide and fertilizer use and irrigation can greatly increase crop yields, but they can also create other environmental problems. Similarly, alterations to natural environments can occur with intensive forest management, fisheries, mining, hunting, and recreational uses of natural resources.

Atmospheric and Climatic Change

Declining air quality is a major environmental concern. Air pollutants and atmospheric depositions affect natural and agricultural ecosystems, but the mechanisms and magnitudes of these interactions are still not well known. Acid deposition and ozone are known to affect aquatic, forest, and agricultural ecosystems. Certain agricultural practices are a potential source of pollutants. Ammonia used as a fertilizer can escape from soil to the atmosphere. Also, ruminant animals are a source of methane. The level of methane in the atmosphere is clearly increasing; the sources of methane, however, are much debated, and the signif

Table 5.6 Area of the United States with Soils Subject to Environmental Constraints

Environmental Constraint	Area of U.S. Affected (percent)
Drought	25.3
Soil shallowness	19.6
Cold	16.5
Wet conditions	15.7
Alkaline salts	2.9
Saline or no soil	4.5
Other	3.4
None	12.1

SOURCE: Boyer, J. S. 1982. Plant productivity and environment. Science 218:443–448.

cance of effects of elevated atmospheric methane levels on ecosystems is unknown. Pesticides can be volatilized from soils and transported through the atmosphere, potentially leading to soil and water contamination in areas far removed from the source. This is probably why dichlorodiphenyltrichloroethane (DDT) levels in the soil in some parts of the country have risen in recent years, despite a ban several years ago on the use of DDT in the United States. The significance and role of increasing atmospheric pollutants and gases on the global carbon and nitrogen budgets needs more thorough investigation.

Rising concentrations of carbon dioxide (CO_2) and other greenhouse gases appear to be responsible for shifts in global climates. Although warming from increased levels of CO_2 and potential climatic change are much debated, research into the environmental and agricultural consequences of warming from increased levels of CO_2 must be undertaken now. Agriculture's contribution to the rise in atmospheric CO_2, particularly through large-scale deforestation, is clearly significant. Remote-sensing technologies constitute an important new tool for global studies of the carbon and nitrogen budgets and must be coupled with substantial quantitative data collected on the ground. A long-term scientific challenge is to develop models that more accurately account for linkages among the active biosphere, lithosphere, and atmosphere.

Many consequences of warming from increased levels of CO_2 on global climatic patterns are unknown, but changes in regional rainfall and water availability could clearly have important effects on agriculture and forestry. There are also fears that the intense heat of summer and intense cold of winter could become more extreme. Melting of the polar ice caps and thermal expansion of the oceans could raise the level of oceans, inundating often highly productive coastal plains with seawater or infiltrating inland groundwater resources with saline water. In addition, if the seasonal winter rainfall patterns common to the southwestern United States shifted to a more uniform rainfall distribution through the year, agricultural practices would change dramatically in that part of the country.

In the 1980s science and technology have made tremendous advances in computer technology, remote sensing, instrumentation, atmospheric chemistry, and other sciences key to understanding the global warming phenomenon. Tremendous advances in oceanography and ocean-atmosphere interactions, such as research on the impacts of the El Niño current in the Pacific Ocean, must be integrated into other environmental and agricultural research programs. Recognizing and estimating physical, chemical, and biological linkages in the environment following warming caused by increased levels of CO_2 through interdisciplinary research will be crucial in achieving this goal.

Biological and Genetic Diversity

Maintaining biological and genetic diversity in agricultural crops is desirable in principle but is hard to ensure when trying to respond to market demands for uniform products. Many questions warrant attention. What constitutes diversity? How much is needed? What resource uses should be included in multiple use plans, and how should potentially conflicting goals be balanced, and by whom? Are forests more or less diverse than they were in presettlement times? Over what sizes of areas should criteria defining biological diversity be applied? What is the role of genetics research in maintaining biological diversity? How will specific management practices influence the effectiveness of multiple-use plans and ecosystem diversity?

Understanding ecosystem structure and function is essential if biological and genetic diversity are to be understood and maintained. It is equally essential if managed ecosystems are to be understood and if they are to provide sustained productivity with minimum economic and environmental expenditures. The brief discussion of ecosystem structure and function in Chapter 4 outlines the status and challenges for this important field of study.

Pests are defined as insects and diseases that occur in such amounts and concentrations within an ecosystem—usually a managed ecosystem—as to cause economic loss. Pests and pesticides are also discussed briefly in Chapter 4. Pesticides of all kinds have a major effect on biological diversity, and sometimes on overall genetic diversity; thus, their study and beneficent use are best considered in terms of ecosystem structure and function, along with the more organism-specific studies.

Forests, Rangelands, and Wildlife

Managing forests and rangelands for multiple uses and biological diversity is easy to mandate but difficult to achieve. Several specific forest management practices-clear-cutting, the use of herbicides for weed and brush control, livestock grazing in national forests, and forest fire control policies—raise complex technical issues that often must be resolved as matters of public policy. Better scientific and improved data on forestland and rangeland conditions will not eliminate the need for difficult choices to be made by the public sector, but they can help provide decisionmakers and the public with a clearer sense of the consequences of alternative choices.

New harvest, pest control, and reseeding technologies are needed for a range of forestland and rangeland applications on both public and private lands. Future practices should focus on the vital need to conserve the biological productivity of rangeland and forestland soils and on the susceptibility of forestland and rangeland ecosystems to degradation when they are mismanaged or exploited too heavily.

Development of a Land Ethic

Increasing human pressures on natural resources heighten the need for a renewed land stewardship ethic. For the long-term maintenance of a clean and productive natural environment, the factors shaping public attitudes toward natural resources will need to be identified; alternative systems to balance production and conservation needs will need to be developed; and the role of government in supporting stewardship will need to be defined. The need to develop a land stewardship ethic is described eloquently in Aldo Leopold's (1968) book *A Sand County Almanac*:

> The first ethics dealt with the relation between individuals. Later accretions dealt with the relation between individuals and society. The Golden Rule tries to integrate the individual to society; democracy to integrate social organizations to the individual.
>
> There is as yet no ethic dealing with man's relation to land and the animals and plants that grow upon it.... The land-relation is still strictly economic, entailing privileges but not obligations.
>
> The extension of ethics to this third element in the human environment is an evolutionary possibility and an ecological necessity.

Identifying the changes in human behavior and agricultural practices needed to meet the challenge of resource stewardship raises complex questions. Answers depend upon creative integration of several disciplines as diverse as physics, anthropology, and forest ecology. In addition, the key role of public policies and institutions in shaping a land ethic and helping individuals meet its mandate must be thoughtfully reassessed in the years ahead.

ENGINEERING, PRODUCTS, AND PROCESS

Engineering activities can be applied to the entire agricultural, food, and environmental system. These activities include providing conceptual frameworks for systematic analysis of problems and questions (both physical and biological); defining scientific and technological questions by physical and mathematical analyses; and designing usable physical (as well as physical and biological) machines and systems to serve useful purposes. The problems engineering addresses range from those at the molecular and cellular levels to those at the level of large machinery.

The engineering research agenda is being transformed by the major issues challenging agriculture today. Key problems, and therefore opportunities, lie in the areas of (1) water quality and water management, (2) sensors, (3) computing and information systems management, (4) bioengineering, (5) bioprocessing, (6) innovation in equipment manufacturing, and (7) production efficiency and resource conservation. Table 5.7 shows some of the relationships between areas of engineering research and their practical or potential applications. The rate at which progress is made, however, will depend on how effectively people with engineering knowledge and research skills are integrated into multidisciplinary teams that include scientists trained in the physical sciences, biology, mathematics, natural resources management, and other disciplines.

Water Quality and Management

Water supply and water quality are clearly critical to agriculture, forestry, and the nation. Eighty percent of the water in the 48 contiguous states is in groundwater aquifers, and nearly 70 percent of the water withdrawn from these aquifers is used for irrigation. This figure is even more striking when one considers that irrigated land is less than 20 percent of the land area under cultivation in the United States.

Water could be used more efficiently in agriculture, and agriculture's adverse effects on water quality could be lessened if soil-plant-air-water interactions were better understood. A systems approach should be used to consider the cost and availability of water, irrigation methods, drainage requirements, crop fertil ity and pest control needs, the timing of field and harvest operations, and methods to protect water quality. Emphasis should be placed on improving methods to predict the availability and application efficiency of water. More accurate and practical infield tools should be used to monitor and, when necessary, to mitigate the contamination of water resources by agricultural and forestry operations. Better ways should also be found to measure the relatively high degree of variability found in soil type, topography, and plant cover and to incorporate that information into management decisionmaking and in-field operations.

Table 5.7 Relationship between Scientific Areas and Practical Applications in Engineering

Scientific Areas	Areas of Practical or Potential Applications
Combustion	Fuel efficiency, emissions, engine materials, biomass fuel
Computing systems	Control systems, production and manufacturing efficiencies, systems analyses
Control systems	Greenhouse environment, water quality, remote navigation
Corrosion	Chemical handling equipment, aquatic system structures
Dynamics	Transport damage to food, crop harvesting method
Electric power	Time of use, impact of transmission lines
Electronics	Sensors, communications, data acquisition
Expert systems	System management, quality control
Fluid mechanics	Irrigation, drainage, soil erosion, environmental control
Heat transfer	Food processing, energy use efficiency
Human factors	Worker safety, efficiency, stress
Hydrology	Water flows and quality, erosion
Image processing	Food quality evaluation, harvesting sensors, animal behavior
Information processing	Crop or irrigation scheduling, artificial intelligence
Instrumentation	Nondestructive tests, detection of contaminants
Manufacturing processes	Computer-aided, customized, short-line manufacturing; plastics; composites
Materials science	Package films, filter membranes, abrasion resistance, sensors, bioengineering
Mass transfer	Flavor migration, soil drainage, contaminant movement
Micrometeorology	Environment control, growth modeling
Packaging	Microenvironment control, tamper-proof and biodegradable packaging
Physical properties	Relationship to quality, sensor development, failure criteria
Radiation	Food preservation, inspection, analysis
Reaction kinetics	Biotechnology, food and waste processing
Remote sensing	Field, forest, and water resource evaluation; yield forecasting
Rheology	Behavior of food concentrates
Robotics	Harvesting and sorting mechanisms, equipment manufacturing, bioengineering
Systems analysis	System modeling, optimization, economics, social impacts
Unit processes	Bioengineering, bioprocessing

Sensors

Design engineering and management systems rely on adequate information about how a production process or system responds to its inputs. New transducer and sensor developments will allow measurements of a wide range of factors that influence the production and processing of food products, including moisture, chemical concentrations, pathogens, and particulate concentrations in facilities and storage structures. Sensors could also help monitor animal behavior and well-being. Improved methods are needed for measuring moisture content; fertility and tilth of soils; and chemical compositions of forestry, aquaculture, and agricultural materials. The development of force and position transducer technologies will allow continued progress in mechanization systems and robotics. Monitoring techniques to improve operator decisionmaking and to increase operator safety and health will be increasingly important.

Computing and Information Management

Developments in sensors linked with advances in computing capacity and convenience will be necessary to achieve innovative applications throughout the agricultural, food, and environmental system. However, developments in this area will depend on continued advances in understanding the fundamental physical and chemical processes relevant to the conditions being monitored. Research must focus on understanding the properties of materials and the physical and biological factors governing effective production processes. Improvements in information processing, expert systems, and artificial intelligence for handling the vast quantities of information will be obtained by coupling reliable electronic instrumentation systems such as biosensors with computing systems.

Bioengineering

Bioengineering is the combination of engineering science with biological materials into an integrated specialty that goes beyond current biochemical and related engineering specialties. For example, use of this new specialty will help researchers understand the surface and physical properties of cells so they can be adsorbed onto solid-phase reactors and develop engineered systems for embryo transfer, photosynthsis in manufactured systems, estrus detection, both low-and high-temperature biology, and delivery of engineered organisms (such as encapsulation of genetically modified seeds and their surrounding nutrients).

Bioprocessing

Bioprocessing is the processing, handling, and reformulation of biological materials using engineered biological systems. For example, anaerobic digesters of manure wastes and cellulosic residues are bioreactors that are used to convert the wastes, through bioprocessing, into fuels. Similarly, bioreactors can be developed to convert biological wastes into protein. Major fields in which bioprocessing has already proved valuable, and will certainly prove even more so in the future, are the production of alternative fuels from wastes and other biological materials; the decomposition of municipal, industrial, and agricultural and food processing wastes; food processing and engineering; and formulation of new products such as biodegradable plastics.

Innovation in Equipment Manufacturing

The continued success of U.S. agriculture also depends on access to efficient, reliable machines and tools for carrying out soil, crop, harvesting, and product processing activities. The equipment manufacturing industry faces a number of problems—labor costs and the need to retool manufacturing plants, for example—for which it must seek engineering solutions. Research on improved manufacturing processes such as computer-aided design and manufacturing, numerically controlled manufacturing, and just-in-time manufacturing and advanced inventory management systems will help. Changes in market demand for equipment will need to be responded to more quickly, particularly if U.S.-based industries are to remain competitive internationally and regain a larger share of the domestic market in small machinery. Equipment that can be used for multiple purposes, some in combination with specially designed attachments, can lower capital and operating costs. Today, many large, specialized machines are idle much of the year or can be used only for a single crop. Support will stimulate innovation in equipment design to address unique needs associated with both small-and large-scale sustainable agriculture operations. These needs include machines to make and apply composted materials, cultivation equipment, new low-cost animal housing systems, and ways to harvest crops grown in polycultures.

Production Efficiency and Resource Conservation

The need for improved production efficiency and resource conservation underlies all of the major issues discussed above. The ability of the agricultural sector to respond to these needs will depend largely on how well basic information is utilized in the design and use of efficient, safe production systems. For this reason, a broader array of systems-based models must be developed to estimate both near-and long-term effects of alternative production practices and management options. Models will help analysts address not only the great diversity that exists in natural ecosystems but also the many factors that must be taken into account when one is trying to estimate real-world interactions in technically complex and dynamic systems like those commonly found in production agriculture. Great progress has been made in recent years in developing useful new analytical tools and models to address questions of soil erosion and water conservation, product and market development, selection of desirable genetic traits in breeding programs, chemical and biological pest management, monitoring of crop diversity, mechanization in cultural practices, human health and safety, and many other issues that directly affect farmers and the nation.

The effects of industrial and urban pollutants on the land, air, and water resources so important to forestry and agricultural production is a growing area of emphasis for engineers. Questions about the effects of acid rain on crops, sulfur emissions from power plants, and urban and industrial pollution of water supplies are under intense investigation in several regions of the country; and conditions in many forest ecosystems in the eastern United States and Rocky Mountain region are clearly growing worse.

MARKETS, TRADE, AND POLICY

The program area of markets, trade, and policy encompasses all of the issues that relate to the economic and societal implications, effects, consequences, profitability, and value of the agricultural, food, and environmental system in their national and international dimensions. It embraces the disciplines commonly associated with the social sciences and with policy and management sciences. In addition, this program area has a close relationship with the biological and physical sciences required for assessing the economic and social value of sustainable agricultural systems, the value of new uses of a particular crop, and the societal and environmental implications of new technologies.

Research on the effects of policy has not kept pace with the growing influence of policy on the performance of U. S. agriculture. For example, the commodity policies pursued during the last half century have resulted in such massive distortions in the technology and location of agricultural production that it has become almost impossible to determine the extent to which production of major U.S. agricultural commodities would decline or grow in a world market environment characterized by a more open national commodity market and more open trade policies. These kinds of deficiencies inhibit policy analysis and development. Thus, policy research should be a major priority and should be coupled with discipline-oriented studies.

Significant policy research has been done by the USDA's Economic Research Service, and they continue to do such studies. Given the magnitude of the needs, including the changing global conditions and the changing global environment, for science and technology—and the interest of the academic and research communities in policy issues and their capacity for strong research—there are major opportunities of joining need and research capacity for furthering this necessary work.

The sections that follow present some aspects of this program area and give some examples of research needs and opportunities.

Markets and Trade

Markets and trade, with particular emphasis on international trade, are surveyed in Chapter 4, as are some of the research needs. The following are some additional research needs and opportunities:

- analyzing the effect of economic policies on trade patterns;
- identifying and characterizing the trade-offs and linkages between domestic agricultural and trade policies;
- devising an optimal international commodity trade policy for the United States;
- assessing institutional relationships—such as state trading, monopolistic business practices, and government involvement—in international agreements and their effects on the performance of international markets, information, and transaction linkages;
- determining the extent to which monetary policy and other institutional factors mask U.S. comparative advantages in the agricultural and food sector;
- accounting for technological differences among countries and for changes in those differences over time;
- incorporating concepts of imperfect competition and institutional interactions into trade policy; and
- improving the conceptual framework for research on international trade and developing and using improved empirical models for policy analysis.

Technological Innovation and Value-Added Products

As noted in the discussions of international trade in Chapter 4, technological innovation and value-added products are two domains in which the United States may have a competitive advantage. In terms of technological innovations, the nation's R&D sector has a historically strong record on which to build, particularly if the new advances in molecular genetics and computers are exploited. In terms of value-added products, the nation is still focused more on bulk commodities than on value-added products, which suggests a major unrealized opportunity.

A key feature of research on markets and trade is the opportunity to derive major advantage from combining scientific and technological analysis with economic, social, and policy analysis in integrated plans of study. Some program and research needs and opportunities include the following:

- identifying the product and process niches where U.S. strength in science and technology may offer a significant advantage;
- identifying the industries and markets where the United States can best utilize its inherent strengths in technology, natural resources, and infrastructure;
- elucidating short-and long-term trends for technological innovation and desirable value-added qualities that would ensure a long-term market niche;
- characterizing the advantageous coupling between biological advances, such as tissue culture and plant growth, with technological approaches, such as those for delivering new plant materials;
- identifying plant and animal characteristics most responsible for major losses in preharvest production and in postharvest transport and processes, and then elucidating mechanisms for eliminating or minimizing those characteristics; and
- identifying opportunities for new uses of commodity products and for major new markets for newer crops, such as rapeseed and rapeseed oils.

Economic Performance

Economic performance refers to the performance of the individual producing or processing unit rather than to the more macro-level issues, such as the behavior of financial institutions; it also designates the social and environmental externalities that accompany production and processing operations. Some of the program and research needs and opportunities include the following:

- creating greater flexibility in commodity price support programs to cost-effectively alter cropping patterns and use new crops and technologies;
- identifying the physical, biotic, and environmental relationships between a farm's actual and optimal economic and environmental performances;
- determining the effects on costs, and on the location of agricultural production, of regulatory or incentive programs designed to reduce the environmental and health effects of the intensification of agricultural and industrial production;
- elucidating the economic effects that, for example, changes in global climate (resulting from the greenhouse effect), acid deposition, and destruction of the ozone layer have on trends in the growth, location, and costs of agricultural production;
- developing more and improved safety practices for the use of equipment and chemicals;
- developing further energy self-sufficiency for producing and processing industries;
- identifying and developing the management and decision tools needed for optimum economic and environmental performance; and
- continuing to craft public policies that will bring economic and environmental goals into congruence with each other and, in particular, advancing the development and adoption of systems for natural resources conservation and low-input sustainable agriculture.

Rural Development

Rural development focuses on sustaining and developing the rural sector of the United States. Program needs and research needs and opportunities include the following:

- determining cost-effective opportunities and strategies to invest public funds in the rural economic infrastructure;
- identifying environmentally acceptable opportunities and methods to recycle and dispose of wastes;
- encouraging increased investment in product and processing development and facilities, with special focus on value-added or new product industries; and
- understanding the social, economic, and environmental forces and policies that have the greatest influence on the vitality of the rural sector of the United States.

RELATIONSHIP BETWEEN PROGRAM AREAS AND RECOGNIZED PRIORITIES

The proposed six major program areas evolved from the Board on Agriculture's general considerations; from its review of the priorities identified by the Joint Council for Food and Agricultural Sciences, the National Agricultural Research Committee (NARC) of the National Association of State Universities and Land-Grant Colleges, and other organizations; and from its review of pertinent Board on Agriculture and National Research Council reports. Table 5.8 summarizes the six major program areas proposed here, current USDA competitive grants program research areas, and the priorities identified by NARC. Table 5.9 lists the six major program areas proposed here, the major research objectives of the Agricultural Research Service (ARS), and funding for those research objectives in fiscal year (FY) 1988. Appendix D contains detailed information on the priorities identified by all these organizations, agencies, and committees.

The comparisons in Tables 5.8 and 5.9 show that the proposed six major program areas fully encompass the priorities identified by state agricultural experiment station research planners and are consonant with the program areas of ARS and with CRGO's current programs, simplifying the transition in program management from the current to the expanded program.

It is important to note that several research needs relate to or could fall within two or more major program areas. For example, physical studies of soil moisture and instrument capabilities in relation to plant physiology and crop response models could be in the areas of plant systems; natural resources and the environment; or engineering, products, and processes. Studies on animal biochemistry, physiology, and endocrinology related to fat and protein metabolism—and thus to nutritionally improved food products with lower fat and cholesterol levels and reduced levels of sodium—could either be in the animal systems or nutrition, food quality, and health program areas. Research on physical and chemical properties of biopolymers—as it applies to potential new uses for basic commodities such as corn, starch, wood fiber, soy-beans, and animal fat—could either be in the engineering, products, and processes or markets, trade, and policy program areas, with secondary input from the plant systems and animal systems program areas.

Because the six proposed program areas encompass the entire agricultural, food, and environmental system, they could be useful when specific new research, education, and extension programs are being considered. A proposed new activity could be considered in relation to one or more program areas; a determination could then be made as to how the activity fits with current emphases in the area. In that way, a comprehensive, integrated organization of specific program activities could evolve.

RELATIONSHIPS AMONG THE SIX MAJOR PROGRAM AREAS, SCIENTIFIC DISCIPLINES, AND NATIONAL PRIORITIES

A key feature of this proposal is to provide strong opportunities and incentives to bring into the agricultural, food, and environmental research system all scientists working in relevant disciplines, including, among others, biology, chemistry, physics, engineering, the various disciplines of biomedicine, and the environmental and social sciences. At present, there are few—and, for some disciplines, no—opportunities to contribute to agricultural, food, and environmental research needs.

A second feature of this proposal is to ensure that scientists who are part of the traditional agricultural research disciplines have an opportunity to participate fully in the proposed expanded grants program. These disciplines include, among others, agricultural economics, agricultural engineering, agronomy, animal science, entomology, fisheries and wildlife, forestry, genetics, horticultural science, nematology, plant pathology, plant science, soil science, and veterinary medicine.

The traditional agricultural sciences have always drawn from the fundamental and basic sciences, and they have effectively used applicable principles and research methodologies. Reciprocally, research in various agricultural areas has contributed significantly to fundamental understanding—such as in the biology of photosynthesis, cytogenetics, mammalian reproduction, hydrology, microbiology, and antibiotics, to name just a few areas. A major purpose of this proposal is to ensure that the links between the fundamental sciences and agriculture remain strong and, indeed, increase.

The potential involvement of seven basic science categories in agricultural, food, and environmental research is illustrated below. Examples of several scientific and engineering disciplines for each cate *gory and examples of possible research themes are also given.*

Table 5.8 Proposed Competitive Grants Program Major Areas, Current Competitive Research Grants Office Program Areas, and National Agricultural Research Committee National Priorities

Proposed Program Area	Current CRGO Research	NARC National Priorities[a]
Plant systems	Plant science (18.0)[b] Pest science (2.0) Biotechnology (portion of 19.0)	Plant genetic improvement, new uses,[c] improved pest control, forest productivity,[c] and plants for urban environments
Animal systems	Animal science (6.0) Biotechnology (portion of 19.0)	Animal efficiency, new uses,[c] and animal health and disease
Nutrition, food, quality, and health	Human nutrition (1.0)	Food quality enhancement and food, diet, and health
Natural resources and the environment	Stratospheric ozone (3.7)	Water quality and quantity, sustaining soil productivity, land use, range production, forest productivity,[c] and ecosystem impacts of atmospheric deposition
Engineering, products, and processes	None	New uses,[c] energy efficiency, and advanced electronics and decision aids
Markets, trade, and policy	None	Integrating agricultural technologies, marketing, policy and global markets, and rural families and communities

[a] Another NARC priority area, biotechnology, encompasses plant productivity, plant disease resistance, nutritional quality of plants, biological control of pests, biologically active materials, diagnostic and immunologic products, animal disease resistance, animal development and productivity, and impacts of biotechnology. Other cross-cutting issues, like sustainable agriculture and foundations of competitiveness, could fall within several major program areas, depending upon the specific focus of the proposed research. See Appendix D for a more complete description of the 21 NARC priority initiatives and objectives.

[b] Values in parentheses are FY 1989 appropriations in millions of dollars. A total of $19.0 million for biotechnology was divided between plant and animal science.

[c] Priority area that falls within more than one major program area.

1. *Physical Sciences:* Chemistry, physics, mathematics, geology, climatology, and atmospheric sciences. Research on basic chemical and physical properties and processes; energy flows in natural systems; chemical reactions and interactions; physics of transport through porous media; and design of new materials and processes.
2. *Molecular and Cellular Biology:* Biochemistry, genetics, cell biology, physiology (plant and animal), endocrinology, and immunology. Research on genome structure and function; genetic markers for disease diagnosis, epidemiology, and genetic improvement and ecological effects; biochemical and genetic

basis of agriculturally important traits; cellular and biochemical basis of host-pathogen interactions; mechanisms of gene expression; and chromosome structure, replication, cell division, and genetic recombination.

3. *Developmental and Organismal Biology:* Microbiology and virology, developmental biology (plant and animal), plant biology, pathology (plant and animal), neurobiology and behavior, and limnology. Research on the health and performance of total organisms; nutrient and physiological needs in growing plants and animals; and genetic transfer methods for reproductive improvement.
4. *Environmental Biology and Ecology:* Ecosystems research, population biology, hydrology, environmental biophysics, soil physics and chemistry, and wildlife and aquatic sciences. Research related to the health and performance of wild and managed ecosystems; soil microbiology and rhizosphere dynamics; short-and long-term interactions between agricultural and forestry production practices and natural resources, aquatic habitats, soil, water, and wildlife; genetic stability of populations (both natural and genetically altered); population dynamics, genetics, biochemistry, and physiology of pathogens and pests; interactions among agricultural systems, soil systems, and water systems; and the fate (and consequences for ecosystems) of natural and synthetic toxins associated with agriculture and forestry.
5. *Biomedical and Related Sciences:* Nutrition, epidemiology, veterinary medicine, and medical sciences. Research focusing on the interactions among food, diet, and health; opportunities to reduce the incidence of cardiovascular disease and certain cancers by modifying foods; detection and control of foodborne pathogens; and reduction of nutritional deficiencies and excesses in special human populations.
6. *Engineering and Information Systems:* Bioengineering and chemical engineering, biostatistics, operations research, computer science, environmental and civil engineering, agricultural engineering, and electrical and mechanical engineering. Research and engineering applications of advanced electronics in robotics, quality control systems, diagnostic probes and sensors, and instrumentation; expert systems for

Table 5.9 Proposed Competitive Grants Program Major Areas, ARS Major Program Areas, and ARS Funding, FY 1988

Proposed Areas	ARS Program Area	ARS Funding, FY 1988 (in millions of dollars)
Plant systems	Productivity and quality—crop	183.9
Animal systems	Productivity and quality—animal	182.3
Nutrition, food quality, and health	Human health and well-being	42.0
Natural resources and environment	Natural resources—management	56.5
Engineering, products, and processes	Agricultural products—domestic and export	88.9
Markets, trade, and policy[a]	None	—
None	Scientific knowledge systems	11.8
Total		565.4

[a] Research in this area is undertaken by USDA's Economic Research Service.

making decisions about farm management, modeling growth, and studying the consequences of alternative policy options; remote sensing of irrigation needs, fertilizer needs, or plant nutrient deficiencies; robotics; and techniques for assessing the quality and properties of foods and forest products.

7. *Social System and Policy:* Anthropology, social and behavioral sciences, law, sociology (including demography and rural sociology), business administration, marketing, political science, and economics (including agricultural economics). Analysis of markets, trade, economics, technology, and policy; the sociology of decisionmaking on farms and by consumers; cultural and anthropological trends, consequences, and causes; effects of demographic change; the information and technology transfer process; and methods of assessing the costs and consequences of policy options.

SCIENCE AND TECHNOLOGY BUDGET PRIORITIES

The legislative and executive branches of the federal government face special difficulties in establishing priorities for allocating funds for research. Science and technology budget requests and recommendations are made on behalf of many different programs and agencies; some requests address mission agency needs, whereas others focus on advancing science in particular areas. Although science and technology programs collectively constitute a major public investment, opportunities in the budget process of either the executive or the legislative branch to assess the overall adequacy, focus, and balance of this multifarious investment are limited. To help address this problem, the budget committees of the U.S. Congress used the FY 1989 budget resolution to seek assistance from the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). The three academies were asked to provide the following (U.S. Congress, House, 1988):

> ... advice on developing an appropriate institutional framework and information base for conducting cross-program development and review of the nation's research and development programs. This [framework] should be structured in such a way that it can be used by both the Executive Branch and Congress as a method for reviewing program contents and strategies and in determining funding and organizational priorities for science and technology.

The academies responded by forming a committee to review the budget process and produce a report. The report, issued in December 1988, highlighted four categories for policymakers to use in evaluating science and technology budget requests (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 1988). These categories are not mutually exclusive; a given R&D program can serve multiple objectives and thus fit into more than one category. By considering the distribution of R&D funding in terms of these categories, individuals and agencies involved in the budget process may identify possible needed adjustments in science and technology budget priorities.

The four basic categories are as follows:

1. the science and technology activities of individual agencies in relation to their own missions;
2. the aggregate contribution of several agencies to the science and technology base of the nation, abase that includes fundamental research, the supporting infrastructure, and the continued production of scientists and engineers;
3. the contribution of science and technology activities (frequently supported by several agencies) to national objectives to which the President, the Congress, or both have given priority (e.g., industrial competitiveness, environmental protection, and prevention and treatment of the acquired immune deficiency syndrome [AIDS]); and
4. major science and technology initiatives that attract attention in any budget year primarily because of their cost and budgetary consequences for other science and technology activities across agencies (e.g., a superconducting supercollider or a space station).

Responding to USDA's Missions

In evaluating science and technology priorities, policymakers should first assess an agency's science and technology activities in relation to the agency's own mission needs and responsibilities. For USDA, the intramural research program of the ARS is generally adequate in this respect, as evidenced by ARS's many cooperative agreements with other USDA mission agencies (see Appendix A) and by the clear relevance of ongoing ARS research to the primary science and technology questions USDA faces. Within the executive branch's budget review process, the need for resources to support ARS research on behalf of mission agency programs is recognized and generally responded to.

What is lacking, however, is a similarly effective federal funding mechanism to attract academic scientists in areas related to ongoing ARS research and to cross-cutting science and technology needs that pertain to the overlapping responsibilities of several agencies. In a limited number of cases, academic scientists conduct research under contract to, or consult with, USDA mission agencies, but the fun strength of the scientific and engineering communities is not engaged.

A broadened, adequately funded USDA competitive grants program would largely remedy this situation. Scientists and administrators from USDA mission agencies would likely participate in competitive grants program advisory committees, planning activities, and peer review panels; and agency scientists—possibly in conjunction with academic colleagues and collaborators—would compete for support through the program.

Strengthening the Science and Technology Infrastructure

The second category for policymakers to use in evaluating science and technology priorities is whether research has the potential to help strengthen the nation's technology base.

Despite modest funding since its inception in 1978, USDA's competitive grants program has illustrated the program's potential for broadening the nation's overall science and engineering infrastructure. Nevertheless, the USDA competitive grants program has not fulfilled even a small portion of that potential, nor has it brought about an adequate network of active linkages and partnerships involving food and agricultural scientists and the broader scientific community. It is simply too small.

Fortunately, other USDA and state-funded science and technology activities such as the state agricultural experiment stations have contributed steadily and strongly to the nation's scientific infrastructure for agriculture and food. Land-grant universities are major centers for higher education and conduct extensive, vital, long-term research programs across the full spectrum of science and engineering disciplines. Other public and private universities do so to the limited extent permitted by funding, but they a have much greater capacity to influence the agricultural, food, and environmental system if the support and incentives are in place.

As Chapters 2 and 3 explained, the shortcomings in USDA's competitive grants program will be largely eliminated if the number of scientists and engineers who can participate in the program is substantially increased; if the average size of grant per principal investigator is doubled; if the average duration of grants is extended, if new program areas in natural resources and the environment; engineering, products, and processes; and markets, trade, and policy are developed; and if new types of grants—multidisciplinary team grants and research-strengthening grants—are offered.

Moreover, a $500 million increase in funding would constitute a sizable investment in a broadened science and technology base. It would also be a clear signal to the science community that agricultural, food, and environmental science and technology are important to the nation's well-being. The reaffirmation of the national importance of agriculture could be among the most significant long-term benefits of the expanded program.

Targeting National Priorities

The third category of priorities identified in the academies' science and technology budget report of NAS, NAE, and IOM (1988) described above involves science and technology that will help achieve national objectives.

The President's FY 1990 budget request includes two sizable increases for USDA research efforts addressing major national needs. The competitive grants program budget request includes a second year of funding for research on the effects of change in stratospheric ozone levels ($3.7 million appropriated in the FY 1989 budget, $7.4 million requested for FY 1990); and following a government-wide review of water quality issues and research needs led by the Office of Management and Budget, $13.9 million in additional funding (nearly a 30 percent increase over the FY 1989 program level) has been proposed for USDA water quality research activities.

Supporting Major Science and Technology Initiatives

The fourth category identified by the report of NAS, NAE, and IOM (1988) is major initiatives of unusual scale and character that would, if funded, invariably reduce the funding available for other major initiatives and possibly for research overall. Contemporary examples include the superconducting supercollider, the space station, and the human genome project.

No single major, costly project in the agricultural, food, and environmental sciences is under serious consideration. Although plant and animal genome mapping activities are likely to expand markedly in the years ahead and will be among the science and technology priorities supported through the funding requested in this proposal, there are no current recommendations calling for a major and unusual commitment of funding to accelerate plant or animal genome mapping. The proposed expanded program involves a substantial increase in funding for agricultural, food, and environmental research, but it does not fit into this fourth category of science and technology activities because it is neither unusual nor distinct.

CONCLUSION

An expanded USDA competitive grants program would provide a comprehensive and catalytic new mechanism for awarding federal support for science and technology activities relevant to agriculture (as it has been broadly defined in this proposal). In so doing, it would offer clear advantages in the following areas:

- defining and pursuing high-priority science and technology projects of national significance carried out by mission agencies;
- strengthening the breadth and quality of the nation's scientific infrastructure; and
- responding to presidential and congressional priorities that reflect pressing national needs.

6

Institutional and Administrative Issues

Effective management of the expanded competitive grants program will require careful attention to and management of a number of institutional and administrative issues. First, the program office must be properly located within the structure of the U.S. Department of Agriculture (USDA). Second, several program transitions must be arranged: program planning and advisory committees must be set up, the peer review process must be managed and its quality ensured, and the program's administrative capacity must be expanded to match the increase in program scope and number of grants. Third, success of the multidisciplinary grants must be ensured. Finally, program evaluation and accountability are essential to the program.

PROGRAM'S LOCATION IN USDA

In fiscal year (FY) 1988, the USDA competitive grants program (funded at $45.4 million) represented less than 5 percent of USDA's Agricultural Research Service (ARS) and Cooperative State Research Service (CSRS) research expenditures. The program is administered within the CSRS, which is one of three major science and education agencies within USDA's Office of Science and Education; the other two are the ARS and the Extension Service (ES). Within CSRS, the Competitive Research Grants Office (CRGO) is one of five offices reporting to an associate administrator. (CSRS has two programmatic associate administrators and three deputy administrators responsible for scientific direction and management.)

As the competitive grants program reaches $550 million in annual expenditures, its size and scope will clearly warrant its elevation within USDA's Office of Science and Education. Various institutional options are likely to be considered; all of them should be evaluated in terms of the following criteria:

- Ensuring the program's openness to high-quality science and providing it with broad appeal, visibility, and stature within the scientific community.
- Providing the CRGO program director and chief scientists with direct access to key policymakers within USDA, particularly the assistant secretary for science and education.
- Developing strong relations between the competitive grants program and the research programs of other federal agencies.
- Attracting nationally prominent scientists and managers to positions of program leadership in CRGO and to service on program advisory committees and peer review panels.

Three of the more likely options are discussed here.

Option I: Major Unit within the Office of Science and Education

Under this option, the expanded CRGO would be a fourth major science and education agency within USDA's Office of Science and Education; thus, it would be taken out of CSRS and elevated within the Office of Science and Education. Its administrator would be on an equal footing with the administrators of ARS, CSRS, and ES as the critical policymakers and line managers of USDA's science, education, and training activities.

This option responds well to the criteria set forth above and has the following advantages:

- A clear signal would be sent to the scientific and engineering communities that USDA is committed to the competitive grants program.
- The leader of the competitive grants program would report directly to the assistant secretary for science and education and would have policy status within the department comparable to the status accorded to the heads of comparable research agencies—for example, the director of the National Institutes of Health (NIH) within the U.S. Department of Health and Human Services and the assistant directors of the National Science Foundation (NSF), who are responsible for each of the major units.
- The leader of the competitive grants program would, as noted, also have policymaking status comparable to that of the heads of the other units within USDA's Office of Science and Education (ARS, ES, and CSRS), whose budgets are generally comparable in size.
- Other USDA agencies, other federal science agencies, and private and public universities would have fair and equitable access to the program.

Under this option, probably only straightforward institutional changes would be necessary and procedural continuity would be ensured.

Option II: Retention within the Cooperative State Research Service

The increased expenditures for competitive grants could continue to be administered by CRGO within CSRS. New professional and support staff positions could be established as needed.

This approach would

- Avoid any need for institutional or legislative changes and ensure procedural continuity.
- Minimize the need to consider other organizational and institutional issues.

Yet this approach has several disadvantages. It would

- Fail to give the competitive grants program greater visibility and stature and foreclose options in strengthening it administratively.
- Lodge decisionmaking authority and budget advocacy for the competitive grants program at an inappropriately low level within USDA's Office of Science and Education.
- Complicate the interactions between CRGO program scientists and the scientists of other agencies, both within USDA and across the government.
- Be less likely to attract top scientists and administrators to positions of program leadership and service.

Option III: Creation of a Separate Institute

A separate institute within ARS could be similar to those of NIH. Some science policy analysts and political leaders have suggested that NIH could be a model forexpanding the scope and improving the quality and responsiveness of USDA's scientific programs. Most NIH research institutes have both intra-and extramural programs. The crux of this option, as it has been suggested, involves the transformation of ARS into the intramural unit of such an institute and removal of the competitive grants program from CSRS. This would lodge it in the institute as the institute's extramural arm. In addition, both the intra-and extramural components of ARS's ongoing research programs would be changed in other ways to strengthen the quality and importance of scientific input in setting priorities and adjusting budgets. The agency's program planning and peer review procedures would also be changed to more closely match those used by NIH.

The advantages of this option are that it would

- Send a strong signal to the scientific community that a major change is under way in the organization and funding of major USDA-supported federal research and development programs, particularly the competitive grants program and ARS.
- Provide a mandate to USDA administrators to follow the proven NIH model.
- Strengthen ARS as an agency by bringing its administrators and scientists into more direct and frequent contact with colleagues in the academic community and the private sector.

This option has disadvantages, however

- It would require substantial legislative change that, in turn, would require a political consensus that would probably prove elusive.
- The traditional balance and relationships among ARS, CSRS, and ES would most likely change significantly, since ARS would be markedly strengthened at the expense of CSRS and at some cost, too, to ES.

- New responsibility would be placed on the administrators of ARS.

After considering these three options, the Board on Agriculture believes the expanded competitive grants program should be a new, fourth unit in USDA's Office of Science and Education, coequal with ARS, ES, and CSRS.

PROGRAM TRANSITIONS

No matter which organizational option is selected, the staff of the competitive grants program will need to secure advice and guidance in defining the needs of the program areas and the scientific and technological opportunities and areas to be emphasized. An additional challenge—one that is important in all competitive grants programs—is to determine the appropriate composition of peer review panels. Administrative questions will also arise as the program's funding increases by $500 million annually.

Program Planning and Advisory Committees

Advice and guidance will be needed—at inception and throughout the program—on a number of key issues, including (1) defining the mission, objectives, and short-and longer-term priorities for each program area; (2) identifying priorities across and among the program areas; (3) ensuring that the areas and quality of science and technology are appropriate; (4) evaluating the results of the research in relation to the mission of the program areas; (5) giving special attention to the results from and value of the multidisciplinary team and research-strengthening grants in each program area; and (6) evaluating the overall effectiveness of the program.

An important mechanism for providing the staff with guidance in defining opportunities is an advisory committee for each of the six program areas. Each advisory committee would be composed of scientists drawn from the range of disciplines critical to advancing science and technology within that particular program area. In addition, individuals from outside the scientific community who have special expertises and perspectives relevant to the program area should also be committee members. Examples of such individuals are producers; processors; leaders from the social, consumer, and environmental sectors; government leaders and policy experts; and leaders from business and industry. The help of people from outside the scientific community is particularly important in evaluating the relation between the program conducted and the mission of the program area.

Ideally, the advisory committees would include both public and private sector scientists. Participation by private sector scientists on such advisory committees is highly desirable and can lead to valuable exchanges of views on the evolving character of practical problems, on the promise of new science and technology, and on ensuring linkages between public and private sector scientists; between science and technology and their further development, innovation, and application; and between science opportunities and the needs of the program area.

Committee members would also include some scientists with basic research experience, some with applied research experience, and some with multidisciplinary research experience. And some members would be experienced in dealing with the market, policy, and institutional forces that shape the relationship between science and society.

The disciplinary composition of the program planning advisory committees could evolve over time, corresponding to changes in science as well as to changes in economic, social, or regulatory concerns.

The six advisory committees would provide the six major program areas with the same kind of overall guidance that the Joint Council for Food and Agricultural Sciences and the Users Advisory Board provide to the USDA Office of Science and Education. In form and function, the advisory committees could be modeled on similar program planning committees used by NIH and NSF (see the box "Program Planning at NIH and NSF").

The Peer Review Process

Ensuring the proper composition and functioning of peer review panels is another important ongoing administrative challenge. This issue is especially critical because people with different backgrounds have different useful views on alternative research strategies. Panels must include people who, collectively, have the capacity to judge the quality of proposals and to recognize the most promising opportunities to advance science and technology and solve problems. Drawing panel members from throughout the scientific community is important to ensure that problems are approached with the most promising and creative strategies, even if they are less proven, and not just with traditional strategies.

Program Planning at NIH and NSF

Competitive grants programs administered by the NIH, NSF, and USDA all use program planning advisory councils or committees to help in the identification of scientific priorities. (Within all three agencies it is the peer review panels in each scientific area that provide the scientific evaluation for awarding grants.)

In each agency, the process of determining the research emphasis has formal and informal components, both of which involve a series of interactions among "bench" scientists, senior program staff, and appointed advisory groups. The informal, or consensus-building, component centers on the peer review process used in evaluating grant proposals. That process provides an ongoing, effective way of monitoring new advances and opportunities in science, because ideas on programs and policy issues often surface from discussions among program staff and scientists during the peer review meetings. For example, the concept of initiating a special effort to map the human genome was raised several times in informal discussions by peer review panels before advisory groups were convened to debate the scientific and policy aspects of instituting such a program.

The formal component of determining the research emphasis is special to each institution.

At NIH, each institute has an advisory council to review and take action on program and policy. The advisory councils are composed not only of outstanding scientists but also of members of the public with demonstrated interests in the health program areas of the particular institute. (Each institute has a specific mission within the field of human health, with the exception of the National Institute of General Medical Sciences, whose mission is to conduct and support research in the basic medical sciences of significance to two or more institutes, or in research areas that fall outside the general area of responsibility of any other institute.)

The knowledge base the advisory councils draw upon when making major decisions about program direction and policy is based on the two levels of review that competitive grants proposals at NIH proceed through. The first level is strictly scientific-a review of the scientific merit of the proposal-and is carried out for all institutes by the Division of Research Grants. The second level of review combines the scientific evaluation from the first-level review with an assessment of the relevance of the proposed research to the mission of the institute. This review is performed by advisory councils and their grant review committees.

NSF has a broad and general charge to promote the progress of science, in contrast to other government agencies that support research targeted at more specific missions. Within NSF, changes in programs and funding initiatives are directed more by scientific opportunities and the general need for skilled human resources than by needs arising from any specific public mission. The National Science Board (NSB), whose members represent all areas of science and are from research institutes, universities, and industry, advises the director of NSF on the structuring of programs, budget priorities, and other key initiatives. The NSB is also required to take action on all grant awards that exceed $6 million.

In developing annual program announcements, each NSF directorate takes NSB guidance about priorities into account. These announcements encourage investigators to submit proposals in certain areas.

USDA has also established a competitive grants program advisory committee. Its purpose and activities are still evolving, and USDA is continuing to try to put into place more effective ways of using the insights and skills of the committee's members in identifying and acting upon program priorities.

Efforts must be made to broaden the expertise represented on review panels so that the panels can fully evaluate the quality and relevance of proposed research. In addition to a broad representation of experts from different disciplines, panels should include people from different levels of the research process to help judge the relevance of the proposed research. For example, reviewers of fundamental research proposals should include representatives with backgrounds in applied research, and reviewers of applied research proposals should include individuals with backgrounds in fundamental research.

A reliable way of ensuring that peer review panels are not limited in their vision of science and technology opportunity is to have a varied group of scientists serve on panels on a rotating basis. When the membership of a panel rotates regularly and is made up by individuals from a range of disciplines, from a variety of institutional affiliations, and with a breadth of research experiences, there will be greater recognition and support of creative approaches.

Each major program area likely will need several peer review panels to review proposals, and more than one panel may need to review some proposals. As a general rule, to justify the cost of convening a panel and yet to avoid imposing excessive work loads on panel members, each panel should review at least $5 million but generally not more than $15 million in requests. Accordingly, if $50 million is appropriated to a given major program area, at least 4 and up to 10 panels might be convened in each major program area. From year to year, the number and composition of panels might warrant adjustment in light of the amount of funding appropriated to each major program area, the types of grants sought by investigators, and the diversity of scientific approaches proposed.

Evaluation of multidisciplinary team grant proposals requires special attention and is discussed in a later section of this chapter.

Administrative Changes

The four features of this proposal that require an increase in funding from about $50 million to $550 million are the following:

- Expanding the number of major program areas from three to six and allotting a minimum of $50 million to each.
- Offering four types of grants, including two types of multidisciplinary team grants.
- Increasing the average annual grant per principal investigator to $100,000.
- Extending the duration of grants from 2 years to 3, 4, or 5 years.

Although the proposed increase in funds is large, the administrative burdens associated with awarding $550 million would not differ greatly from those associated with the current program. Only the first two features will need to be accompanied by significant administrative changes. A program advisory committee (or council) will have to be appointed, staffed, organized, and started for each program area (concurrently, a decision will have to be made on the fate of the current CRGO advisory committee). To administer the three new major program areas, the competitive grants office will have to secure additional staff assistance and appoint peer review panels. Procedures and program announcements will have to be expanded to provide grant applicants with guidance on the program areas, the four types of grants and how they will be evaluated, and the special requirements of multidisciplinary team grants.

Otherwise, the administrative changes will be minor. In recent years the program has reviewed 2,000 or more proposals in an annual program cycle, awarding some 400 to 500 grants (averaging about $100,000 per grant—$50,000 per year for 2 years). Under a fully funded program consistent with that proposed here, if the success rate for awards were to increase from 22 to 32 percent (approximating the current rate at NIH), the competitive grants office would award just over 1,000 grants each year (see Table 3.7 for the average expected amounts awarded through each type of grant) and would have to review 3,000 proposals, or 1,000 more than it does at present.

NEED TO MANAGE FOR MULTIDISCIPLINARY SUCCESS

The need for multidisciplinary research—both fundamental and mission-linked—is widely recognized in the agricultural, food, and environmental community, particularly among producers, processors, and farm organizations and those within other parts of the private sector. Likewise, the difficulty of funding truly multidisciplinary research is widely acknowledged. Accordingly, this initiative has emphasized the need to provide a significant new source of support for multidisciplinary research (see Chapter 3).

The management of multidisciplinary grants, however, raises both scientific and administrative issues. They include

- selecting peer review panels whose membership is suitable for evaluating the proposals, because most members are likely to be experts in the relevant discipline, some are likely to be experts in cognate disciplines that can advance understanding of the proposed research, and a few are likely to be experienced in multidisciplinary research;
- avoiding undue disciplinary biases, yet ensuring major scientific strength;
- ensuring that the mission-linked proposals relate to major problems, yet also focus on scientific advances and do not have only a practical orientation;
- ensuring that the plan of study is appropriate for the proposal's objectives;
- evaluating the results and the processes used so that they become a basis for increasing the effectiveness of subsequent multidisciplinary research;
- creating and sustaining effective linkages between mission-linked research and the development and applications sectors; and
- managing the grant, the research, and the relationships so that the grant's objectives are achieved.

Managing the proposed multidisciplinary aspects of the competitive grants program can proceed from, and build on, an already strong base of experience and results: the McKnight grants (a forerunner of the proposed grants), NSF's centers of excellence programs, and NIH's program and training grants. Furthermore, the state agricultural experiment stations (SAESs) are, to a large extent, built on the multidisciplinary model, particularly with respect to strong mission linkages to the development and applications sector (e.g., the Cooperative Extension Service).

Multidisciplinary grants programs offer significant roles for scientists from federal agencies such as ARS and NIH, from universities both within and outside the SAESs, and from the private sector. Federal agency and SAES scientists, with their long experience in multidisciplinary research, can help identify priorities, evaluate proposals and results, and evaluate the management systems proposed for the research. Cooperative extension staff, too—both SAES scientists with extension responsibilities and extension specialists and advisers—can be directly involved in mission-linked multidisciplinary team research. They could serve as research staff, adapt results to site-or region-specific conditions, develop new technologies, adapt existing technologies to new conditions, and disseminate research results and information about the applicability of technologies.

Nevertheless, USDA should not expect to resolve in 1 or 2 years, in a normal manner, all the scientific and administrative issues that will arise in the context of awarding the two types of multidisciplinary grants. Special efforts will probably also be needed. Extra time and attention may well have to be given to determining how best to advance science through multidisciplinary interactions. In the first few years of grant making, special attempts should be made to assess both the successful and the less successful projects in an effort to determine the evaluation criteria and features of proposals that warrant attention in future years. These insights can then become the basis for improving the criteria and the selection and administrative procedures.

In addition, institutions and scientists must find a mutually acceptable basis for collaboration, overcome career advancement barriers, and secure suitable longer-term funding. Partnerships must form across disciplines and sometimes between public and private sector scientists—and if money is available for team research, they will. Since real-world problems are evolving constantly, ongoing research will benefit if several scientists with varied experiences attempt to provide a solution to a problem. Partnerships also will help facilitate the processes of developing and transferring information and technology—a key objective if the nation is to capitalize more quickly on science and technology breakthroughs.

PROGRAM EVALUATION AND ACCOUNTABILITY

A program with an increased investment of the magnitude now being proposed should be systematically assessed to see how well its goals are being met. Another reason to conduct ongoing evaluations is the proposal's several unusual features: a strong emphasis on multidisciplinary grants, the new type of mission-linked team grant, the research-strengthening grants, and the breadth of the program areas covered by the grants. All of these features make ongoing program evaluation particularly important.

Five questions will be central in the evaluations:

1. Are science and technology priorities within the major program areas defined insightfully and do they relate to national needs?
2. Are scientists from across the entire science and technology community seeking grants and submitting high-quality proposals?
3. Are the four types of grants achieving their intended purposes?
4. Is the program effectively linked to, and does it routinely communicate with, other USDA programs, programs of other federal science agencies, state programs and needs, and the private sector?
5. Are grantees achieving important science and technology breakthroughs, and are these breakthroughs receiving important and timely application?

Some of these questions can and should be raised annually. Others, particularly the last one, should be assessed at longer intervals, after a realistic amount of time has passed and sufficient experience with the program has been gained. At that time it will also be important to assess whether adequate funding is being awarded through the two types of multidisciplinary grants and whether adjustments are needed in administrative criteria or procedures to more effectively encourage top-quality multidisciplinary research activides.

Appendixes

A

Public and Private Sector Programs and Funding Trends

Agricultural, food, and environmental programs are funded by a variety of public and private sector sources. This appendix provides an overview of the funding trends of the U.S. Department of Agriculture (USDA), other federal agencies, and public sources. The first section describes federal research and development (R&D) expenditures by agency and area of science. The second section surveys 1989 budget authority levels of USDA agencies and recent expenditure levels, trends, and priorities by major mission within USDA. The final section provides an overview of the publicly funded R&D system as it relates to agricultural and forestry research and recent expenditures.

Federal R&D Expenditures by Agency and Area of Science

The history of federal support for R&D since World War II has been marked by significant but uneven growth, depending on the area of research being examined. Since 1980 there has been a dramatic shift toward military R&D compared with that for civilian research. Total federal R&D expenditures rose over 420 percent (in constant 1982 dollars) between 1955 and 1988 ($12.177 billion to $51.250 billion). Table A.1 shows this trend and the percentage of the total for each government agency.

The trend in federal support for agricultural research in the U.S. Department of Agriculture has been among the most constant and slowest growing across the various agencies of the federal government. Within USDA, support for different agencies and areas of research has shifted gradually over the years (for details see the section below entitled "Overview of the Publicly Funded R&D System"; also see the boxed article "Appropriations, Obligations, and Expenditures").

Many federal agencies have experienced dramatic shifts in available R&D funding. Behind each major shift lies some combination of profound events or change in national priorities. The energy crisis driven by the Organization of Petroleum Exporting Countries (OPEC) in the mid-1970s pushed U.S. Department of Energy (DOE) R&D expenditures upward from $3.548 billion in 1975 to $6.040 billion in 1979 as the search for alternative energy sources intensified. (Comparisons across years have been adjusted to constant 1982 dollars unless otherwise noted. Price deflators used to calculate constant 1982 dollars are given in Table A.2.) The worldwide collapse in oil prices and a loss of confidence in advanced nuclear power and oil shale technologies that were pursued aggressively by DOE contributed to a 33 percent drop in DOE R&D expenditures since reaching a peak of $6.040 billion in 1979. The meteoric rise in funding for the National Aeronautics and Space Administration (NASA)—$0.207 billion in 1955 to $17.374 billion in 1965—marked the beginning of the Apollo space program and the early years of space exploration. Expenditures for NASA have since retracted to about $3.636 billion in 1988.

Figure A.1 displays the trends graphically and highlights the dominance of U.S. Department of Defense (DOD) and NASA spending in determining changes in the overall federal R&D.

Trends in funding of civilian R&D are displayed in Figure A.2. Research funding for USDA has remained nearly stable over the period. National Science Foundation (NSF) funding has grown steadily since the early 1980s. U.S. Department of Health and Human Services (DHHS) funding has increased steadily and consistently over the past 30 years. As with

DOD and NASA (Figure A.1), DOE has experienced much more volatile funding trends.

Table A.1 Trends in Federal Obligations for Total Research and Development, by Major Agency, FY 1955–1988

Year	USDA	DHHS	NSF	DOE	NASA	All Other Agencies	Total Nondefense Agencies	DOD
Values Adjusted to Constant 1982 Dollars (in millions)								
1955	$347	$327	$46	$1,574	$207	$325	$2,586	$9,591
1960	505	1,284	300	3,059	1,483	759	7,390	22,938
1965	788	3,050	657	4,353	17,374	1,156	27,525	23,753
1970	738	3,205	758	3,533	9,974	2,410	20,941	19,319
1975	728	4,155	1,031	3,548	5,311	2,603	17,376	15,620
1980	804	4,421	1,031	5,560	3,783	2,938	18,357	16,352
1985	837	4,865	1,195	4,410	2,955	2,227	16,490	26,458
1988	778	5,079	1,379	4,027	3,636	1,862	16,761	34,489
Agency Percentage of Total Annual Nondefense R&D Funding								
1955	13.4	12.6	1.8	60.9	8.0	12.6	100	
1960	6.8	17.4	4.1	41.4	20.1	10.3	100	
1965	2.9	11.1	2.4	15.8	63.1	4.2	100	
1970	3.5	15.3	3.6	16.9	47.6	11.5	100	
1975	4.2	23.9	5.9	20.4	30.6	15.0	100	
1980	4.4	24.1	5.6	30.3	20.6	16.0	100	
1985	5.1	29.5	7.2	26.7	17.9	13.5	100	
1988	4.6	30.3	8.2	24.0	21.7	11.1	100	

NOTE: Totals are not exact because of rounding. Abbreviations: USDA, U.S. Department of Agriculture; DHHS, Department of Health and Human Services; NSF, National Science Foundation; DOE, Department of Energy; NASA, National Aeronautics and Space Administration; DOD, Department of Defense.
SOURCE: Adapted from National Science Foundation. 1955–1988. Federal funds for research and development, detailed historical tables: Fiscal years 1955–1988. P. 22–38, Table B, in Federal Obligations for Total Research and Development by Major Agency and Performer. Fiscal Years 1955–1988, Table B, in Federal Obligations for Total Research and Development by Major Agency and Performer: Fiscal Years 1955–1988. Washington, D.C.: Division of Science Resources Studies, National Science Foundation.

Research Shares by Area of Science

Federal R&D priorities have shifted considerably in the 1980s, as is evident in Table A.3, which shows the percent share of total federal R&D by field of science in FY 1980 and 1988.

The decline in the relative share of federal research expenditures committed to agriculture in the 1980s—from 3.86 to 3.22 percent (see Table A.3)—is a result of two factors. First, the expenditures on agricultural research have not kept pace with inflation, and real funding for other areas of research has increased substantially. It is noteworthy that the two science and technology fields that have experienced large declines in relative research shares—agriculture and engineering—are the two areas most closely tied to the economic performance of several major sectors of the economy.

Support for agricultural research throughout the 1980s was constrained by several factors. The strong commercial performance of U.S. agriculture in the

1970s reinforced the view that U.S. agriculture enjoyed a sizable technological advantage relative to other countries. Funding for agricultural science and technology appeared less pressing than other needs in the USDA budget. As the economic crisis within agriculture emerged in the 1980s, the U.S. Congress was compelled to rapidly and markedly increase farm income support payments, despite a growing national budget deficit and progressively tight fiscal constraints. Farm credit and disaster relief programs became much more costly, and a major new soil conservation program began to push erosion control expenditures upward sharply in the FY 1987 budget.

Appropriations, Obligations, and Expenditures

It is important to understand what research funding data represent. Accurate data on public support for research are available from several different sources, but the aggregation and comparison of such data from different sources can be difficult and sometimes confusing. The data presented in the tables and figures in this appendix have been identified by source; and care has been made to distinguish among budget requests, appropriations made by law, obligations made by government agencies, and records of actual expenditures. A brief description of what each of these means is given here.

The federal government's fiscal year runs from October 1 to September 30 of the calendar year that names the fiscal year (FY); hence, FY 1990 begins on October 1, 1989. For each fiscal year, government agencies prepare a budget request that goes forward to the U.S. Congress in the January preceding the fiscal year as part of the President's budget proposal. Congress responds to these budget requests by preparing and passing appropriations bills to be signed into law by the President. Appropriations bills, as law, specify what monies can be obligated and spent by an agency and for what purposes. The appropriation is the budget authority against which an agency obligates funds during that fiscal year. Normally, funds appropriated but not obligated during the fiscal year are returned to the U.S. Treasury. The actual expenditure of obligated funds might be spread out over several years. One example of this is a 3-year research grant. The total dollar amount of the grant for the full 3 years may be obligated in 1 fiscal year, but expenditures against the grant occur over 3 years.

Because Congress often modifies a budget request before it becomes law, it is important to distinguish between a budget request and an appropriation or budget authority. Since agencies almost always obligate all the funds they are appropriated within a fiscal year, the dollar amount of an agency's budget authority or appropriation is usually identical to the obligations made that year. For example, the FY 1990 budget summary from an agency or the appropriations hearing record from Congress often provides data covering 3 fiscal years: data for FY 1988 are actual obligations since FY 1988 has ended; data for FY 1989 are called current estimates based on the budget authority (i.e., FY 1989 appropriations), because the fiscal year is still in progress and all the obligation of funds will not be completed until September 30, 1989; and data for FY 1990 are simply the budget request to Congress (i.e., what the agency wants to be able to obligate in FY 1990).

One major source of data on research support for agricultural research is the Inventory of Agricultural Research based on the Current Research Information System (CRIS), which records all fiscal year expenditures by USDA research agencies, state agricultural experiment stations, forestry schools, and other related institutions. These data on expenditures are valuable because they itemize funds from federal, state, and other sources. However, it cannot be directly compared or checked against fiscal year appropriations because, as noted above, obligations from one fiscal year can end up as expenditures over several fiscal years.

More detailed data are available from the National Science Foundation on plant biology research among the agencies of the federal government. Table A.4 shows support from federal agencies for competitively awarded research grants for plant biology.

U.S. Department of Agriculture Expenditure Levels, Trends, and Priorities

The USDA's budget authority is summarized in Table A.5. Total department appropriations in 1989 are estimated at $59,644 million. Budget items that individually account for more than a 5 percent share of the total USDA budget authority in 1989 are:

- Food stamps and nutrition programs: $20.437 billion (34 percent of total).
- Commodity Credit Corporation: $15.103 billion (25 percent of total).
- Farmers Home Administration programs: $13.786 billion (23 percent of total).
- U.S. Forest Service: $3.184 billion (5 percent).

Table A.2 Price Deflators for Adjusting to Constant 1982 Dollars

Year	Deflator	Year	Deflator
1955	20.8	1972	43.8
1956	21.9	1973	47.1
1957	22.9	1974	52.2
1958	24.1	1975	57.7
1959	24.6	1976	61.5
1960	24.9	1977	65.8
1961	25.4	1978	70.4
1962	26.3	1979	76.8
1963	26.9	1980	85.5
1964	27.6	1981	93.4
1965	28.5	1982	100.0
1966	29.8	1983	104.0
1967	31.2	1984	108.6
1968	33.1	1985	112.6
1969	35.1	1986	115.3
1970	38.1	1987	119.5
1971	41.0	1988	123.7

SOURCE: Adapted from Council of Economic Advisers. 1988. P. 253, Table B-3, in Economic Report of the President. Washington, D.C.: U.S. Government Printing Office.

The science and education budget authority in 1989 was $1.300 billion, or only 2 percent of total USDA appropriations.

Major Shifts in USDA Budget Priorities

Despite the fiscal discipline required to meet the Gramm-Rudman-Hollings deficit reduction goals in recent years, there has been considerable buoyancy in USDA's budget in recent years. Priorities have not been frozen by fiscal austerity.

Table A.6 summarizes USDA expenditures from 1980 to 1987 in eight major categories. It provides several insights regarding fiscal priorities, as follows:

- Changing levels of price support program expenditures have driven changes in overall USDA spending.
- Nutrition program expenditures—the largest budget function within USDA in the early and late 1980s—have been one of the most stable areas, growing at or just above the rate of inflation in most years.
- U.S. agriculture's economic crisis in the mid-1980s was met by a sevenfold increase in credit and rural development program spending, which rose from $1.024 billion in 1981 to a peak of $7.481 billion in 1985. Funding for these programs has since fallen precipitously.
- Most smaller USDA programs proceed from year to year with nearly stable budgets, including agricultural research and education programs.
- The 10-year Conservation Reserve Program authorized by the Food Security Act of 1985 began exerting a sizable influence on erosion control expenditures in FY 1987. The nearly 30 million acres enrolled in the program in early 1989 will result in about $1.3 billion in expenditures, more than tripling federal funds devoted to reducing erosion. By the FY 1991 budget, 40 million acres are likely to be enrolled, resulting in an estimated expenditure of $1.8 billion each year for 6 years. By FY 1997, when the first 10-year contracts begin expiring, spending will decline if no new land is brought into the reserve program.
- In FY 1980 the $841 million spent on research and education programs constituted 3.4 percent of the USDA total budget and 24.3 percent of total farm price and income support payments; in 1987 the $1.127 billion spent on research and education accounted for 2.2 percent of the total USDA budget and 4.4 percent of farm price and income support expenditures.

Overview of the Publicly Funded R&D System

Agricultural, food, and environmental research is undertaken in all 50 states in a variety of public institutions and in thousands of laboratories, field stations, and other facilities. This research is supported by funds from federal, state, and local governments and a wide range of private sources.

In 1985, in the public and private sectors combined, there were about 23,000 active doctoral-level scientists conducting, managing, or administering food and agricultural research (National Research Council, 1988b). About two-thirds, or 16,000, of these scientists were employed by public programs and academic institutions. Table A.7 presents a breakdown of employment patterns in the food and agricultural sciences in 1985. Note that for each doctoral-level scientist working in the more applied agricultural fields, there are about two scientists working in basic sciences related to agriculture. A major goal of this proposal is to attract more of these nearly 46,000 scientists—people who are well-qualified but who are not provided support for food and agricultural research—into research that addresses agricultural needs. (Statistics on the number of scientists employed by field, including those reported in Table A.7, must be interpreted with caution. The distinctions between basic and applied disciplines often are not clear; some scientists working in applied disciplines are carrying out basic research, and some scientists counted in basic disciplines are conducting applied research.)

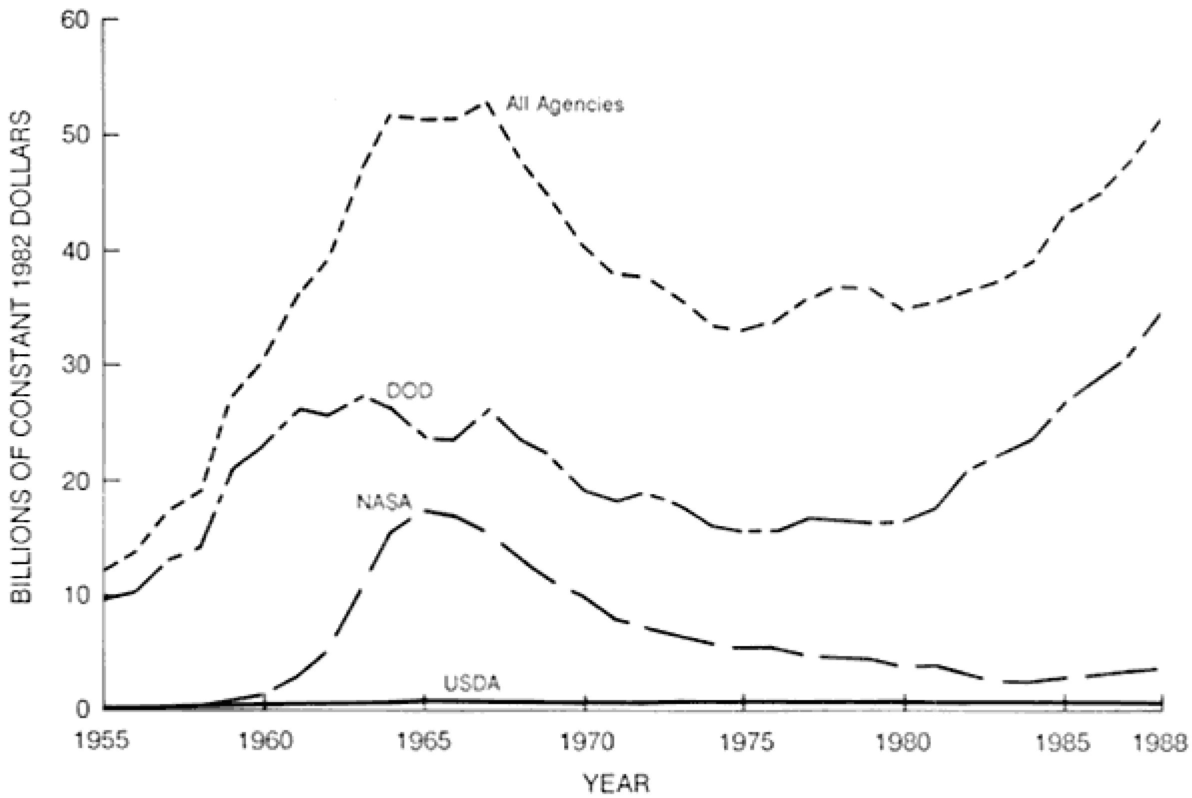

Figure A.1
Trends in federal support for R&D for all agencies and for selected agencies, 1955–1988 (in billions of constant 1982 dollars).
SOURCE: Adapted from National Science Foundation. 1955–1988. Federal funds for research and development, detailed historical tables: Fiscal years 1955–1988. P. 22–38, Table B, in Federal Obligations for Total Research and Development by Major Agency and Performer: Fiscal Years 1955–1988. Washington, D.C.: Division of Science Resources Studies, National Science Foundation.

The publicly funded agricultural research system has three principal missions: undergraduate and graduate teaching, research and technology development, and extension education activities. These three missions link publicly funded researchers and educators with farmers, agribusinesses, community leaders, and others interested in some aspect of agriculture or its effect on resources, communities, or the economy. Extension programs deliver research-based educational programs to producers, small businesses, youth groups, and community and resource development agencies; and they assist in technology transfer.

The key institutions that constitute the publicly funded component of the nation's agricultural and food sciences infrastructure are (1) USDA's Agricul tural Research Service, which is USDA's intramural research agency; (2) USDA's Economic Research Service; (3) USDA's U.S. Forest Service; and (4) the state agricultural experiment stations and cooperative extension services, which are funded in part by USDA but most substantially by state and county governments. Federal and state government agencies have worked in partnership over the years to establish, develop, and create partnerships across these institutions.

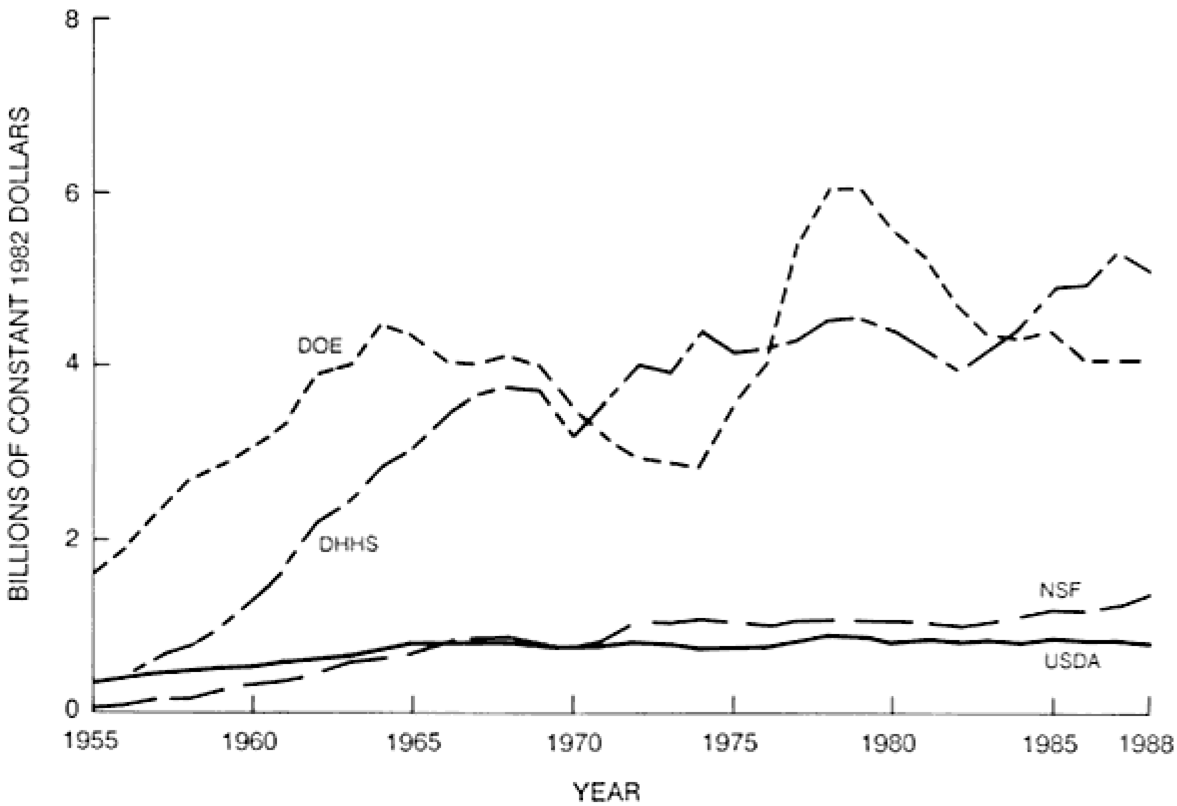

Figure A.2
Trends in federal agency support for R&D for selected civilian agencies, 1955–1988 (in billions of constant 1982 dollars)
SOURCE: Adapted from National Science Foundation. 1955–1988. Federal funds for research and development, detailed historical tables: Fiscal years 1955–1988. P. 22–38, Table B, in Federal Obligations for Total Research and Development by Major Agency and Performer. Fiscal Years 1955–1988. Washington, D.C.: Division of Science Resources Studies, National Science Foundation.

Agricultural Research Service

The Agricultural Research Service (ARS) conducts basic and applied research, some of it targeted at helping USDA agencies resolve scientific and technical issues that arise as they fulfill their program responsibilities. It carries out programs in six major areas (see Table A.8), and its FY 1989 estimated appropriation is $568 million. The ARS employs about 2,670 scientists and engineers, about 2,500 of whom have doctoral degrees. Thus, ARS scientists account for a little more than 10 percent of the current total doctoral-level scientists in agricultural research reported in Table A.7. (Appendix D includes a list of current ARS research objectives, as articulated in the agency's most recent 5-year plan.)

In planning and carrying out its research programs, the ARS works closely with other federal research agencies, as well as with USDA's mission agencies that rely on technology and science to carry out their program responsibilities. For example, the ARS has cooperative agreements with several USDA agencies to conduct a variety of research activities. Table A.9 lists some of the research called for in these agreements.

The ARS conducts research at some 127 domestic and 7 foreign locations, including five major regional

Table A.3 Relative Shares of Federal Research Obligations, by Field of Science, FY 1980 and 1988

	Billions of Dollars		Relative Share of Total Research (%)	
Field of Science	1980	1988	1980	1988
Life sciences	4.903	5.935	36.15	39.39
Agricultural	0.523	0.486	3.86	3.22
Biological	2.410	3.043	17.76	20.20
Medical and life sciences	1.970	2.406	14.53	15.97
Physical sciences	2.340	2.798	17.25	18.57
Engineering	3.311	3.328	24.40	22.08
Other sciences	3.010	3.006	22.20	19.96
Total research	13.564	15.067	100.0	100.0

NOTE: Data are compiled by NSF under the three categories of research, development, and application. Research data only are included here.
SOURCE: Adapted from National Science Foundation. 1980 and 1988. Federal funds for research and development, detailed historical tables: Fiscal years 1980 and 1988. In Federal Obligations for Total Research and Development by Major Agency and Performer: Fiscal Years 1980 and 1988. Washington D.C.: Division of Science Resources Studies, National Science Foundation.

Table A.4 Federal Support for Plant Biology Academic Basic Research, FY 1978–1989 (in millions of dollars)

Agency	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
NSF	22.2	26.1	28.3	34.1	41.4	43.4	52.4	60.6	57.6	61.8	64.2	69.7
USDA	9.6	9.7	12.2	12.6	13.0	14.5	14.5	26.9	25.6	25.6	24.6	NA
DOE	18.9	19.4	23.6	27.5	20.6	21.5	24.1	25.2	24.6	27.9	30.8	31.0
NIH	NA	NA	NA	NA	20.0	20.0	20.0	21.0	25.0	27.0	29.0	32.0
NASA	NA	NA	0.9	1.2	0.9	1.0	1.4	1.5	1.6	1.0	1.0	1.0
Total					95.9	100.4	112.4	135.2	134.4	143.3	149.6	

NOTE: Values for FY 1989 are estimates. NA, Not available. NIH, National Institutes of Health.
SOURCE: Adapted from data compiled by the Interagency Plant Science Committee, National Science Foundation, Washington, D.C., 1989.

Table A.5 U.S. Department of Agriculture Budget Authority by Organizational Units and Agencies, 1990 Budget Summary (in thousands of dollars)

Organizational Units and Agencies	1988 Actual	1989 Current Estimate	1990 Budget
Science and education			
Agricultural Research Service	$559,493	$584,402	$604,618
Cooperative State Research Service	352,019	340,917	295,398
Extension Service	357,963	361,370	324,840
National Agricultural Library	12,194	13,268	14,947
International affairs and commodity programs			
Agricultural Stabilization and Conservation Service	1,289,179	2,011,722	1,228,791
Foreign Agricultural Service	92,217	95,417	98,620
Commodity Credit Corporation	11,081,280	15,103,925	12,548,818
Office of International Cooperation and Development	10,008	10,254	8,918
P.L. 480	1,059,596	1,098,100	723,279
Natural resources and environment			
Soil Conservation Service	686,871	704,597	631,950
U.S. Forest Service	2,475,102	3,184,462	2,511,389
Small community and rural development			
Farmers Home Administration	15,231,451	13,786,438	10,799,582
Federal Crop Insurance Corporation	428,523	313,992	388,565
Rural Electrification Administration	1,294,834	1,605,833	129,460
Food and consumer services			
Food and Nutrition Service	20,169,558	20,437,080	20,290,640
Section 32	366,742	405,873	522,746
Temporary Emergency Food Assistance Program	50,000	170,000	120,000
Human Nutrition Information Service	8,623	8,823	9,468
Marketing and inspection services			
Federal Grain Inspection Service	7,020	8,115	8,255
Animal and Plant Health Inspection Service	336,615	338,753	284,872
Food Safety Inspection Service	393,052	406,004	423,949
Agricultural Cooperative Service	4,611	4,655	2,303
Agricultural Marketing Service	121,500	125,794	119,475
Office of Transportation	2,397	2,397	1,395
Packers and Stockyards Administration	9,402	9,562	9,562
Economics			
Economic Research Service	48,277	49,536	51,914
National Agricultural Statistics Service	61,341	63,788	71,238
World Agricultural Outlook Board	1,730	1,820	2,045
Administration			
Office of the Secretary	5,710	5,953	6,115
Departmental Administration	20,664	21,533	22,500
Office of Budget and Program Analysis	4,252	4,389	4,554

research centers located in Beltsville, Maryland; Wyndmoor, Pennsylvania; Peoria, Illinois; New Orleans, Louisiana; and Albany, California. Many other ARS research facilities are located at or near academic institutions. This allows for some interaction between ARS scientists and faculty of the academic institutions. In addition, some ARS staff hold adjunct faculty appointments and participate in graduate teaching programs.

Organizational Units and Agencies	1988 Actual	1989 Current Estimate	1990 Budget
Hazardous Waste Management	2,000	5,000	25,688
Working Capital Fund	$5,708	$4,708	$3,750
Rental Payments and Building Operations	68,969	70,764	74,268
Advisory Committees	1,308	1,494	1,494
Office of Governmental and Public Affairs	8,673	8,859	9,068
Office of the Inspector General	48,795	50,510	52,530
Office of the General Counsel	18,734	20,836	22,340
Gifts and bequests	1,585	2,328	50
Offsetting receipts	($1,462,378)	($1,798,977)	($1,606,761)
Total, U.S. Department of Agriculture	$55,235,618	$59,644,294	$50,842,633

SOURCE: Adapted from U.S. Department of Agriculture. 1989a. P. 77 in 1990 Budget Summary. Washington, D.C.: U.S. Department of Agriculture.

The relative lack of an economics research capacity in the ARS, coupled with only limited and sporadic interaction with scientists in USDA's Economic Research Service, has been recognized as a problem for years (V. Ruttan, University of Minnesota, personal communication, 1989). An improved capacity to estimate the economic impacts of R&D priorities and technologies within USDA is dependent on progress toward overcoming this problem.

Economic Research Service

The Economic Research Service (ERS) of USDA was established in 1961 "to provide economic and other social science information and analysis for improving the performance of agriculture and rural America" (U.S. Department of Agriculture, Economic Research Service, 1989). It collects and maintains a number of historical data series on farm type, size, and number; production and input levels; trade; effects of farm policy; and socioeconomic characteristics of rural areas of the United States.

The ERS also provides key statistical and analytical support to both the executive and the legislative branches of the federal government. It is called upon not only to quantify the effects of recent policy and market developments but also to estimate the probable future consequences of policy alternatives under consideration.

The work of the ERS is organized into four major divisions, which were supported by a $49.3 million budget in FY 1989 (see Table A. 10). The agency has limited extramural funds to contract for research by the academic sector, but it has never been authorized to administer a competitive grants program that is broadly open to analysts in the academic sector.

An expanded USDA competitive research grants program that includes grants in markets, trade, and policy would greatly increase the collaborative relationship of ERS specialists with other economists and scientists. The expertise and data of the ERS will be pertinent to policy-related studies and the work of

Table A.6 U.S. Department of Agriculture Budget Outlays (Obligations) by Major Mission Area, 1980–1987 (in thousands of dollars)

Category	Function	1980	1981	1982	1983	1984	1985	1986	1987
1	Price and income supports	$3,460,115	$3,992,481	$13,289,910	$20,629,877	$10,469,053	$23,750,359	$29,615,339	$25,495,811
2	Research and education	841,388	924,809	973,647	1,012,530	1,055,615	1,077,361	1,100,790	1,126,714
3	Agricultural land and conservation	2,596,314	2,753,623	2,736,392	2,621,168	2,640,213	2,865,283	2,689,345	2,691,496
4	Nutrition programs	14,016,430	16,204,538	15,580,781	17,872,627	17,996,565	18,470,430	18,512,51,53	18,826,113
5	International commodity assistance	1,126,472	1,303,758	989,731	1,062,823	1,159,104	1,791,365	1,186,216	1,048,060
6	Inspection and and food safety	635,017	747,068	752,349	668,008	746,671	804,404	777,077	790,505
7	Rural development	2,870,387	1,024,682	2,488,384	3,111,829	4,107,123	7,480,822	5,649,713	1,308,767
8	USDA total	$25,803,621	$27,168,776	$37,024,020	$47,252,964	$38,468,615	$56,557,772	$59,855,188	$51,630,807

NOTE: Budget outlay categories are as follows:

1 Price and income supports is the total of Account 351 (Farm Income and Price Supports) as compiled by USDA.

2 Research and education includes the Agricultural Research Service, Cooperative State Research Service, and the Extension Service.

3 Agricultural land and water conservation includes budget Account 302; and the U.S. Forest Service, Conservation Reserve Program, and Natural Resources Management (water) are from Account 301.

4 Nutrition programs include School Lunch; Food Stamps; Women, Infants and Children; Child Nutrition; and other nutrition programs.

5 International commodity assistance includes the 151 Account, the Export Enhancement Program, Targeted Export Enhancement Program, and Foreign Agricultural Service.

6 Inspection and food safety includes the Animal and Plant Health Inspection Service, the Federal Grain Inspection Service, the Agricultural Marketing Service, the Food Safety and Quality Service Trust Fund, and the Food Safety and Inspection Service.

7 Rural development includes budget Account 452 (Farm Home Administration and the Rural Electrification Administration).

8 Total USDA expenditures also include miscellaneous programs and administrative office expenses not included in the previous seven. categories.

SOURCE: Derived from outlay data by budget function provided by the Office of Budget and Program Analysis, U.S. Department of Agriculture, Washington, D.C., 1989.

mission-oriented teams in natural resources and the environment, and plant and animal productivity studies. Other research programs will also find ERS analysts and data to be as important resources for incorporating economic performance measures into biological and physiological assessments of crop and livestock production.

Table A.7 Doctoral-Level Scientists, by Employment Sector, 1985

Employment Sector	Academia[a]	Industry[b]	Government	Total
Applied agriculture[c]	9,900	7,000	3,800	20,600
Animal	2,500	1,100	300	3,900
Plant and soil	3,200	1,300	800	5,300
Food	700	1,800	200	2,700
Natural resources and environment	2,000	2,000	2,100	6,100
Other	1,500	900	300	2,700
Agricultural economics	1,900	300	400	2,700
Total applied agriculture and agricultural economics	11,800	7,300	4,200	23,300
Agriculture-related basic sciences[d]	31,300	9,600	5,000	45,900

NOTE: Totals are not exact because a small number of Ph.D.'s (less than 0.1 percent) did not report their employment sectors and because of rounding.

[a] This sector does not include postdoctoral students.

[b] This sector includes self-employed Ph.D.'s.

[c] Applied agriculture disciplines include many scientists who conduct basic research.

[d] Agriculture-related basic science disciplines include some scientists who conduct applied research.

SOURCE: Adapted from National Research Council. 1988a. Educating the Next Generation of Agricultural Scientists. Washington, D.C.: National Academy Press.

U.S. Forest Service

Principal federal responsibility for research on the nation's forests and for technologies useful in the manufacture of pulp and wood-based products is vested in the U.S. Forest Service. Table A.11 summarizes funding and personnel trends in U.S. Forest Service research between 1977 and 1989.

Forestry research is wide-ranging. Priority R&D targets include the effects of global climatic change on forest productivity, the behavior of fires and the ways in which ecosystems respond to catastrophic forest fires (like those in Yellowstone National Park in the summer of 1988), issues involving water quality and wildlife, new uses for wood, and increasing productivity through management of the 182 million acres of forestland—much of it private—in 13 southern states. The scientific disciplines that play a part in forestry research range from the basic biological sciences (e.g., genetics and physiology), to pest control and disease specialties (e.g., entomology and pathology), to management of wildlife and ecosystems and several engineering and design specialties.

State Agricultural Experiment Stations

The state arm of the publicly funded agricultural research system is composed of 50 land-grant universities, each of which has a state agricultural experiment station. There are also six historically black state universities that conduct agricultural research and teaching programs. Many faculty members in colleges of agriculture, home economics, and forestry have appointments that split their responsibilities between teaching and research or research and extension; a few are involved in all three activities.

State agricultural experiment station programs and scientists are routinely called upon by state agencies, state legislatures, citizens' groups, the media, and farm organizations to provide solutions to problems, technical assistance, information, and assistance in building consensus among organizations that have differing views on agricultural, food, or conservation policies or differing perspectives on agricultural, food, economic, and conservation issues important within the state. Faculty of land-grant colleges of agriculture and state agricultural experiment stations must balance their commitment to meeting these demands with their teaching or extension responsibilities and their responsibilities to advance science or conduct applied research to help resolve practical problems faced by the state's farmers, agribusinesses, or consumers.

Table A.8 Agricultural Research Service Program Funding Levels (in millions of dollars)

Program	1988 Actual	1989 Current Estimate	1990 Budget
Six major areas			
Natural resources	60.8	66.1	76.1
Plant science	211.7	214.0	214.4
Animal science	93.5	94.5	100.7
Commodity conversion and delivery	105.3	107.8	112.5
Human nutrition	44.4	45.7	45.7
Integration of systems	12.4	13.0	13.0
Repair and maintenance	11.6	21.3	17.7
Contingency research funds	0.9	0.9	0.9
Trust funds	3.5	5.0	5.0
Total, ARS research	544.1	568.3	586.1
Construction			
Buildings and facilities	7.8	16.0	18.5
Total, ARS research and construction	551.9	584.3	604.6

SOURCE: Adapted from U.S. Department of Agriculture. 1989a. 1990 Budget Summary. Washington, D.C.: U.S. Department of Agriculture.

In recent years a growing number of citizens' groups, constituencies, and private sector organizations have become politically active in trying to redefine or modify the focus or balance among teaching, research, and extension activities at land-grant universities and state agricultural experiment stations. These pressures and the states' responses to them differ markedly across the nation. As a result, this component of the public research system is becoming more heterogeneous than it once was.

Funding for research comes from federal formula funds that require one-for-one matching funds by states, as well as additional state appropriations made to the state agricultural experiment stations. Supplementary research funding comes from several sources, including the sale of commodities produced by state agricultural experiment stations, funds from commodity organizations through producer group checkoff programs, grants and contracts from industry, and state and federal grants administered by a large variety of agencies. The boxed article "Formula Funding Mechanisms: Payments to Agricultural Experiment Stations under the Hatch Act" describes the legislative basis for experiment station formula funds.

Table A.12 shows trends in the funding of the Cooperative State Research Service (CSRS), the prin cipal federal R&D agency that provides support to land-grant colleges of agriculture and state agricultural experiment stations. Table A.13 summarizes the trend in research funding at state agricultural experiment stations and cooperating institutions between 1972 and 1987. Until 1965, Hatch Act formula funds accounted for virtually all funding through the CSRS. In that year, and for 5 of the next 6 years, a modest level of funding was provided to build research facilities. Other formula funding through the CSRS budget appropriation began in 1964 with the McIntire-Stennis Forestry Research Act and in 1967 with formula grants to the 1890 institutions and Tuskegee University.

In 1966, a special grant was included in the CSRS budget appropriation. The grant targeted funds for a specific area of research at a specific institution. For the next few years the funding appropriated for special grants remained modest—less than $2 million per year—until major growth in special grant appropriations occurred to $6.8 million in FY 1976, to $15.7 million in FY 1979, and to $32.0 million in FY 1985.

In 1979 competitive research grants as well as animal health and disease research grants (Section 1433) were added to the CSRS budget appropriation.

Table A.14 gives a breakdown of the FY 1988 funds provided to each state, the District of Columbia, and U.S. territories through the CSRS budget. Fiscal year 1988 funding provided by other federal, state, and private sources to state agricultural experiment stations and other cooperating institutions in each state, the District of Columbia, and U.S. territories is shown in Table A.15. For purposes of comparison, the farm income by state or territory is given in Table A.16, and Tables A.17 and A.18 provide comparisons of different funding sources.

Table A.9 Examples of ARS Research That Supports the Program Responsibilities of Other USDA Agencies

Mission Agency	ARS Role (Examples)
Soil Conservation Service	Research on soil erosion prediction equations and improved conservation systems.
Food Safety Inspection Service	Research on hazard evaluation methods in meat and poultry plants; improved rapid assay methods for pathogens and chemical contaminants.
Agricultural Marketing Service	Research on methods to enforce compliance with food labeling, food grading systems, and standards of identity.
Federal Grain Inspection Service	Research on methods to measure the properties and composition of grain and to ensure that grain meets standards of quality; development of more rapid and accurate probes to check for chemical or mycotoxin (such as aflatoxin) contamination.
Human Nutrition Information Service	Research on bioavailability of nutrients; the nutrient compositions of foods; unique dietary needs of special population groups, including the aged and children.
Animal and Plant Health Inspection Service	Research on integrated pest management strategies to control grasshoppers; the detection and elimination of blue tongue and brucellosis; management strategies to control livestock pests; methods to detect pathogenic diseases in imported plants, animals, and genetic materials.

SOURCE: Compiled by the Board on Agriculture from communications with officials of the Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C., 1989.

Table A.10 Economic Research Service Program Levels, FY 1989

Division	Millions of Dollars	Staff-Years
Commodity analysis	9.6	192
Agricultural and trade analysis		
Trade and policy	2.6	51
Agricultural and trade indicators	1.0	22
Developed market economies	1.3	26
Developing economies	1.4	29
Centrally planned economies	0.9	16
Other	0.6	12
Division total	7.8	156
Resources and technology		
Natural resources	2.4	49
Resource policy	1.2	26
Inputs, technology, productivity	1.9	12
Other	1.7	34
Division total	7.2	121
Agricultural and rural economy	10.8	160
ERS total[a]	49.3	860

[a] The totals include other extramural and administrative activities.

SOURCE: Adapted from U.S. Department of Agriculture, Economic Research Service. 1989. The ERS in 1989. April. Washington, D.C.: U.S. Department of Agriculture.

Table A.11 U.S. Forest Service Research Program Levels, 1977–1989

Budget and Personnel Levels	1977	1981	1985	1989
Total budget (millions of constant 1982 dollars)	129.4	115.0	102.3	107.1[a]
Extramural research	11.4	12.8	6.7	NA
Percent extramural	8.8	11.1	6.5	NA
Personnel levels (person-years)				
Scientists	949	958	799	NA
Support	1,591	1,662	1,601	NA

NOTE: NA, Not available.

[a] In estimated 1982 dollars by using the 1988 deflator of 123.7. Adapted from U.S. Department of Agriculture. 1989a. 1990 Budget Summary. Washington, D.C.: U.S. Department of Agriculture.

SOURCE: Adapted from Giese, R. L. 1988. Forest research: An imperiled system. Journal of Forestry 86(June):15–22 (Table 3).

Formula Funding Mechanisms: Payments to Agricultural Experiment Stations under the Hatch Act

Funds under the Hatch Act are allocated to the state agricultural experiment stations of the 50 states, the District of Columbia, Puerto Rico, Guam, the Virgin Islands, Micronesia, American Samoa, and the Northern Mariana Islands for research to promote sound and prosperous agriculture and rural life. The Hatch Act provides that the distribution of federal payments to states for FY 1955 shall become a fixed base and that any sums appropriated in excess of the 1955 level shall be distributed in the following manner:

- 20 percent shall be allotted equally to each state;
- not less than 52 percent shall be allotted to the states as follows:

—one-half in an amount proportionate to each state's share of the total rural population of all states, and
—one-half in an amount proportionate to each state's share of the total farm population of all states;

- not more than 25 percent shall be allotted to the states for cooperative research in which two or more state agricultural experiment stations are cooperating to solve problems that concern the agriculture of more than one state; and
- 3 percent shall be available to the secretary of agriculture for the administration of the act.

The Hatch Act also provides that any amount in excess of $90,000 available for allotment to any state, exclusive of the regional research fund, shall be matched by the state out of its own funds available for research and for the establishment and maintenance of facilities necessary for the performance of such research. Also, in the case of Guam, the Virgin Islands, Micronesia, American Samoa, and the Northern Mariana Islands, agencies are required by law to waive any requirement for local matching funds for federal formula funds under $200,000.

Three percent of funds appropriated under the Hatch Act is set aside for federal administration, which includes disbursement of funds and a continuous review and evaluation of the research programs of the state agricultural experiment stations supported wholly or in part from Hatch Act funds. USDA's Cooperative State Research Service encourages and assists in the establishment of research linkages and partnerships within and between the states and actively participates in the planning and coordinating of research programs between the states and the department at the regional and national levels.

Competitive Research Grants Office

The USDA competitive research grants program is lodged administratively within CSRS. Table A.19 shows competitive grant funding trends and program areas from FY 1978 through FY 1989.

Extension Service

The Extension Service is the third federal agency in the science and education system in USDA. Extension is responsible for education and technology transfer activities designed to bring to farmers the scientific progress made through research. The USDA Extension Service provides formula funding to the states under the Smith-Lever Agricultural Extension Act. States are required to provide a one-to-one match of the federal formula funds. Funding for extension activities also comes from other state appropriations and in many instances from local county and regional governments. The coordinated federal, state, and local extension activities are collectively referred to as the Cooperative Extension Service.

Many faculty members at state land-grant universities have appointments with academic departments that are split across two or three missions and sources of funding. A common appointment would include 25 to 50 percent research supported largely by federal formula funds, 25 percent to 50 percent teaching supported by state funds, and 25 to 50 percent extension supported through a combination of federal and state funds. Accordingly, it is important to consider trends in extension funding in evaluating the funding base for academic research, education, and technology transfer activities. Current federal law is judged by most research administrators to prohibit the Exten sion Service from actually carrying out research. As a result, most federal data on USDA R&D activities do not include Extension Service funding levels.

Table A.12 Cooperative State Research Service Program History of Appropriations for Research, FY 1955–1988[a]

Funding Mechanism	1955	1965	1975	1980	1985	1988
Formula funding						
Hatch Act	$18,954	$45,423	$77,036	$118,566	$156,484	$155,545
McIntire-Stennis Act	—	1,000	7,070	10,000	13,053	17,500
Evans-Allen Act, 1890 institutions	—	—	11,824	17,785	23,474	23,333
Animal Health & Disease, Section 1433	—	—	0	6,000	5,760	5,476
Tide V, rural development	—	—	1,500	1,500	—	—
Special research grant[b]	—	—	3,400	15,198	33,230	50,580
Competitive research grants	—	—	—	15,500	46,000	42,372
Forestry competitive grants Other	—	—	—	—	7,840	3,000
Agricultural Marketing Act	500	—	—	—	—	—
Direct federal administration	141	334	919	1,482	1,475	4,094
Total CSRS	$19,595	$46,757	$101,749	$186,031	$287,316	$301,900

[a] Excludes appropriations for research facilities, buildings, and higher education-strengthening grants and fellowships.
[b] Includes other CSRS grant programs: alcohol fuels; rangeland; native latex/critical agricultural materials; agriculture centers; international trade centers; agricultural productivity, Subtitle C; supplemental and alternative crops; and other grants under Section 1472.
SOURCE: Adapted from data compiled by the Budget Office. Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C., 1989.

The USDA Extension Service expenditures in FY 1988, current estimates for FY 1989, and expenditures requested in the FY 1990 budget are presented in Table A.20.

Combined USDA Funding Trends

Agricultural Research Service and formula funds to state agricultural experiment stations have accounted for most USDA support for food and agricultural research. Since 1955, the relative share of USDA research expenditures through ARS has fallen from well over 50 percent to less than 40 percent. Trends in research support by major USDA agency since 1955 are presented in Table A.21.

Higher Education Activities in USDA

Support for the higher education fellowship program was initiated by USDA in 1985 with a $5 million appropriation for training grants and $2 million for strengthening grants. Since 1986, the training grants have received $2.8 million annually and about $2 million has been appropriated each year for grants to strengthen higher education in agricultural research. Several organizations have called for a substantial increase in support for undergraduate and graduate fellowships to help meet the need across the agricultural research sector for talented, highly trained individuals (see, for example, National Research Council, 1988b, p. 34). To help attract scientists to food and agricultural research, the ARS has expanded its postdoctoral fellowship program substantially in the 1980s, and it currently offers 100 awards each year.

Table A.13 Sources of Expenditures to State Agricultural Experiment Stations and Other Cooperating Institutions, FY 1972–1987

Funding Source	1972	1977	1982	1987
Federal				
USDA	21.6	21.1	22.2	18.4
CSRS				
Formula	18.8	16.4	16.1	12.3
Other	0.9	2.7	2.7	3.6
Other USDA	1.9	2.0	3.4	2.5
Other federal	7.8	8.9	10.2	10.2
State appropriations	56.6	54.9	51.6	53.8
Product sales	6.4	6.3	5.9	5.2
Industry	4.6	5.3	5.8	6.5
Other	3.0	3.5	4.3	5.9
Percentage total	100.0	100.0	100.0	100.0
Total funding (in millions of dollars)	363	622	1,058	1,449
Scientist-years	6,058	6,919	7,531	7,821
Dollars/scientist-year (in thousands)	60	90	140	185

SOURCE: Adapted from U.S. Department of Agriculture, Cooperative State Research Service. 1973, 1978, 1983, 1988. Inventory of Agricultural Research, Fiscal Years 1972, 1977, 1982, and 1987. Washington, D.C.: Cooperative State Research Service, U.S. Department of Agriculture.

Table A.14 Cooperative State Research Service for funding for Agricultural, Forestry, and Veterinary Research and Development, federal Obligations by State or Territory, FY 1988

State or Territory	Formula[a]	Other Formula[b]	Special Research Grants	Competitive Research Grants[c]	Higher Education Grants	Research Facilities and Federal Administration[d]	Total CSRS Funds
Alabama	$3,366,014	$3,331,309	$101,381	$183,000	$254,994	$0	$7,236,698
Alaska	836,050	329,110	5,000	0	50,000	0	1,220,160
Arizona	1,637,354	314,729	373,145	875,000	50,000	4,437,750	7,687,978
Arkansas	2,902,616	1,744,767	486,860	210,000	152,497	363,750	5,860,490
California	4,294,758	962,867	2,716,305	6,351,327	338,000	0	14,663,257
Colorado	2,259,405	545,027	243,611	605,000	146,000	0	3,799,043
Connecticut	1,543,601	211,575	185,338	237,000	50,000	0	2,227,514
Delaware	1,089,885	574,783	0	0	152,496	0	1,817,164
District of Columbia	476,964	0	0	110,709	152,497	0	740,170
Florida	2,447,831	1,518,453	1,549,477	945,988	296,496	48,500	6,806,745
Georgia	3,954,450	2,177,963	1,453,202	1,535,775	200,497	48,500	9,370,387
Hawaii	1,099,005	140,837	2,559,929	30,000	50,000	7,713,558	11,593,329
Idaho	1,770,136	461,835	435,927	191,800	50,000	0	2,909,698
Illinois	4,584,251	406,121	2,749,860	2,059,207	290,000	0	10,089,439
Indiana	4,122,088	400,690	598,331	1,241,014	50,000	0	6,412,123
Iowa	4,850,957	451,842	781,346	571,550	338,000	6,183,750	13,177,445
Kansas	2,842,448	316,593	3,183,009	947,000	98,000	0	7,387,050
Kentucky	4,166,166	2,106,843	513,830	444,760	152,496	0	7,384,095
Louisiana	2,696202	1,641,717	645,357	305,000	152,497	0	5,440,773
Maine	1,536,176	542,482	158,916	74,130	50,000	0	2,361,704

State or Territory	Formula[a]	Other Formula[b]	Special Research Grants	Competitive Research Grants[c]	Higher Education Grants	Research Facilities and Federal Administration[d]	Total CSRS Funds
Maryland	$2,069,022	$1,028,897	$288,108	$1,311,222	$200,496	$0	$4,897,745
Massachusetts	1,866,247	262,554	934,133	1,861,368	50,000	0	4,974,302
Michigan	4,192,640	600,915	2,440,946	2,491,946	290,000	0	10,016,447
Minnesota	4,215,434	577,554	578,464	1,275,583	242,000	0	6,889,035
Mississippi	3,473,920	1,972,200	6,530,817	106,243	296,497	1,266,750	13,646,427
Missouri	3,909,750	2,041,592	833,134	978,900	248,497	0	8,011,873
Montana	1,753,480	422,224	189,962	100,000	50,000	0	2,515,666
Nebraska	2,783,752	301,524	1,519,989	294,300	50,000	0	4,949,565
Nevada	1,020,725	77,066	5,000	100,000	50,000	0	1,252,791
New Hampshire	1,200,439	274,872	23,210	120,000	50,000	0	1,668,521
New Jersey	2,293,132	221,027	587,429	556,300	50,000	48,500	3,756,388
New Mexico	1,362,826	273,279	455,589	200,000	50,000	0	2,341,694
New York	4,608,443	736,146	995,083	3,093,150	338,000	0	9,770,822
North Carolina	5,505,386	2,765,458	423,597	1,863,736	278,937	0	10,837,114
North Dakota	2,006,894	145,970	2,976,733	100,000	50,000	8,051,000	13,330,597
Ohio	4,887,374	443,383	832,344	594,200	98,000	0	6,855,301
Oklahoma	2,591,197	1,447,560	895,693	776,261	296,496	48,500	6,055,707
Oregon	2,369,988	698,029	1,681,830	973,3525	50,000	8,245,000	14,018,372
Pacific Territoriese	1,727,338	0	160,300	0	200,000	0	2,087,638
Pennsylvania	5,126,469	573,481	1,079,531	1,177,225	50,000	15,714,000	23,720,706

State or Territory	Formula[a]	Other Formula[b]	Special Research Grants	Competitive Research Grants[c]	Higher Education Grants	Research Facilities and Federal Administration[d]	Total CSRS Funds
Puerto Rico	$3,608,987	$12,508	$403,643	$0	$50,000	$0	$4,075,138
Rhode Island	1,040,549	88,851	15,000	262,450	50,000	0	1,456,850
South Carolina	2,893,497	1,624,812	577,153	108,602	152,496	0	5,356,560
South Dakota	2,050,865	202,441	50,811	97,700	50,000	0	2,451,817
Tennessee	4,050,782	2,039,361	236,940	1,017,000	248,497	0	7,592,580
Texas	5,323,273	2,870,002	1,143,633	1,721,000	296,497	48,500	11,402,905
U.S. Virgin Islands	704,663	0	201,449	0	50,000	0	956,112
Utah	1,488,012	223,699	96,984	140,000	50,000	0	1,998,695
Vermont	1,230,703	292,003	0	0	50,000	7,954,000	9,526,706
Virginia	3,531,368	1,950,777	1,302,872	1,118,501	200,497	97,000	8,201,015
Washington	2,983,371	732,939	2,515,298	1,070,263	50,000	12,648,800	20,000,671
West Virginia	2,258,004	376,053	83,128	0	50,000	363,750	3,130,935
Wisconsin	4,209,720	613,205	224,981	2,486,231	50,000	0	7,584,137
Wyoming	1,305,636	198,132	5,000	98,690	50,000	0	1,657,458
Other[f]	224,400	36,100	375,000	0	0	0	635,500

State or Territory	Formula[a]	Other Formula[b]	Special Research Grants	Competitive Research Grants[c]	Higher Education Grants	Research Facilities and Federal Administration[d]	Total CSRS Funds
SBIR set-aside[g]	1,888,928	560,813	515,392	544,464	0	27,112	3,536,709
Unobligated program funds[h]	880,690	0	0	0	0	48,500	929,190
Federal administration[i]	4,406,325	1,444,030	1,860,000	1,814,880	142,620	3,240,280	12,908,135
Unobligated administrative funds	24,414	0	0	0	0	261,500	285,914
Total	$155,545,000	$46,309,000	$51,780,000	$45,372,000	$7,604,000	$76,859,000	$383,469,000

[a] Formula includes only Hatch Act funds.
[b] Other formula includes McIntire-Stennis Forestry Research Act funds, including support to cooperating schools of forestry; Evans-Allen funds to 1890 land-grant institutions; and animal health and disease funding, which includes cooperating schools of veterinary medicine.
[c] Competitive research grants are all funds administered by the Competitive Research Grants Office of CSRS. This includes the forestry competitive research grants program ($3 million in 1988).
[d] Research facilities obligations totaled $72,765,000 and federal administration direct appropriations for aquaculture research in. Hawaii totaled $4,094,000 in 1988.
[e] Pacific Territories include American Samoa, Guam, Micronesia, and the Northern Mariana Islands.
[f] Other represents direct charges against program funds to support the operation of the Current Research Information System. (CRIS) inventory of research program data.
[g] SBIR set-aside is the 1.25 percent of program funds that is set aside to make Small Business Innovative Research (SBIR) grants.
[h] Authorized Hatch Act formula funds require a one-to-one match with local, state, or territory funds. Unobligated funds are those. that did not qualify with matching local funds.
[i] Federal administration is nonprogram funds that support the administration of the program.
SOURCE: Adapted from data compiled by the Budget Office, Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C.. 1989.

Table A.15 Other Federal (Non-CSRS) and Nonfederal Expenditures for Agricultural, Forestry, and Veterinary Research and Development, as Reported by CRIS, FY 1988 (in thousands of dollars)

State or Territory	USDA CGCA[a]	Other Federal[b]	State Appropriation	Product Sale	Industry	Other Nonfederal	Non-CSRS Support
Alabama	$982	$897	$14,041	$4,675	$1,075	$1,916	$23,586
Alaska	0	0	2,450	0	6	15	2,471
Arizona	1,048	1,404	15,574	236	741	1,062	20,065
Arkansas	678	458	15,065	0	1,006	2,547	19,754
California	1,613	23,696	89262	2,228	12,486	862	130,147
Colorado	1,807	15,253	7,658	3,403	545	5,393	34,059
Connecticut	7	656	6,591	0	47	627	7,928
Delaware	1	114	3,615	236	380	588	4,934
District of Columbia	0	0	295	0	0	0	295
Florida	2,725	4,438	54,426	0	7,194	3,648	72,431
Georgia	834	1,642	39,582	0	531	2,439	45,028
Hawaii	486	2,239	8,316	353	0	1,152	12,546
Idaho	155	561	9,744	1,443	1,453	508	13,864
Illinois	2,074	2,093	13,384	2,989	2,494	1,405	24,439
Indiana	429	5,928	17,225	4,166	3,266	2,533	33,547
Iowa	2,387	1,561	18,630	1,102	7,023	2,385	33,088
Kansas	342	3,637	16,367	4,976	1,861	1,418	28,601
Kentucky	0	0	14,331	0	0	0	14,331
Louisiana	303	374	21,575	2,834	2,164	2,153	29,403
Maine	252	544	4,029	492	937	842	7,096

State or Territory	USDA CGCA[a]	Other Federal[b]	State Appropriation	Product Sale	Industry	Other Nonfederal	Non-CSRS Support
Maryland	$13	$87	$10,557	$601	$0	$0	$11,258
Massachusetts	134	382	3,687	273	892	288	5,656
Michigan	2,123	5,003	19,933	2,686	4,670	3,667	38,082
Minnesota	1,337	2,436	33,554	0	2,009	3,528	42,864
Mississippi	642	995	17,063	4,061	1,610	3,017	27,388
Missouri	523	1,948	12,457	2,961	822	2,335	21,046
Montana	739	2,286	8,240	1,710	531	1,375	14,881
Nebraska	2,412	1,442	12,530	9,098	1,721	888	28,091
Nevada	11	441	3,254	496	133	484	4,819
New Hampshire	0	0	2,097	196	0	0	2,293
New Jersey	115	711	9,471	0	1,357	2,110	13,764
New Mexico	740	271	6,219	209	311	868	8,618
New York	1,815	16,903	37,560	10,603	6,206	13,153	86,240
North Carolina	2,806	6,220	39,690	1,177	3,485	5,815	59,193
North Dakota	465	561	11,636	1,958	637	1,662	16,919
Ohio	143	1,934	22,742	2,587	2,077	2,234	31,717
Oklahoma	204	874	12,044	1,659	1,061	765	16,607
Oregon	2,292	5,642	18,241	1,530	2,464	2,760	32,929
Pacific Territories[c]	0	0	523	0	0	0	523
Pennsylvania	1,225	4,989	14,124	0	2,081	3,133	25,552

State or Territory	USDA CGCA[a]	Other Federal[b]	State Appropriation	Product Sale	Industry	Other Nonfederal	Non-CSRS Support
Puerto Rico	$0	$0	$5,389	$680	$0	$0	$6,069
Rhode Island	0	263	1,742	0	0	38	2,043
South Carolina	155	113	14,483	78	1,221	596	16,646
South Dakota	146	36	4,023	467	403	798	5,873
Tennessee	50	286	13,257	3,158	565	267	17,583
Texas	2,563	7,557	40,333	7,691	7,671	712	66,527
U.S. Virgin Islands	0	0	294	0	0	0	294
Utah	588	2,232	5,745	397	1,226	412	10,600
Vermont	373	346	2,054	3	717	27	3,520
Virginia	1,272	4,039	20,789	0	2,974	2,889	31,963
Washington	1,814	4,507	19,334	843	1,864	4,094	32,456
West Virginia	129	133	2,364	592	146	212	3,576
Wisconsin	751	13,384	21,329	0	6,919	402	42,785
Wyoming	0	625	3,406	0	37	451	4,519
Total	$41,703	$152,141	$822,324	$84,847	$99,019	$90,473	$1,290,507

[a] Funds received through Contract Grants and Cooperative Agreements (CGCA) from USDA agencies other than CSRS.

[b] All funds from federal sources other than USDA research appropriations. This includes grants and contracts from the National Science Foundation and the National Institutes of Health.

[c] See footnote *e* of Table A.14.

SOURCE: Adapted from U.S. Department of Agriculture, Cooperative State Research Service. 1989. Inventory of Agricultural Research, Fiscal Year 1988. Washington, D.C.: U.S. Department of Agriculture

Table A.16 Farm Income as Cash Receipts from Farm Marketing and Government Payments, by State, FY 1987 (preliminary) (in thousands of dollars)

State	Farm Marketing Income	Government Payments	Total Income
Alabama	$2,148,055	$125,228	$2,273,283
Alaska	29,434	2,378	31,812
Arizona	1,780,770	97,338	1,878,108
Arkansas	3,143,394	397,644	3,541,038
California	15,521,832	462,011	15,983,843
Colorado	3,191,446	341,991	3,533,437
Connecticut	365,833	4,517	370,350
Delaware	484,551	12,176	496,727
Florida	5,226,998	42,532	5,269,530
Georgia	3,086,887	245,184	3,332,071
Hawaii	558,502	377	558,879
Idaho	2,046,522	234,373	2,280,895
Illinois	6,174,477	1,477,640	7,652,117
Indiana	3,872,363	670,244	4,542,607
Iowa	8,780,269	1,987,685	10,767,954
Kansas	5,721,509	966,320	6,687,829
Kentucky	2,418,611	178,338	2,596,949
Louisiana	1,419,707	209,299	1,629,006
Maine	413,258	8,110	421,368
Maryland	1,127,799	48,963	1,176,762
Massachusetts	392,656	4,833	397,489
Michigan	2,503,884	391,143	2,895,027
Minnesota	5,809,265	1,193,845	7,003,110
Mississippi	1,979,027	302,538	2,281,565
Missouri	3,690,604	489,800	4,180,404
Montana	1,347,409	352,330	1,699,739
Nebraska	6,823,053	1,274,843	8,097,896
Nevada	243,180	3,887	247,067
New Hampshire	103,877	2,808	106,685
New Jersey	562,963	11,386	574,349

State	Farm Marketing Income	Government Payments	Total Income
New Mexico	$1,147,261	$93,346	$1,240,607
New York	2,526,500	109,304	2,635,804
North Carolina	3,715,190	190,172	3,905,362
North Dakota	2,308,102	719,783	3,027,885
Ohio	3,421,774	431,877	3,853,651
Oklahoma	2,752,219	362,769	3,114,988
Oregon	1,860,740	127,438	1,988,178
Pennsylvania	3,224,220	71,766	3,295,986
Rhode Island	75,305	119	75,424
South Carolina	931,155	114,086	1,045,241
South Dakota	2,722,648	504,827	3,227,475
Tennessee	1,932,695	156,745	2,089,440
Texas	9,086,482	1,441,175	10,527,657
Utah	596,083	44,513	640,596
Vermont	412,378	7,067	419,445
Virginia	1,692,179	87,285	1,779,464
Washington	2,841,424	292,170	3,133,594
West Virginia	220,937	10,584	231,521
Wisconsin	5,016,983	405,969	5,422,952
Wyoming	641,996	35,976	677,972
Total	$138,094,406	$16,746,732	$154,841,138

SOURCE: Adapted from U.S. Department of Agriculture. 1988. Table 584, p. 413, in Agricultural Statistics. Report No. 001-000-04532-6. Washington, D.C.: U.S. Government Printing Office.

Table A.17 Comparison of Research Funding Sources, by State or Territory

State or Territory	CRG/ Formula	Special Research Grants/ Formulas	State Appropriations/ Formula	Other Federal/ Formula	Special Research Grants/ CRG	State Appropriations/ CRG	Other Federal/ CRG	Special Research Grants/ State Appropriations
Alabama	2.73	1.51	209.65	13.39	55.40	7,672.68	13.39	0.72
Alaska	0.00	0.43	210.27	0.00	NA	NA	0.00	0.20
Arizona	44.82	19.12	797.81	71.92	42.65	1,779.89	71.92	2.40
Arkansas	4.52	10.48	324.16	9.86	231.84	7,173.81	9.86	3.23
California	120.80	51.66	1,697.76	450.70	42.77	1,405.41	450.70	3.04
Colorado	21.57	8.69	273.07	543.89	40.27	1,265.79	543.89	3.18
Connecticut	13.50	10.56	375.52	37.38	78.20	2,781.01	37.38	2.81
Delaware	0.00	0.00	217.16	6.85	NA	NA	6.85	0.00
District of Columbia	23.21	0.00	61.85	0.00	0.00	266.46	0.00	0.00
Florida	23.85	39.07	1,372.22	111.89	163.79	5,753.35	111.89	2.85
Georgia	25.04	23.70	645.46	26.78	94.62	2,577.33	26.78	3.67
Hawaii	2.42	206.47	670.73	180.59	8,533.10	27,720.00	180.59	30.78
Idaho	8.59	19.53	436.56	25.13	227.28	5,080.29	25.13	4.47
Illinois	41.26	55.10	268.20	41.94	133.54	649.96	41.94	20.55
Indiana	27.44	13.23	380.85	131.07	48.21	1,387.98	131.07	3.47
Iowa	10.78	14.73	351.32	29.44	136.71	3,259.56	29.44	4.19
Kansas	29.98	100.76	518.10	115.13	336.11	1,728.30	115.13	19.45
Kentucky	7.09	8.19	228.45	0.00	115.53	3,222.19	0.00	3.59
Louisiana	7.03	14.88	497.36	8.62	211.59	7,073.77	8.62	2.99
Maine	3.57	7.65	193.83	26.17	214.37	5,435.05	26.17	3.94

State or Territory	CRG/ Formula	Special Research Grants/ Formulas	State Appropriations/ Formula	Other Federal/ Formula	Special Research Grants/ CRG	State Appropriations/ CRG	Other Federal/ CRG	Special Research Grants/ State Appropriations
Maryland	42.33	9.30	340.78	2.81	21.97	805.13	2.81	2.73
Massachusetts	87.44	43.88	173.20	17.94	50.19	198.08	17.94	25.34
Michigan	51.99	50.92	415.83	104.37	97.95	799.90	104.37	12.25
Minnesota	26.61	12.07	700.06	50.82	45.35	2,630.48	50.82	1.72
Mississippi	1.95	119.92	313.31	18.27	6,147.06	16,060.35	18.27	38.27
Missouri	16.45	14.00	209.31	32.73	85.11	1,272.55	32.73	6.69
Montana	4.60	8.73	378.73	105.07	189.96	8,240.00	105.07	2.31
Nebraska	9.54	49.27	406.12	46.74	516.48	4,257.56	46.74	12.13
Nevada	9.11	0.46	296.41	40.17	5.00	3,254.00	40.17	0.15
New Hampshire	8.13	1.57	142.14	0.00	19.34	1,747.50	0.00	1.11
New Jersey	22.13	23.36	376.71	28.28	105.60	1,702.50	28.28	6.20
New Mexico	12.22	27.85	380.11	16.56	227.79	3,109.50	16.56	7.33
New York	57.87	18.62	702.77	316.26	32.17	1,214.30	316.26	2.65
North Carolina	22.53	5.12	479.88	75.20	22.73	2,129.59	75.20	1.07
North Dakota	4.64	138.27	540.49	26.06	2,976.73	11,636.00	26.06	25.58
Ohio	11.15	15.61	426.62	36.28	140.08	3,827.33	36.28	3.66
Oklahoma	19.22	22.18	298.21	21.64	115.39	1,551.54	21.64	7.44
Oregon	31.73	54.82	594.55	183.90	172.76	1,873.71	183.90	9.22
Pacific Territories[a]	0.00	9.28	30.28	0.00	NA	NA	0.00	30.65
Pennsylvania	20.65	18.94	247.79	87.53	91.70	1,199.77	87.53	7.64

State or Territory	CRG/ Formula	Special Research Grants/ Formulas	State Appropriations/ Formula	Other Federal/ Formula	Special Research Grants/ CRG	State Appropriations/ CRG	Other Federal/ CRG	Special Research Grants/ State Appropriations
Puerto Rico	0.00	11.15	148.81	0.00	NA	NA	0.00	7.49
Rhode Island	23.24	1.33	154.24	23.29	5.72	663.75	23.29	0.86
South Carolina	2.40	12.77	320.54	2.50	531.44	13,335.85	2.50	3.99
South Dakota	4.34	2.25	178.54	1.60	52.01	4,117.71	1.60	1.26
Tennessee	16.70	3.89	217.68	4.70	23.30	1,303.54	4.70	1.79
Texas	21.01	13.96	492.27	92.23	66.45	2,343.58	92.23	2.84
U.S. Virgin Islands	0.00	28.59	41.72	0.00	NA	NA	0.00	68.52
Utah	8.18	5.67	335.63	130.40	69.27	4,103.57	130.40	1.69
Vermont	0.00	0.00	314.89	22.72	NA	NA	22.72	0.00
Virginia	20.40	23.77	379.21	73.68	116.48	1,858.65	73.68	6.27
Washington	28.80	67.68	520.25	121.28	235.02	1,806.47	121.28	13.01
West Virginia	0.00	3.16	89.75	5.05	NA	NA	5.05	3.52
Wisconsin	51.55	4.66	442.24	277.51	9.05	857.88	227.51	1.05
Wyoming	6.56	0.33	226.50	41.56	5.07	3,451.21	41.56	0.15

NOTE: Values are percents resulting from division by formula, competitive research grants (CRG), or state appropriations from Tables A.14 and A.15. For example, in FY 1988 Wyoming received competitive research grants that were equal in value to 6.5 percent of the federal formula funds received; in other words, Wyoming state appropriations were more than two times (226 percent) the value of federal formula funds received. NA, Not available.

[a] See footnote *e* of Table A.14.

Table A.18 Research Funding Sources as a Percentage of Total Farm Income, by State

State	Formula Funding	Special Research Grants	Competitive Research Grants	State Appropriations	Total CSRS Funds
Alabama	0.29	0.01	0.00	0.62	0.32
Alaska	3.66	0.00	0.02	7.70	3.84
Arizona	0.10	0.05	0.02	0.83	0.41
Arkansas	0.13	0.01	0.01	0.43	0.17
California	0.03	0.04	0.02	0.56	0.09
Colorado	0.08	0.02	0.01	0.22	0.11
Connecticut	0.47	0.06	0.05	1.78	0.60
Delaware	0.34	0.00	0.00	0.73	0.37
Florida	0.08	0.02	0.03	1.03	0.13
Georgia	0.18	0.05	0.04	1.19	0.28
Hawaii	0.22	0.01	0.46	1.49	2.07
Idaho	0.10	0.01	0.02	0.43	0.13
Illinois	0.07	0.03	0.04	0.17	0.13
Indiana	0.10	0.03	0.01	0.38	0.14
Iowa	0.05	0.01	0.01	0.17	0.12
Kansas	0.05	0.01	0.05	0.24	0.11
Kentucky	0.24	0.02	0.02	0.55	0.28
Louisiana	0.27	0.02	0.04	1.32	0.33
Maine	0.49	0.02	0.04	0.96	0.56
Maryland	0.26	0.11	0.02	0.90	0.42
Massachusetts	0.54	0.47	0.24	0.93	1.25
Michigan	0.17	0.09	0.08	0.69	0.35
Minnesota	0.07	0.02	0.01	0.48	0.10
Mississippi	0.24	0.00	0.29	0.75	0.60
Missouri	0.14	0.02	0.02	0.30	0.19
Montana	0.13	0.01	0.01	0.48	0.15
Nebraska	0.04	0.00	0.02	0.15	0.06
Nevada	0.44	0.04	0.00	1.32	0.51
New Hampshire	1.38	0.11	0.02	1.97	1.56
New Jersey	0.44	0.10	0.10	1.65	0.65
New Mexico	0.13	0.02	0.04	0.50	0.19
New York	0.20	0.12	0.04	1.42	0.37
North Carolina	0.21	0.05	0.01	1.02	0.28
North Dakota	0.07	0.00	0.10	0.38	0.44
Ohio	0.14	0.02	0.02	0.59	0.18

State	Formula Funding	Special Research Grants	Competitive Research Grants	State Appropriations	Total CSRS Funds
Oklahoma	0.13	0.02	0.03	0.39	0.19
Oregon	0.15	0.05	0.08	0.92	0.71
Pennsylvania	0.17	0.04	0.03	0.43	0.72
Rhode Island	1.50	0.35	0.02	2.31	1.93
South Carolina	0.43	0.01	0.06	1.39	0.51
South Dakota	0.07	0.00	0.00	0.12	0.08
Tennessee	0.29	0.05	0.01	0.63	0.36
Texas	0.08	0.02	0.01	0.38	0.11
Utah	0.27	0.02	0.02	0.90	0.31
Vermont	0.36	0.00	0.00	0.49	2.27
Virginia	0.31	0.06	0.07	1.17	0.46
Washington	0.12	0.03	0.08	0.62	0.64
West Virginia	1.14	0.00	0.04	1.02	1.35
Wisconsin	0.09	0.05	0.00	0.39	0.14
Wyoming	0.22	0.01	0.00	0.50	0.24

NOTE: Values are the research dollar per state farm Tables A.14 and A.15 divided by the total state farm income from Table A.16. example, Wyoming received formula funds equal to 0.22 percent of the value of state farm income.

Table A.19 Appropriations for the Competitive Research Grants Program, by Program Areas, FY 1978–1989 (in thousands of dollars)

Program Area	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Plant science	$10,000	$10,000	$13,000	$13,000	$13,440	$15,000	$15,000	$16,500	$13,787	$12,126	$12,126	$8,000
Soybean research								518	493	493	493	493
Acid precipitation								695	—	—	—	—
Alcohol fuels								540	661	514	514	514
Biotechnology								—	—	—	5,000	—
Animal science	—	—	—	—	—	—	—	4,500	4,279	4,279	6,000	6,000
Brucellosis								500	475	475	475	475
Reproductive efficiency								2,500	2,377	2,377	2,377	—
Pest science	—	—	—	—	—	—	—	3,000	2,853	2,853	2,853	2,000
Gypsy moths								1,000	951	951	951	—
Pine bark beetle								1,000	951	951	951	—
Boll weevil/bollworm								1,000	951	951	951	—
Human nutrition	5,000	5,000	3,000	3,000	2,880	2,000	2,000	2,000	2,377	2,377	2,377	1,000
Biotechnology (animal and plant)	—	—	—	—	—	—	—	20,000	19,016	19,016	19,016	19,016
Stratospheric ozone	—	—	—	—	—	—	—	—	—	—	—	3,700
Total, competitive research grants[a]	15,000[b]	15,000	16,000[c]	16,000	16,320	17,000	17,000	46,000	42,312	40,651	42,372	39,716
Forestry competitive grants	—	—	—	—	—	—	—	7,840	6,506	6,000	3,000	—

[a] Includes 3 percent federal administration in FY 1979–1985; includes 4 percent federal administration beginning in FY 1986.
[b] A total of $600,000 was available for federal administration in FY 1978; funds were appropriated to the ARS.
[c] Includes FY 1980 rescission under P.L. 96-304: $400,000 for plant science and $100,000 for human nutrition.
SOURCE: Adapted from data compiled by the Budget Office, Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C., 1989.

Table A.20 Extension Service Expenditures through the U.S. Department of Agriculture, by Program (in millions of dollars)

Program	1988 Actual	1989 Current Estimate	1990 Budget
General formula programs			
Smith-Lever Act	$241.6	$241.6	$241.6
1890 land-grant colleges and Tuskegee University	18.3	18.3	24.0
D.C. extension	0.9	1.0	1.0
Subtotal	260.8	260.9	266.6
Earmarked programs			
Priority initiatives	0.0	0.0	5.0
Water quality	0.0	1.5	6.5
Rural revitalization	0.9	1.0	1.0
Low-income nutrition (EFNEP)	58.6	58.6	21.6
Pest management	7.2	7.2	7.2
Pesticide impact assessment	1.6	1.6	2.6
Other earmarked programs	5.7	5.9	—
Subtotal	74.0	75.8	43.9
1890 land-grant college extension facilities	9.5	9.5	9.5
Renewable resources extension	2.8	2.8	—
Section 1440 grants	3.4	3.4	—
Federal administration (direct appropriation)	7.4	9.1	5.0
Total, ES	357.9	361.5	325.0

SOURCE: Adapted from U.S. Department of Agriculture. 1989a. 1990 Budget Summary. Washington, D.C.: U.S. Department of Agriculture.

Table A.21 Research Expenditures by the U.S. Department of Agriculture, 1950–1988 (in millions of constant 1982 dollars)

Agency	1955	1965	1970	1975	1980	1985	1988
ARS	178.96	478.5	419.5	392.5	422.4	432.4	420.2
CSRS	92.6	156.3	164.0	177.9	219.5	136.7	119.7
U.S. Forest Service	35.4	126.0	119.5	135.8	113.2	100.1	102.0
ERS	22.79	39.8	44.2	43.4	41.5	41.0	37.9
Total	329.75	800.6	747.2	749.6	796.6	710.2	679.8

NOTE: ARS, Agricultural Research Service; CSRS, Cooperative State Research Service; ERS, Economic Research Service.
SOURCE: Adapted from data compiled by the Office of Budget, Planning, and Evaluation, U.S. Department of Agriculture, Washington, D. C., 1989.

B

Private Sector Research Activities and Prospects

Charles M. Benbrook

The level and focus of publicly supported research and development (R&D) in the food and agricultural sciences must be evaluated in relation to research needs and ongoing private sector R&D activities. Corporations now account for nearly $2.5 billion in food and agricultural sciences R&D, over half the nation's approximate $4.6 billion annual total investment. Table B.1 summarizes the scale of public and private sector R&D expenditures by major categories in 1986, the last year for which a reasonably complete set of estimates on private sector R&D is available.

Accurate and comprehensive data on industry R&D trends are difficult to obtain. Estimates in this proposal draw upon data compiled by several government agencies, trade associations, private firms, and the press. An annual survey by *Business Week* magazine of corporate R&D is one of the most useful data sets. Battelle Memorial Institute also issues an annual report on probable levels of R&D expenditures, drawing on National Science Foundation and other data sources. The tables and analysis provided in this appendix are offered as a general overview of corporate R&D.

The capacity of private firms to support R&D is a function of gross sales, profit levels, and the percentage of either gross sales or income that a company is willing to commit to R&D. There is a remarkable range in the willingness of companies to commit funds to R&D, either as a percentage of gross sales or net income.

Private R&D Support By Area Of Technology

Private sector R&D data are generally reported by company or industry subsector. It is more difficult to obtain private R&D data disaggregated by field of research or area of technology. In a recent review of private sector R&D, Pray and Neumeyer (1989) presented data for 1984 that provide some perspective on R&D focus (see Table B.2). About two-thirds of private sector R&D is carried out by agricultural input industries; one-third is done by firms engaged in the postharvest processing and marketing of food products. Agrichemical company R&D focusing on the development of improved crop protection chemicals accounts for 45 percent of the total research effort on manufactured production inputs, even though the sale of pesticides accounts for between 10 and 15 percent of manufactured input expenditures. The very low rate of R&D expenditures on plant nutrients (2.3 percent) is modest compared with expenditures on fertilizers by farmers (about 20 to 30 percent of input expenses).

Charles M. Benbrook is executive director of the Board on Agriculture of the National Research Council.

Table B.1 Public and Private Sector Agricultural R&D Expenditures, 1986

		Expenditures as Percentage of:		
Sector and Category	1986 Expenditures (millions of dollars)	Total Public Expenditure	Total Private Expenditures	Public & Private Expenditures
Public				
ARS	478.1	24.3		10.8
State agricultural experiment stations				
Formula programs	179.0	9.1		4.0
Other federal[a]	176.4	9.0		4.0
State	741.7	37.8		16.7
Private industry	85.1	4.3		1.9
Other nonfederal	139.7	7.1		3.2
U.S. Forest Service	120.1	6.1		2.7
Economic Research Service	44.1	2.2		1.0
Total Public	1,964.2	99.9[b]		44.3
Private				
Agricultural chemicals	695.0		28.2	15.7
Fertilizer	40.0		1.6	1.0
Seed industry	170.0		6.9	3.8
Farm machinery	300.0		12.2	6.8
Animal health	323.0		13.1	7.3
Food processing	940.0		38.1	21.2
Total private	2,468.0		100.1[b]	55.8
Total public and private	4,432.2			

[a] Other federal includes competitively awarded and contract funds from other federal science agencies (National Institutes of Health, National Science Foundation, U.S. Department of Energy, Agency for International Development, U.S. Department of the Interior, and the U.S. Environmental Protection Agency).

[b] Totals do not add to 100 percent because of rounding.

SOURCE: Public sector expenditures adapted from: U.S. Department of Agriculture, Cooperative State Research Service. 1988. Inventory of Agricultural Research, Fiscal Year 1987. Washington, D.C.: U.S. Department of Agriculture. Private sector expenditures adapted from the following: For agricultural chemicals, National Agricultural Chemicals Association. 1986. Industry Profile Survey, 1986. National Agricultural Chemicals Association, Washington, D.C. Photocopy. For the fertilizer and seed industries, Agricultural Research Institute. 1985. A Survey of U.S. Agricultural Research by Private Industry III. Bethesda, Md.: Agricultural Research Institute. For farm machinery, data were based on 3.75 percent rate of R&D expenditures and $8.0 billion in gross sales (J. H. Ebbinghaus, Farm and Industrial Equipment Institute, personal communication, 1989). For animal health, Animal Health Institute, Domestic New Sales Survey, press release, May 16, 1988. For food processing, Institute of Food Technologists. 1988. Table 6 in Special Report: The Growth and Economic Impact of the Food Processing Industry. Chicago: Institute of Food Technologists.

Table B.2 Private Sector Food and Agricultural Research Expenditures for Input and Postharvest Industries, 1984

Technology Area	Expenditures[a] (millions of dollars)	Percentage of Total
Input industries		
Plant breeding	115	7.5
Pesticides	695	45.2
Plant nutrients	36	2.3
Policy/economics	14	0.1
Biologics	147	9.6
Biotechnology	152	9.9
Animal nutrition	68	4.4
Machinery	290	18.9
Energy	21	1.4
Total inputs	1,538	99.3[b]
Postharvest processing and marketing		
Human food	636	84.0
Food biotechnology	80	10.6
Tobacco	4	0.05
Packaging	28	3.7
Natural fibers	9	1.2
Total postharvest	757	99.55[b]

[a] Table 2 in the report by Pray and Neumeyer (1989; see complete source below) provides four estimates of R&D by technology field. The single expenditure levels here are considered most likely estimates, taking into account sampling methods and other data.
[b] percentages do not add to 100 because of rounding.
SOURCE: Adapted from Pray, C., and C. Neumeyer. 1989. Table 2 in Trends and Composition of private Food and Agricultural R&D Expenditure in the United States. New Brunswick, N.J.: Department of Agricultural Economics, Cook College, Rutgers University.

Further perspective can be gained on private sector research priorities by assessing research expenditures in light of the value added at each stage within an industry—production, transport, processing, manufacturing, and retailing. Table B.3 summarizes the relationship between the value added and R&D as food products flow from the farm to the consumer.

It is evident from Table B.3 that the intensity of the research effort declines markedly at each subsequent stage in the food production system, even when R&D expenditures are expressed as a percentage of the value added at each stage in the food system.

Trends In Public And Private Sector Research Focus

Over time sizable shifts have occurred between the public and the private sector roles in agricultural research (see Table B.4). The private sector R&D role has increased markedly relative to that of public sector R&D in the areas of plant protection and nutrition, mechanization, and postharvest research. The relative role of the public sector has grown appreciably in only one area, livestock research. Surprisingly, evidence suggests remarkable stability in the share of overall

Table B.3 Private Sector R&D Priorities at Various Stages in the Food Production System, 1985 (in billions of dollars)

Stage	Farm Production Sector	Food Manufacturing Processing	Service and Retailing
Gross sales	$144	$300	$406
Value added	63	104	100
R&D expenditures	1.54	0.75	NA
R&D as percentage of value added	2.4	0.7	—

NOTE: NA, Not available. R&D in the retail sector is very low and focuses on consumer trends.
SOURCE: For farm production sector gross sales, adapted from U.S. Department of Agriculture, Economic Research Service. 1987. Table 4 in Farm Sector Review. Report ECIFS7-4. Washington, D.C.: U.S. Department of Agriculture. The value-added figure is gross sales minus expenses, including farm origin and other operating inputs from U.S. Department of Agriculture, Economic Research Service. 1987. Table 6 in Farm Sector Review. Report ECIFS 7-4. Washington, D.C.: U.S. Department of Agriculture. For food manufacturing and processing, adapted from Best, D. 1988. Competing through R&D. Prepared Foods November:72–76. For service and retailing, U.S. Department of Agriculture, Economic Research Service. 1988a. Table 88 in Food Consumption, Prices, and Expenditures, 1966–87. Statistical Bulletin No. 773. Washington, D.C.: U.S. Department of Agriculture.

Table B.4 Public and Private Sector Support for Food and Agricultural Research, 1961 and 1984 (in constant 1984 dollars)

	1961		1984	
Research Area	Public	Private	Public	Private
Crop breeding and management	$155	$68	$228	$29
Plant protection, nutrition	200	139	262	638
Livestock	148	113	359	215
Mechanization	16	53	13	295
Postharvest	187	567	100	727
Total[a]	809	1,081	1,770	2,359
Percentage of public plus private sector total	43	57	43	57

[a] The total is not the start of the columns because it includes other categories and expenditures that could not be classified.
SOURCE: Adapted from Pray, C., and C. Neumeyer. 1989. Trends and Composition of Private Food and Agricultural R&D Expenditure in the United States. New Brunswick, N.J.: Department of Agricultural Economics, Cook College, Rutgers University.

public and private sector R&D. As recorded by Pray and Neumeyer (1989), the private sector accounted for 58 percent of overall research expenditures in both 1961 and 1984.

Private Sector Capacity To Increase R&D

Further insight into the capacity of the private sector to support increased R&D in the future can be gained by disaggregating the total sales of agricultural products and production inputs across all U.S. farm operations according to major types of farms and categories of inputs and by reviewing likely trends in crop prices and planted acreages.

Private R&D undertaken by each industry sector within the food and fiber system is generally limited in focus to some feature, aspect, or process within that sector that can be sold as a production input, machine, tool, or service. Agrichemical firms conduct research related to plant physiology, insect ecology, chemistry, and environmental fate of chemicals. Seed companies work on plant breeding techniques and the incorporation of desirable traits into new cultivars. Food processing companies support research on manufacturing techniques and ways to modify food properties. In recent years some food companies have begun R&D programs, often in collaboration with biotechnology research firms, to alter certain key properties and traits of food crops to improve the efficiency or consistency of food manufacturing processes or to otherwise improve product quality.

Across all farms in 1986, farmers earned about $152 billion in gross cash income, which included $11.8 billion in direct payments from the government. Crop farms earned $72.0 billion, and livestock producers earned $80.0 billion. Crop farmers had total cash expenses of $45.2 billion, while livestock producers incurred $54.9 billion in expenses, yielding a net crop farm income of $26.8 billion and a net livestock farm income of $25.1 billion. Table B.5 summarizes this information by type of farm and major crop.

The capacity of the private sector to support additional research varies greatly across areas of science and reflects the commercial potential to market products in industry subsectors. The level and scope of private sector R&D activity in the six major program areas described in Chapter 5 are presented in Table B.6. Industry-by-industry reviews of prospective research funding trends follow.

Table B.5 Economic Indicators of the Production Sector of the U.S. Food and Fiber System by Type of Farm, 1986 (in nominal dollars)

		Millions of Current Dollars		
Farm Type and Crop	Number of Farms (thousands)	Gross Income	Total Expenses	Net Income
Crop farms	887	$71,963	$45,191	$26,772
Wheat	70	4,911	2,903	2,008
Corn	165	13,838	9,482	4,356
Soybeans	93	4,340	3,230	1,110
Livestock farms	1,327	60,002	54,863	25,140
Dairy	229	21,900	16,889	5,011
Cattle	677	28,192	20,502	7,690
Hogs	127	9,897	7,020	2,826
Poultry	27	12,145	3,010	9,135
All farms	2,214	151,966	100,054	51,912

SOURCE: Adapted from U.S. Department of Agriculture, Economic Research Service. 1988b. Income distribution by type of farm, 1985–1986. Table 8 in Economic Indicators of the Farm Swwr. Farm Sector Review, 1986. Report ECIFS 6–3. Washington, D.C.: U.S. Department of Agriculture.

Table B.6 Private Sector R&D Activity in Six Major Program Areas

Program Area	Industry Sector Performing R&D	Level of Investment[a]	Scope of Ongoing R&D[b]
Plant productivity	Seed, agrichemical, and fertilizers	High	Moderate
Animal productivity	Pharmaceutical, animal genetics, feed manufacturing	High	Broad
Nutrition, food quality, and health	Food processing, consumer products	Modest	Moderate
Natural resources and environment	Machinery, agrichemical	Modest	Narrow
Engineering, products, and processes	Equipment, food processing, commodity processing	Modest	Narrow
Markets, trade, and policy	Multinational companies	Modest	Narrow

[a] High, moderate, or modest, as indicated by the percentage of net profits devoted to R&D.
[b] Broad, moderate, or narrow relative to the research needs within each major program area.

Pesticide Industry

The agrichemical industry accounted for about $5.5 billion in total sales in 1986—about $4 billion in the United States and $1.5 billion abroad. Of the $5.5 billion total, about $700 million—or about 13 percent of gross sales—was invested in R&D (National Agricultural Chemicals Association, 1986).

It is important to note that only a portion of agrichemical industry R&D supports basic and applied research that advances scientific knowledge. Two factors limit the relevance of agrichemical R&D in supporting scientific progress. First, much research effort is required to develop the information needed to attain or defend pesticide registrations from the U.S. Environmental Protection Agency. This work is often of limited value in advancing scientific knowledge since it is product and situation specific and is designed to satisfy regulatory requirements rather than advance scientific knowledge. Second, the results of much agrichemical industry R&D never fully enter the public arena because of the need of private companies to protect proprietary knowledge and technological production and R&D methods.

The capacity of the industry to expand this total by increasing the percentage of sales directed to research is doubtful because of several factors:

- R&D expenditures rose sharply in aggregate and as a percentage of sales in the late 1970s and early 1980s.
- Most agrichemical companies are divisions of larger chemical and energy companies. R&D expenditures as a percentage of chemical industry sales average only 3.7 percent, or 31.8 percent of profits. Agrichemical divisions within most major companies already support total R&D at rates at least twice those of the industry-wide averages as a percentage of sales or profits.
- Competition in the industry is growing as a number of effective new products in major markets are driving down pesticide prices and profit margins on a per-acre-treated basis.
- Consolidation within the industry on a worldwide basis is reducing the number of firms with viable, ongoing R&D programs and will probably reduce total R&D investment (see the section "Corporate Consolidation" later in this appendix).

- Costs to defend existing registered products increase as the U.S. Environmental Protection Agency moves ahead with the pesticide reregistration process.
- There are fewer unexploited opportunities remaining in chemical synthesis and screening in families of chemistry from which viable products have emerged.
- Experimentation by farmers and research at state agricultural experiment stations focuses on alternative biological and cultural practices for pest control.
- Genetic resistance is emerging in certain target pest populations, a factor that limits; the average useful life of several products.
- The relatively high cost of capital has shortened the time period during which R&D investments must demonstrate the capacity to earn profits.

Expanded crop production acreage in 1989 and future years will tend to increase gross agrichemical industry sales and, hence, R&D. The acreage planted to major field crops is expected to rise by about 15 percent in 1989, which could increase industry sales by $500 million to $700 million. If the industry-wide average committed to R&D remains unchanged at 12.7 percent of gross sales and planted acreage remains at or about the 1989 level for several years, both of which are optimistic assumptions, the expansion of harvested acreage and product sales might result in a $60 million to $90 million annual increase in agrichemical industry R&D in the 1990s.

Over the next decade, price competition, efforts by farmers to cut production costs, and renewed interest in integrated pest management and other cultural pest control methods are likely to place downward pressure on agrichemical prices. For these reasons, even under an optimistic scenario for planted acreage and prices, agrichemical industry R&D in the 1990s could remain comparable to that in 1989. Under less favorable circumstances, planted acreage could retract back toward 1986–1987 levels, soft commodity prices could place further downward pressure on all cash production expenses, and the percentage of sales and profits devoted to pesticide R&D might fall toward the average for the entire chemical industry. Taken together, these bearish factors could reduce pesticide industry R&D by 5 to 20 percent in the 1990s. The possible passage of restrictive and costly new environmental regulatory laws by states, the federal government, or both must be regarded as a major source of uncertainty.

Seed Industry

Farmers spent just over $3 billion on seeds in 1987. Two leading seed companies, Pioneer Hybrid International and DeKalb, spent $49.9 million and $24.9 million, respectively, on R&D, or 5.9 and 6.8 percent, respectively, of gross sales.

Together, Pioneer and DeKalb account for over one-third of total seed industry sales. The commitment of these firms to R&D is very high. Pioneer devoted over 50 percent of its profits to R&D; DeKalb devoted over 86 percent. Across the industry, between 5 and 7 percent of gross sales is devoted to research—an estimated $150 million to $210 million annually.

Seed industry sales are even more responsive to planted acreage than are agrichemical industry sales. While seed production and sales were down in 1988 because of the severe drought and government land retirement policies, inventories are generally adequate, and stronger sales are anticipated in 1989. The volume of industry-wide sales in the 1990s, however, is not expected to rise much above the 1989 level and would retract moderately if surpluses were to return. No change from current levels is expected in the percentage of sales devoted to R&D under a pessimistic forecast of the economic conditions that affect the industry.

Under an optimistic scenario for future R&D, there is some prospect that a higher portion of total seed sale revenues will be devoted to R&D because of the rapid infusion of biotechnology techniques in all facets of plant variety assessment, development, and improvement. Advances in biotechnology that improve plant resistance to stress or plant responsiveness to water, sunlight, or production inputs add value to crop cultivars. Hence, farmers may be willing to pay a somewhat higher price for such improved varieties. This prospect of delivering new value to farmers through seeds has attracted considerable new capital to support private sector research in this area, both in traditional seed companies and agrichemical and biotechnology firms, many of which are integrating into the seed industry through acquisitions and joint ventures. In an interesting and relatively recent development, many companies that have never conducted plant breeding or molecular biology research (like Eastman Kodak and Frito-Lay) are pursuing ways to modify the chemical, nutritional, cooking, or storage stability of basic crops through biotechnology.

A change in government commodity and conservation policies may also increase seed industry sales. At present, most farmland planted to row crops (about 175 million acres) is left barren in the fall after crops are harvested. In order to help control erosion, improve water quality, and increase farm income, new policies are under consideration to encourage the establishment of cover crops in the fall. The annual planting of such crops as vetch, clover, rye, and oats would markedly increase demand for certain types of seed.

Under an optimistic scenario for successful commercial applications of biotechnology in plant variety development and government policies that have an impact on industry sales, the portion of gross sales devoted to R&D might rise from about 5 to 7 percent to as much as 10 to 12 percent. Over the next several years, this increase would generate a cumulative increase of perhaps 50 to 75 percent in seed industry R&D, amounting to some $75 million to $150 million in additional R&D expenditures annually. This new private sector research activity could prove vital in moving new molecular biology techniques from the laboratory to the field.

Fertilizer Industry

Farmers annually spend some $5.4 billion on fertilizers. These products are manufactured and sold by an industry with a very low rate of R&D as a percentage of gross sales. Fertilizer industry R&D is not expected to contribute markedly to advancing the nation's scientific knowledge base, although it does support important work on the properties and effects of basic plant nutrients following the use of particular fertilizer formulations, and on methods to improve the efficiency of fertilizer applications.

Machinery

Farm equipment and machinery manufacturers devote about 3.5 to 4.0 percent of their gross sales to R&D. Industry sales were about $8.0 billion in 1988, reflecting a much stronger demand for tractors, combines, and other large farm equipment than during the mid-1980s. Data are not available to disaggregate industry R&D estimates based on consumer lawn and garden and recreational equipment sales (snowmobiles, lawn mowers, garden tillers, trimmers, chainsaws, etc.).

The impact of industry consolidation on R&D investments during the 1980s is also not yet clear, given the volatile record of industry sales and profitability in the 1980s.

Under an optimistic scenario, the general recovery of the agricultural sector will continue, strengthening the demand for farm machinery. Farmers will replace equipment that they retained through the 1980s and will diversify their machinery base to include new tillage, planting, and harvesting machines. Industry sales could reach $1 billion, with 3.75 percent of sales devoted to R&D. This would provide a $75 million increase in R&D over the 1987–1988 level. Under a pessimistic scenario, however, R&D investments will not grow above the estimated 1988 level.

Livestock Industry

The total production expenses of livestock operations was about $55 billion in 1986, about $16 billion of which was for feed and $10 billion was for breeding stock, calves, feeder pigs, and other livestock. This $26 billion in production expenses is generally paid to other farmers or businesses that largely act as intermediate handlers of farm commodities. These expenditures thus are not likely to support private sector R&D investments directly. One of the nation's largest animal feed and agricultural commodity processing firms, Archer Daniels Midland, devoted just 0.1 percent of its sales and 1.2 percent of its pretax profits to research in 1987 (Business Week, 1988). This research focused mostly on the conversion of corn to ethanol and biodegradable plastics.

Animal drug and pharmaceutical companies sold $2.34 billion in health care products to livestock farmers in 1987 (Animal Health Institute, Domestic New Sales Survey, press release, May 16, 1988). Table B.7 summarizes Animal Health Institute data on sales and research expenditures by major category of product sales.

The average 15.7 percent commitment of gross sales of animal health care products to research is extremely high by any standard. The major companies undertaking such work are almost all active in human medicine and drug manufacturing. The health care industry as a whole devoted an estimated 7.9 percent of gross sales to R&D, just over half the rate in the animal health care business (Business Week, 1988). Four major firms that are active in both businesses—Up John, Merck, Pfizer, and Eli Lilly—committed 14.1, 11.2, 8.2, and 12.8 percent, respectively, of gross corporate sales (both in medical and animal care divisions) to R&D. These are all well above the industry average.

Table B.7 Gross Sales and Research Expenditures in the Animal Health Care Industry, 1987

Product Class	Gross Sales[a] (millions of dollars)	R&D Expenditures (millions of dollars)	Percent R&D of Gross Sales
Pharmaceuticals			
Antimicrobials	268.3	NA	NA
All other	692.4	NA	NA
Total	960.7	233.6	24.3
Biologicals	242.3	39.8	16.4
Feed additives			
Antibacterials	301.6	NA	NA
All other	839.8	NA	NA
Total	1,141.4	78.4	6.9
Industry totals	2,344.4	369.0[b]	15.7

NOTE: NA, Disaggregated data not available.

[a] Preliminary estimates for 1987.

[b] Industry total includes $16.0 million of R&D on insecticides and $1.2 million on diagnostics.

SOURCE: Adapted from Animal Health Institute, Domestic New Sales Survey, press release, May 16, 1988.

The prospects for increased R&D rest largely on the likelihood of increased product sales. In recent years industry sales have grown well ahead of the rate of inflation. A range of emerging technologies and products, including new diagnostics, vaccines, growth hormones, and probiotics, among others, suggests considerable long-term growth potential in industry sales.

An optimistic scenario for animal care industry R&D rests on four assumptions:

1. Continued progress by the animal product industry in improving the nutritional attributes of meat, poultry, and dairy products—and hence, consumer demand for livestock products.
2. Successful commercialization of animal growth hormones, particularly bovine and porcine somatotropins.
3. Resolution of current controversies about the use of certain drugs, hormone therapies, and new biotechnologies.
4. Improved recognition by farm managers of the need for animal health maintenance and monitoring as key steps in preventing disease and poor performance.

Optimistically, industry sales could continue to grow at 5 percent annually in real terms, with no decline in the current percentage of commitment of sales revenue to R&D. This would result in an $18.4 million annual increase in R&D expenditures ($0.05 \times \$2,344.4 \times 0.157 = \$18.4$).

Less favorable conditions could result from emerging food safety concerns and setbacks in the regulatory review of new animal health care biotechnologies. Farmers may also prove to be less willing to adopt the new generation of growth-promoting and disease-preventing drugs. Based on more pessimistic trends, animal health care research could slip back toward 12 percent of sales and gross sales might drop up to 15 percent from 1987 levels. Under these conditions, animal research expenditures would fall nearly $130 million, or by about one-third.

Veterinary Services

Total animal health care expenditures include the purchase of drugs (about $2.3 billion in 1987) and payments for veterinary services. A 1985 survey estimated annual agriculture veterinary service expenses at $638 million (B. E. Hooper, American Veterinary Medical Association, personal communication, 1989). Veterinary expenditures for companion animals (principally, dogs and cats) currently exceed $5 billion annually and constitute over 85 percent of total veterinary expenditures.

Veterinarians are private business people and rarely conduct research. The nation's R&D effort in veterinary medicine is carried out at 27 schools of veterinary medicine, which spend some $163 billion in research (1988–1989 estimate based on R&D activity at 26 of 27 schools). Federal support for research on food-producing animals, which has fallen from $15 million in FY 1979 to $10.8 million in FY 1987, is currently less than 7 percent of veterinary school R&D (B. E. Hooper, American Veterinary Medical Association, personal communication, 1989). Most veterinary school R&D focuses on companion animals and horses.

Factors Influencing Private Sector R&D

A variety of factors will influence corporate R&D priorities, as well as the overall level of private R&D expenditures. Clearly, the general economic status of the farm sector and trends in planted acreage are critical variables, since sales in many agricultural input industries are roughly proportional to the amount of land planted in crops each year.

Corporate Consolidation

Another factor that warrants attention is corporate consolidation, a trend which is occurring in all major agricultural input, food processing, consumer product, and retail industry subsectors. Three meat packers now account for most red meat sales. Eight chemical companies hold 70 percent of the $17 billion world market for agrichemicals, and also dominate the U.S. market (S. Cath, Agricultural Research Institute, personal communication, 1989). A half dozen companies dominate the seed, farm machinery, and animal health industries on a worldwide basis and in most countries, including the United States. Further consolidation on a global scale is expected in the 1990s because of increasingly fierce competition, growth in the size of company needed to support state-of-the-art R&D and marketing activities, and economic and political advantages gained by large companies that are able to secure raw materials, locate manufacturing plants, and penetrate markets anywhere in the world.

The impact of corporate consolidation and leveraged buyouts on R&D investments has been studied by the National Science Foundation. Twenty-four of 200 leading private performers of R&D that were involved in recent mergers or leveraged buyouts reduced combined R&D spending 5.3 percent between 1986 and 1987 (measured in current dollars). The other 176 leading firms supporting private R&D increased R&D by 5.4 percent in the same period (National Science Foundation, press release, February 2, 1989). As a result, growth in private sector R&D since 1985 "has all but disappeared" (National Science Foundation, 1989).

A recent food processing industry R&D survey found that R&D investments by companies with less than $10 million in sales averaged 3.0 percent or more of sales but dropped significantly to less than 1.0 percent of sales for companies with sales exceeding $250 million (Best, 1988).

Corporate restructuring can also have an impact on R&D priorities. Several seed companies have been bought by agrichemical companies in the 1980s, often because of the perceived potential of pesticide-producing companies to increase their market share through sales of pesticide-resistant plant varieties. A flurry of research in both public and private sector laboratories in the 1980s on biotechnological methods to develop pesticide-resistant varieties was driven more by perceived near-term commercial opportunities than intrinsic scientific interest or broad consensus that pesticide-tolerant plant varieties offer great promise in addressing environmental concerns.

Mergers involving large food processing and manufacturing companies with major retail firms raise different concerns with regard to consumer choice in the marketplace. Because of the proliferation of new products, there is strong competition for shelf space in supermarkets. Companies that gain preferential in-store placement and that promote new or established products can gain an important edge.

Corporate consolidation across national boundaries provides companies the opportunity to reduce costs by securing low-cost raw materials, locating plants where manufacturing costs can be minimized, and moving the finished products into several differ ent consumer markets. Multinational companies increasingly view the United States as a rich consumer market but as a costly place to locate manufacturing facilities. The ability of U.S. agriculture to serve as a reliable, low-cost supplier of basic farm commodities has also been questioned in recent years because of aggressive policies designed to hold land out of production in order to increase commodity prices and farm income. Sometimes erratic government trade, regulation, tax, and food safety policies in the United States also cause corporations to reflection the reliability and cost of using the United States as a source of raw commodities or as a place to locate a production facility.

Overall, corporate restructuring will influence the level, focus, and impact of private sector R&D. The full range of consequences from the wave of leveraged buyouts that began in the mid-1980s is not yet clear, nor is there any indication that the trend toward consolidation has slowed. Nonetheless, the evidence to date raises several concerns that warrant ongoing analysis and monitoring.

C

Setting and Acting Upon Budget Priorities

Research priorities within each of the six proposed major program areas should be identified by the research community and communicated annually to both the executive and the legislative branches of the federal government. As national needs change, so too will priorities, at least in some major program areas. For example, the President's fiscal year (FY) 1990 budget request highlights the need for a water quality initiative, which could include as a component research within the natural resources and the environment program area. In response to a decision to offer grants on water quality, the research community, organized through a program advisory committee, would need to articulate the areas of research most essential to establishing an improved science base for water quality protection. Proposals would then be sought in response to a program announcement describing high-priority water quality research needs.

Current Priority-Setting Mechanisms

The U.S. Department of Agriculture (USDA) receives guidance annually or periodically from numerous organizations and committees. They include two important entities established by die U.S. Congress in Title XIV of the Food and Agricultural Act of 1977: the Joint Council for Food and Agricultural Sciences (JCFAS) and the National Agricultural Research and Extension Users Advisory Board (UAB). They also include several committees organized by the National Association of State Universities and Land-Grant Colleges (NASULGC). In addition, the Agricultural Research Service (ARS) uses a number of internal and external mechanisms in setting priorities, and other private and public organizations also make their views known. Figure C.1 presents the channels of dialogue that play a role in setting USDA's research and development (R&D) priorities.

The purpose of JCFAS is to foster coordination of the agricultural research, extension, and teaching activities of the federal government, the states, colleges and universities, and other public and private institutions. In the 1980s, the JCFAS has played an important role in fostering dialogue and coordination across federal research agencies. It has also become a key forum for debate and consensus building on significant issues involving the agricultural and food sciences. Each year JCFAS issues a report on agricultural research priorities and accomplishments, including recommendations for future budgets. (See Appendix D for a listing of JCFAS priorities.)

The UAB, which is composed principally of farmers and ranchers, state government officials, academic scientists, extension specialists, and representatives of private organizations, is charged by the U.S. Congress with providing comments and recommendations on the President's annual budget proposal. The UAB's review cycle begins in January, when the President's budget is made public, and entails a series of meetings at which the budget is reviewed and a report is developed. Each year the UAB's report is issued in April. This allows time for the congressional appropriations committees to weigh the recommendations before taking action on the President's budget. Subcommittees of the appropriations committees typically do this in June or July. (The recommendations of the UAB appear in Appendix D.)

The academic committees organized by NASULGC include the following:

- *ESCOP*: The Experiment Station Committee on Policy conducts an annual budget review and priority setting exercise that produces reports to both USDA and the U.S. Congress. An ad hoc budget review subcommittee is set up each year and carries out one of the most comprehensive and authoritative analyses of the Cooperative State Research Service's (CSRS's) budget as it relates to federal and state agricultural research needs. ESCOP also has played a leadership role in several special projects, including the 1982–1984 biotechnology initiative that resulted in a $20 million biotechnology program area in the 1985 competitive grants program.

- *ECOP*: The Extension Committee on Policy is analogous to ESCOP in composition and function. Each year it carries out an in-depth review of the Cooperative Extension Service's budget and offers recommendations to both USDA and the U.S. Congress.
- *RICOP*: The Resident Instruction Committee on Policy addresses issues related to funding and policy that affect higher education. It has been a strong advocate of the higher education fellowship program that CSRS initiated in 1985. It has analyzed trends in the enrollments within, and the degrees awarded by, colleges of agriculture. These studies have helped focus the U.S. Congress on the need for an expanded federal commitment to higher education fellowships in the agricultural and food sciences.

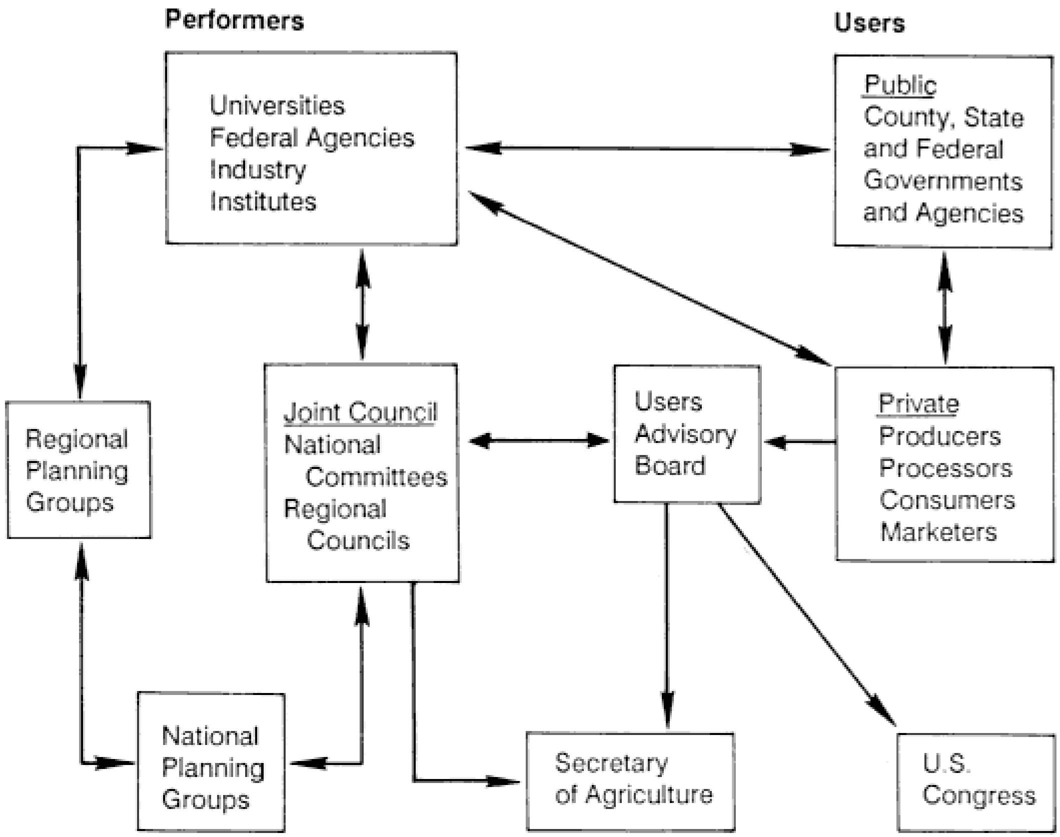

Figure C.1
Channels of dialogue that play a role in setting USDA's R&D priorities. SOURCE: Adapted from Miller, L. A. 1988. Continuing the Momentum: History, Growth, and Future Challenges. Washington, D.C.: Joint Council for Food and Agricultural Sciences, U.S. Department of Agriculture.

In developing its budget requests, USDA generally follows to some degree the budget recommendations offered by ESCOP, ECOP, and RICOP. Requests from these organizations are balanced first with other priorities within USDA and then with priorities across the federal government during the Office of Management and Budget's review of USDA's budget request. Later in the process, the U.S. Congress also evaluates the science and technology priorities and funding needs identified by these organizations.

It should be noted that during the debates within ESCOP and its special biotechnology task force, the issue of which funding mechanisms to use in distributing a hoped for increase in funds was much discussed and initially divisive. Some argued for reliance on either an existing formula or a new one, others favored special grants, and a third group argued for competitive grants. The question was resolved in favor of competitive grants, setting the stage for a major expansion in the size of the competitive grants program between 1984 and 1985.

Within USDA, ARS undertook a major internal review of priorities in the 1980s. The review resulted in a detailed 5-year plan. In addition, members of the ARS national program staff periodically review ongoing research, often calling upon scientists outside the agency for help. (See Appendix D for details.)

ARS receives guidance from several advisory councils and ad hoc committees set up for that purpose, including several under the auspices of the National Research Council's (NRC's) Board on Agriculture. Recent and current ARS-sponsored projects within the NRC include the following:

- The Plant Gene Expression Center (PGEC) Advisory Council's guidance to the ARS-University of California PGEC. The PGEC Advisory Council, in place since 1986, focuses on the scientific direction and quality of ongoing work at the ARS-University of California PGEC.
- The Committee on Peer Review Procedures' assessment of the peer review procedures used within ARS. The committee's report, *Improving Research Through Peer Review*, was released in July 1987 (National Research Council, 1987b).
- Reports issued by two briefing panels: *Report of the Briefing Panel on Agricultural Research* (National Research Council, 1983a) and *Report of the Research Briefing Panel on Biotechnology in Agriculture* (National Research Council, 1985b).
- An ongoing multifaceted program—global in scope—on the collection, assessment, preservation, and use of plant, animal, fish, and forest genetic resources. Several reports released in 1990 will summarize the findings and recommendations of this project.

A number of other private organizations often produce reports and recommendations on agricultural research needs. A principal way for these groups to advance their budgetary recommendations is to testify before agricultural appropriations subcommittees.

The congressional Office of Technology Assessment is periodically charged with issuing reports on food and agricultural science priorities, and it has done significant work in the area of agricultural research, land use, and biotechnology. Many other publicly chartered organizations are active in reviewing ongoing scientific programs or are concerned about specific issues, occasionally issuing analyses of agricultural and food science priorities.

In response to basic shifts in the challenges confronting USDA and the agricultural community, major program areas might change somewhat over the years. Priorities within each major program area could be expected to change more frequently.

Congressional Budget Actions

Congressional action on annual executive branch budget proposals for USDA's competitive grants program, from FY 1980 through FY 1989, appears in Table C.1, which present the President's budget request, the funds voted by the appropriations bills of the House and Senate, and the conference agreement between the two houses of the U.S. Congress. The percentages given below the dollar amounts show the percent increase or (decrease) from the President's budget request.

Specificity of Program Guidance by the U.S. Congress Through the Appropriations Process

The level of funds appropriated to different accounts, agencies, and programs reflects overall fiscal priorities. The U.S. Constitution vests responsibility for such decisions with the U.S. Congress, working in partnership with the executive branch. The nature and degree of congressional involvement in providing guidance, restrictions, and earmarks within agency and program budgets varies a great deal across the government. Even within an agency like USDA, the extent and variability of congressional guidance offered in different areas of the budget are revealing. Examples from the FY 1989 budget process are presented. The conference report covering the USDA FY 1989 budget covers just over seven pages in the September 18, 1988, *Congressional Record* (U.S. Congress, 1988), and includes detailed instructions and guidance on how funds are to be used within each program:

TABLE C.1 Congressional Action on the Proposed Budget for USDA's Competitive Research Grants Program, FY 1980-FY 1989 (in thousands of dollars)

Funding in:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
President's budget proposal	$30,000	$25,000	$22,880[a]	$22,880	$21,500	$50,000	$46,000	$42,425	$44,500	$54,500
House action	0	0	10,000	10,000	10,000	32,193	34,000	32,840	28,368	29,428
Percent change	100	100	56	56	53	35	26	23	36	46
Senate action	25,000	25,000	19,500	18,000	21,500	50,000	46,500	41,651	44,500	41,842
Percent change	17	0	15	21	0	0	1	2	0	23
Conference agreement	15,500[b]	16,000	16,320	17,000	17,000	46,000	42,312[c]	40,651	42,372	39,716
Percent change	48	46	29	26	21	8	8	4	5	27

[a]Budget submitted in March 1982 was $26,000,000 but was amended to $22,880,000 in September.
[b]Excludes FY 1980 rescission under P.L 96-304 of $400,000 for plant science and $100,000 for human nutrition.
[c]Appropriations Act funding for competitive research grants was $44,233,000 but was reduced to $42,312,000 because of Gramm-Rudman-Hollings.

SOURCE: Adapted from data provided by the Office of Budget, Planning, and Evaluation, U.S. Department of Agriculture, Washington, D.C., 1989.

- The $21 billion appropriated for nutrition programs is accompanied by less than a page of amendments and instructions in the conference report. In addition to establishing funding levels for specific programs, like food stamps, language calls for only two specific projects:

—$5.2 million to develop a system for independent verification of school food service claims, of which half is to be used for training state and local food service officials in new procedures for meal counting and claim procedures. A $50,000 earmark is provided to continue a study by the Mississippi School Food Service Institute.

—A farmer's market coupon demonstration project is agreed upon, specifying that $2 million may be used for this project.

- The $8.8 billion appropriated to the Commodity Credit Corporation to cover reimbursement for net realized losses will go toward expenditures for commodity price and farm income support payments. This appropriation is made with 18 lines of text. No explanatory notes or instructions are offered regarding the use of these funds (authorizing legislation establishes program rules and payment levels).
- Science and education agencies received appropriations of $1.3 billion, about 1.8 percent of USDA's total $69.97 billion budget. Nearly three pages of detailed instructions, amendments, and earmarks accompany this section of the seven-page USDA budget conference report. The U.S. Congress shifted spending priorities most dramatically in the ARS budget, including several cuts in the research account and several earmarked increases in the buildings and facilities account. Specifically:

—There were 30 distinct changes made in the ARS research budget, ranging from a less than $100,000 change to a $2 million cut of new funding sought to increase water quality research.

—A total of $28.35 million was appropriated for 31 building and feasibility studies. The President's budget requested $11 million for just one building project. (This project involved establishment of a new seed storage laboratory at Fort Collins, Colorado. The need and design of this facility has been studied by the Board on Agriculture [National Research Council, 1988c].) The geographic location of the additional 30 projects correlates closely with the states represented by members on the agricultural appropriations sub-committees.

—Total changes of $26 million in the proposed ARS research budget, representing about 4.6 percent of total research activity; $17.35 million of additional funding appropriated for buildings and facilities, representing another 3 percent of total agency resources. (The funds needed to equip and staff the new research facilities established in the FY 1989 budget will pose a difficult challenge for agency administrators in future years.)

D

Statements of Program Objectives and Funding Response

A variety of U.S. Department of Agriculture (USDA) agencies, committees, councils, and private organizations conduct periodic as well as ad hoc reviews of agricultural and food science and engineering priorities. This appendix provides additional details on some of the most important statements of systemwide or agency-specific priorities, including the following:

- Agricultural Research Service (ARS) objectives from its most recent 5-year plan.
- Joint Council for Food and Agricultural Sciences (JCFAS) 5-year plans and annual reports on priority research.
- The Users Advisory Board (UAB) priority statements.
- National Agriculture Research Committee, convened by the National Association of State Universities and Land-Grant Colleges statement of systemwide priorities.
- A review of the impact of priority-setting mechanisms on budget allocations.

Agricultural Research Service

The ARS objectives from the agency's 5-year plan are presented in the report *Agricultural Research Service Program Plan* (U.S. Department of Agriculture, Agricultural Research Service, 1983). An implementation plan to act upon these objectives has also been published (*Agricultural Research Service Program Plan: 6-Year Implementation Plan, 1986–1992* [U.S. Department of Agriculture, Agricultural Research Service, 1985]). The six objectives are described here.

The purpose of objective 1 was to develop the means for managing and conserving the nation's soil and water resources for a stable and productive agricultural system. There were four approaches for fulfilling objective 1: (1) develop the technology for assessing and predicting long-term changes in the quantity and quality of soil, water, and air resources available to agriculture; (2) provide the technology needed for improving, protecting, and restoring the productive capacity of agricultural soils; (3) develop improved water management systems and practices to achieve effective and efficient use of water resources; and (4) develop improved subsystems and models that integrate the use of soil, water, and air resources for the optimal management of major land resource areas.

The purpose of objective 2 was to develop the means for maintaining and increasing the productivity and quality of crop plants by four approaches: (1) broaden the germplasm resources of plants and beneficial organisms to ensure maximal genetic diversity for improved productivity; (2) select and modify the germplasms of plants, beneficial organisms, and pests; (3) develop improved production practices for maintaining and increasing crop productivity and quality and for reducing costs; and (4) develop improved methods for reducing crop losses caused by weeds, diseases, insects, nematodes, and other pests.

The purpose of objective 3 was to develop the means for increasing the productivity of animals and the quality of animal products, which was to be done by six approaches: (1) increase the genetic capacity of animals for production; (2) improve the efficiency of reproduction and reproduction-related biological processes; (3) improve animal nutrition and feed efficiency to increase productivity and product quality; (4) develop ways to prevent or control losses from diseases, parasites, and toxicants and other substances that limit animal performance and reduce the quality of animal products; (5) develop a means for control ling insects, ticks, and mites that affect animals and humans; and (6) devise means for improving and integrating procedures and facilities for production and transport of animals to increase productivity, reduce costs, and minimize stresses.

The purpose of objective 4 was to devise means for improving and integrating procedures and facilities for production and transport of animals to increase productivity, reduce costs, and minimize stresses. This was to be done by four approaches: (1) develop means for enhancing the inherent properties and uses of agricultural materials; (2) develop the means for meeting foreign and domestic user and regulatory requirements relating to toxic factors in food, feed, and other agricultural products; (3) develop means for reducing or eliminating postharvest losses caused by pests, spoilage, and physical and environmental damage; and (4) develop the means for increasing the efficiency of systems for processing, handling, storing, and distributing agricultural products.

The purpose of objective 5 was to develop the means for promoting optimum human health and well-being through improved nutrition and family resource management, which was to be done by four approaches: (1) define the nutrient requirements of humans at all stages of the life cycle; (2) determine the nutrient content of agricultural commodities and processed foods in the form that they are eaten, and establish the bioavailability of their nutrients; (3) improve the nutritional status of humans and the well-being of families by making techniques available for assessing the effectiveness of nutrition and home economics programs; and (4) integrate knowledge of human nutritional needs into the food and agricultural system.

The purpose of objective 6 was to develop the means for integrating scientific knowledge of agricultural production, processing, and marketing into systems that optimize resource management and facilitate the transfer of technology to users. This was to be done by developing integrated systems for the efficient production, processing, and marketing of agricultural products.

Joint Council for Food and Agricultural Sciences

JCAFS's 5-year plan for 1988 to 1993 identified seven critical societal concerns on which the USDA's R&D programs should focus and was put forth in the *Five-Year Plan for the Food and Agricultural Sciences: A Report to the Secretary of Agriculture* (U.S. Department of Agriculture, Joint Council for Food and Agricultural Sciences, 1980). These seven concerns were as follows: (1) restoring a competitive and profitable agricultural system; (2) revitalizing rural areas of the United States; (3) maintaining water quality; (4) enhancing the future through biotechnology; (5) advancing knowledge and scientific expertise in the agricultural sector; (6) understanding food, diet, and health relationships; and (7) managing germplasms and maintaining genetic diversity.

It is interesting to assess these 5-year priorities in contrast to annual priorities.

The fiscal year (FY) 1987 priorities were to (1) increase agricultural profitability through management; (2) improve water quality and management; (3) expand biotechnology efforts on plants, animals, and microbes; (4) develop the necessary scientific and professional human capital; and (5) improve human nutrition and understanding of the relationship between diet and health.

The FY 1988 priorities were to (1) enhance profitability in the agricultural system; (2) expand biotechnology to enhance the benefits from plants and animals; (3) improve water quality and management; (4) strengthen the development of professional and scientific expertise; (5) enhance productivity and conservation of soils; (6) expand domestic and foreign markets and uses for agricultural and forest products; (7) preserve plant germplasms and beneficially improve plants; and (8) improve human nutrition and the understanding of the relationship between diet and health.

The FY 1989 priorities are to (1) maintain and preserve water quality; (2) expand biotechnology and its applications; (3) develop and maintain scientific knowledge and expertise; (4) improve understanding of food, diet, human nutrition, and health relationships; (5) sustain soil productivity; (6) assess new and expanded uses for agricultural products; (7) preserve germplasms and genetically improve plants; and (8) improve food processing, quality, distribution, and safety.

Users Advisory Board

Agency Budget Recommendations

The UAB has reviewed the President's FY 1989 budget for the USDA in the *Appraisal of the Proposed*

1989 Budget for Food and Agricultural Sciences: Report to the President and Congress (National Agricultural Research and Extension Users Advisory Board, 1988). While generally supporting the proposals of the executive branch, the UAB has made suggestions for (1) the best ways to utilize the level of funding that has been called for and (2) some ways in which increased funding or shifting of funds between categories would allow the USDA to do a better job of achieving the nation's agricultural priorities.

Agricultural Research Service

The UAB endorses the administration's $20.2 million funding increase for ARS, but proposes some reallocations and restrictions. Specific recommendations include continued comprehensive planning for research; increased interdisciplinary efforts; mandatory peer review; economic impact analysis of proposed research; renovation of the Beltsville, Maryland, research facility; closing or consolidation of excess laboratory facilities; shifting of $10 million from plant research to animal science research; and giving top priority to research on alternative uses for agricultural products.

Cooperative State Research Service

The UAB would increase the Cooperative State Research Service (CSRS) budget by $3 million and reallocate some funds among program areas. This would provide an additional $6 million for animal health and disease research, $3 million for aquaculture research, $3 million for higher education programs, and $338,000 for rangeland research.

Economic Research Service

The UAB proposes a reallocation aimed at equalizing funding between two Economic Research Service divisions and stresses the need to focus on agricultural labor issues.

Extension Service

The UAB proposes a shift of funds from food and nutrition education to programs directed toward agriculture and natural resources. The reallocations would provide $7 million for pest management, $10 million for water quality, and $2.8 million for renewable resources.

U.S. Forest Service

The UAB suggests shifting $6 million to the Cooperative State Research Service to fund a forestry competitive grants program. The UAB also suggests several high-priority forestry issues that the agency should emphasize.

Human Nutrition Information Service

The UAB supports the proposed Human Nutrition Information Service budget and suggests that the agency set research priorities through strategic planning, track major market shifts, increase cooperation with other agencies, and devote more time to communicating its findings to the public.

National Agricultural Research Committee

Table D.1 provides a list of 21 initiatives and objectives of the National Agricultural Research Committee, which is convened by the National Association of State Universities and Land-Grant Colleges.

A Review of the Impact of Priority-Setting Mechanisms on Budget Allocations

The impact of a specific recommendation or organization's activities on bringing about change in funding priorities is often difficult to trace. A few notable exceptions can be cited, including the biotechnology initiative led by the Experiment Station Committee on Policy in the mid-1980s, the Resident Instruction Committee on Policy's advocacy of a higher education fellowship program, and the Carnegie Institution report *A Nation at Risk* (1984), which galvanized public concern about the inadequate state of public education.

One approach to gauge the impact of priority-setting mechanisms on funding decisions is to isolate and analyze actual significant changes in funding levels that have occurred from one budget to the next. Typically, the U.S. Congress will state in conference and full committee reports its reasons for cutting or expanding an existing program or initiating a new one. It may cite a particular report, or a set of recommendations offered by an advisory body. In most cases several reports and recommendations lie behind any major shift in priorities. Table D.2 summarizes sig

TABLE D.1 National Agricultural Research Committee Initiatives and Objectives

1. Maintain and protect water quality and quantity
   - Groundwater quality
   - Water quantity
   - Water use efficiency
   - Conservation practices
   - Water use policy
   - Household water use
2. Biotechnology
   - Plant productivity
   - Plant disease resistance
   - Nutritional quality of plants
   - Biological control of pests
   - Biologically active materials
   - Diagnostic and immunologic products
   - Animal disease resistance
   - Animal development and productivity
   - Impacts of biotechnology
3. Genetic improvement of economically important plants
   - Gene characterization
   - Germplasm acquisition and maintenance
   - Plant breeding
   - Resistance to pests
   - Soil microorganisms
   - Consumer preferences
   - New uses for plant products and components
4. Sustaining soil productivity
   - Erosion-soil property relationships
   - Soil conservation policy
   - Soil conservation economics
   - Status of soil productivity
   - Tillage management interactions
   - Soil dynamics
5. Improved management of crop pests and diseases
   - Incidence, prediction, and management
   - Pesticide and pest management
   - Quantifying constraints to plant productivity
   - Epidemiological systems
   - Biological control techniques
   - Integration of pest management into crop production systems
6. Food processing, preservation, and quality enhancement
   - Processing and preservation
   - Quality enhancement
   - Food safety
   - By-products and the environment
7. Animal efficiency in food production
   - Animal genetics
   - Reproductive physiology
   - Animal nutrition
   - Animal protein and lipid synthesis
   - Animal management systems
8. New and expanded uses for agricultural and forest products
   - New and alternative crops
   - Processing technologies
   - Added value
9. Integrating agricultural technologies
   - Assessment of new technologies
   - Market forces and enterprise profitability
   - Capital investment and financial requirements
   - Integrated systems
   - Alternative systems
   - Optimal input systems
10. Interrelationships of food and the nutritional and health status of humans
    - Human nutritional requirements
    - Dietary practices
    - Nutritional quality of foodstuffs
    - Bioavailability of nutrients
    - Health influences from diet
11. Marketing of agricultural and forest products
    - Supply, demand, and price relationships
    - Grades and standards
    - Market efficiency and performance
    - International market development
    - Market strategies and power
    - Consumer preferences and quality
12. Animal health and disease
    - Immunological advances
    - Integrated health management
    - Epidemiology of animal diseases
    - Residue and toxicology studies
13. Impact of agricultural and forestry policy on global markets
    - Commodity, factor, and financial
    - Market relationships
    - Political economy of domestic and foreign commodity policy

nificant shifts in USDA research funding priorities since FY 1983.

- Comparative productivity growth and competition in world markets
- Impacts of emerging technological changes for public policy
- Policy and institutional design

14. Rural family and community well-being
    - Economic alternatives and diversification
    - Family stress factors
    - Displacement assistance
    - Resource management
    - Environmental and safety factors for families
    - Organizing capacities and governance of communities
    - Interdependence among agriculture, families, and communities
15. Agricultural and forestland use
    - Land use policies, land values, and tax base
    - Land use alternatives
    - Recreation resource management
    - Consolidation of forestland and agricultural land information
16. Energy-efficient systems
    - Efficient plant and animal production and processing systems
    - Efficient energy conversion technologies
    - Alternative sources
    - Extraction procedures and practices
17. Sensors and computing systems for food and agriculture
    - Sensor technology development
    - Electronic systems for plant and animal production
    - Electronic systems for food processing
18. Productivity of rangeland and pastureland
    - Rangeland ecology and management
    - Plant-animal interactions
    - Water management
    - Plant improvement
    - Weed and brush management
19. Forest productivity
    - Silvicultural techniques and practices
    - Genetics and superior tree production
    - New processes, products, and uses for wood
    - Forest health
20. Effects of atmospheric deposition on ecosystems
    - Chemical exposures
    - Amount-response relationships
    - Accumulation of toxicants in plants and animals
21. Plants for the urban environment
    - Plant materials
    - Management and maintenance strategies

SOURCE: Adapted from Experiment Station Committee on Organization and Policy. 1988. Table 5 in Research Initiatives: A Midterm Update of the Research Agenda for the State Agricultural Experiment Stations. College Station, Tex.: Texas Agricultural Experiment Station.

One of the important organizations that influences the priority-setting process is the Joint Council for Food and Agricultural Sciences. JCFAS was established in 1977 by the U.S. Congress to facilitate coordination and prioritization of research, education, and technology policy among the agencies of USDA, other federal agencies, and state performers of research and extension activities.

JCFAS developed its first 5-year plan for the food and agricultural sciences in 1984, and has since issued an updated 5-year plan on a biennial basis (see discussion earlier in this appendix). In addition, JCFAS publishes a yearly report to the secretary of agriculture on priorities for research, extension, and higher education. These reports articulate national research and education priorities and offer recommendations regarding how federal research activities should be redirected or focused to better address top-priority issues. The evolution in the priorities noted in six most recent annual priorities reports (1985–1990), in contrast to the most recent 5-year plan issued in 1988, is summarized in Table D.3.

The priorities identified by JCFAS in annual and 5-year reports reflect its sense of changing scientific needs and opportunities. Two of the top priorities listed in the 1988 5-year plan were not among the top

Table D.2 Significant Annual Shifts in Funding Priorities in USDA Research Agency Budgets, FY 1983–FY 1989

	ARS		CSRS	
Fiscal Year	Area	Funding Change (millions of dollars)	Area	Funding Change (millions of dollars)
1983	Basic research	+9.6	Hatch Act	+3.4
	Animal health	+4.0	Cooperative forestry research	-1.2
	Range and pasture	+0.5		
	NPGS	+3.8	1890 institutions	+0.2
	Acid precipitation	+0.9	Plant science competitive grants	+6.4
	Land and water conservation	+5.1	Animal health formula funds	-5.8
	Human nutrition	+1.0		
1984	Basic animal biotechnology	+0.8	Animal science competitive grants	+4.5
	Basic plant biotechnology	+1.3	Animal health formula funds	-5.8
	Postdoctorate fellowship	+0.5		
	Basic postharvest resources			
	Exports	+1.0		
	Grain quality	+0.6		
	Human nutrition	+1.2		
1985	Basic animal science	+0.4	Hatch Act	+3.0
	Livestock disease diagnosis	+0.2	Cooperative formula	-0.3
			1890 institutions	+0.5
	Animal genetic disease resistance	+0.4	Animal science competitiveness	+4.5
	Agricultural systems	+0.6	Biotechnology	+28.5
	Plant germplasms	+0.6	Animal health formula	-5.8
	Plant protection	+0.6		
	Biocontrol	+0.4		
	Soil fertility	+0.6		
	Soil erosion	+0.5		
	Basic postharvest	+0.9		
	Basic postharvest exports	+0.8		
	Strengthening of 1890 institutions	+2.0		
	Graduate fellows	-5.0		
1986	Groundwater quality	+0.5	Eliminate special grants	-28.5
	New methods for SCS resource assessments	+0.5	Eliminate section 1433 formula funds	-5.76
			Reduce higher education funding	-5.8
	Plant germplasms	+3.2		

	ARS		CSRS	
Fiscal Year	Area	Funding Change (millions of dollars)	Area	Funding Change (millions of dollars)
	Animal health	+0.75		
	Alternative quarantine treatment	0.5		
1987	Plant germplasms	+3.5	Eliminate special grants funds	-30.3
	New products and uses	+10.0	Eliminate 1983 formula funds	-5.7
			Reduce higher education (elimination of graduate training and Morris-Nelson programs)	-5.8
			Reduce competitive grants (elimination of categories designated by U.S. Congress)	-1.8
1988	Plant germplasms	+73	Increases of formula programs	+83
	Improve meat quality through reduction of fats	+2.1	Eliminate special grants	-52.0
			Competitive grants for plant science centers	+39
	Planning for construction of new National Seed Storage Lab (instead of plant gene germplasms)	+1.0	Eliminate Section 1433 formula funds	-5.5
			Reduce higher education	-5.6
1989	Groundwater quality	+5.0	Reduce forestry formula	-4.5
	Global change	+0.7	1890 institutions and Tuskegee University	+2.0
	Food safety	+4.5		
	Repair and maintenance	+4.0	Eliminate Section 1433 formula funds	-5.5
			Reduce higher education	-5.4
			Reduce special grants	-44.5
			Competitive grants	+12.1
			Increases directed land for:	
			Plant science centers	
			Animal science	
			Biotechnology	
			Global change	

NOTE: Abbreviations: NPGS, National Plant Germplasm System; SCS, Sod Conservation Service.
SOURCE: Adapted from data provided by the Office of Budget, Planning, and Evaluation, U.S. Department of Agriculture, Washington, D.C., 1989.

priorities identified for 1989 and 1990: revitalizing rural areas of the United States and restoring international competitiveness. Rural development has not been cited as a top-priority concern in any of these years, apart from the 1988 5-year plan. Some priorities emerge quickly but prove to be short-lived, such as competitiveness. Other categories, such as developing biotechnology, maintain a fairly consistent ranking. Few priorities, however, have shifted consistently in the annual ranking of priorities. Water quality is the one exception, rising steadily from seventh place in 1985 to first in 1989 and 1990.

Table D.3 Evolution of Research Priorities in Reports of the Joint Council on Food and Agricultural Sciences: Ranking of 1988 5-Year Research Priorities in Annual Priorities Reports, 1985–1990

	Annual Priorities Ranking					
1988 5-Year Priorities	1990	1989	1988	1987	1986	1985
Restoring a competitive and profitable agricultural system	[a]	[a]	[a]	[a]	[a]	[a]
Revitalizing rural areas of the United States[b]	[a]	[a]	[a]	[a]	[a]	[a]
Maintaining water quality	1	1	3	2	4	7
Enhancing the future through biotechnology	2	2	2	3	1	1
Advancing knowledge and scientific expertise in agriculture	3	3	4	4	3	3[c]
Understanding food, diet, and health relationships	4	4	8	5	6	6
Managing germplasms and maintaining genetic diversity	5	7	7	[a]	[a]	[a]

[a] Was not included among the top-ranked priorities, was included in a listing of other priorities, or was included as an aspect of other listed priorities.
[b] Rankings involved emphasis on water quality management in 1985 and 1986.
[c] Identified in 1985 as plant molecular biology research.
SOURCE: National Agricultural Research and Extension Users Advisory Board. 1987. Appraisal of the Proposed 1988 Budget for Food and Agricultural Sciences: Report to the President and Congress. Washington, D.C.: U.S. Department of Agriculture.

While Table D.3 provides a useful snapshot of how JCFAS perceives budget priorities, it does not contain information on how budget allocations actually shifted in response to a perceived change in priorities. This response can be gauged, at least crudely, by contrasting significant changes in USDA research expenditures for FY 1983 to FY 1989 (see Table D.2) to changes in JCFAS priorities (see Table D.3). Recent changes in funding priorities suggest that three of seven priority issues identified in the JCFAS annual reports have received little or no new funding (competitiveness, revitalizing rural areas of the United States, understanding diet and health); some areas receiving increased funding were not among JCFAS's top priorities (new uses and climatic change). Increased funding for research in two areas preceded identification by JCFAS as a top priority (biotechnology and germplasms); in one case (water quality), funding increases appeared to follow in a logical sequence after identification as a top-priority research need. In the case of the priority of advancing knowledge, the funding response has been modest and intermittent.

Funding changes are noted below in each of the seven top-priority areas of research identified in the 1988 JCFAS 5-year plan (see Table D.3).

1. *Restoring Competitiveness*. This issue emerged as priority number one in the 1987 and 1988 annual JCFAS reports. There was little or no change in funding directed toward this issue in subsequent budgets. One executive branch initiative relevant to competitiveness was advanced by the Extension Service. The extension competitiveness and profitability initiative has not received significant new funding to date.
2. *Revitalizing Rural Areas of the United States*. This 5-year plan priority was not previously identified in earlier annual JCFAS priority reports, nor did it warrant mention as a top priority in the 1989 and 1990 reports. There has been little or no new or redirected funding devoted to research on this issue.
3. *Maintaining Water Quality*. Water quality has risen steadily in the relative rankings since 1985. Modest new funding for groundwater quality research in ARS ($0.5 million) was included in the FY 1986 budget, and a more substantial increase was included in the FY 1989 ARS budget ($5 million). The President's proposed FY 1990 budget includes $10 million in additional funding for ARS water quality research and just under $4 million through the CSRS and $5 million through the Extension Service. This is the one top-priority area in which increases in appropriated funds appear to be responsive to JCFAS priority reports.
4. *Enhancing the Future through Biotechnology*. Since the mid-1980s, biotechnology has been identified consistently as a highly significant scientific opportunity for food and fiber industries. The first new funding for plant and animal biotechnologies was included in the FY 1984 budget for ARS ($1.3 and $0.8 million, respectively). The FY 1985 CSRS budget for the competitive grants program included the major increment of new funding for biotechnology: $28.5 million. Since FY 1985, no major new funding has been appropriated for biotechnology, and considerable slippage (about 30 percent) has occurred in the level of competitive grants available for biotechnology research.
5. *Advancing Knowledge and Expertise*. This priority led to the initiation of the USDA higher education fellowship program in FY 1984. The ARS expanded its fellowship program in FY 1988 to include a total of 100 fellows. Efforts have been under way for 4 years to expand the higher education fellowship program and secure funding for institutional strengthening grants.
6. *Understanding Diet and Health*. This priority has risen to number four among annual priorities. No new funding has been devoted specifically to this areas, although considerable scientific effort supported by animal science and human nutrition funding from ARS and CSRS has been directed toward understanding diet and health.
7. *Managing Germplasms*. Within the ARS budget, increases for the National Plant Germplasm System were appropriated in FY 1983, prior to its identification as a top-priority issue in 1986. Further modest ARS budget increases were provided in FY 1985 and FY 1986, and there were major increases in FY 1987 and FY 1988 ($3.5 million and $7.3 million, respectively).

One advantage of competitive grants programs is the ability to quickly adjust research priorities by calling for proposals in areas of particular need. The six major competitive grant program areas proposed here would ensure opportunities to support cutting-edge science and technology development in each of the top-priority areas identified by JCFAS.

References

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

Best, D. 1988. Competing through R&D. Prepared Foods November: 72–76.

Boyer, J. S. 1982. Plant productivity and environment. Science 218:443–448.

Bryan, F. L. 1980. Foodborne diseases in the United States associated with meat and poultry. Journal of Food Protection 43:140–150.

Business Week. June 20, 1988. A perilous cutback in research spending. Pp. 139–162.

Capalbo, S., and J. Antle, eds. 1988. Agricultural Productivity: Measurement and Explanation. Baltimore: Johns Hopkins University Press.

Carnegie Institution. 1984. A Nation at Risk. New York: Carnegie Institution.

Council of Economic Advisers. 1988. Economic Report of the President. Washington, D.C.: U.S. Government Printing Office.

Council of Economic Advisers. 1989. Economic Report of the President. Washington, D.C.: U.S. Government Printing Office.

Evenson, R. 1968. The Contribution of Agricultural Research and Extension to Agricultural Production. Ph.D. thesis. University of Chicago, Chicago, 111.

Evenson, R., P. Waggoner, and V. Ruttan. 1979. Economic benefits from research: An example from agriculture. Science 205:1101–1107.

Experiment Station Committee on Organization and Policy. 1984. Research and Agricultural Trade. College Station, Tex.: Texas Agricultural Experiment Station.

Experiment Station Committee on Organization and Policy. 1988. Research Initiatives: A Midterm Update of the Research Agenda for the State Agricultural Experiment Stations. College Station, Tex.: Texas Agricultural Experiment Station.

Federation of American Societies for Experimental Biology, Life Sciences Research Office. 1984. Assessment of the Iron Nutritional Status of the U.S. Population Based on Data Collected in the Second National Health and Nutrition Examination Survey, 1976–1980. Bethesda, Md.: Federation of American Societies for Experimental Biology.

Food Marketing Institute. 1989. Trends: Consumer Attitudes and the Supermarket, 1989. Washington, D.C.: Food Marketing Institute.

Fox, G., R. Evenson, and V. Ruttan. 1987. Balancing basic and applied science. The case for agricultural research. Bioscience 37:507–509.

Furtick, W. R. 1989. International dimension for the U.S. agricultural research agenda. Speech presented at the Conference on International Agricultural Research: Its Relationship to U.S. Agricultural Productivity and Competitiveness, Washington, D.C., April 10, 1989.

Giese, R. L. 1988. Forest research: An imperiled system. Journal of Forestry 86(June): 15–22.

Harrington, D., G. Schluter, and P. O'Brien. 1986. Agriculture's Links to the National Economy. Economic Research Service, Agriculture Information Bulletin No. 504. Washington, D.C.: U.S. Department of Agriculture.

Hauschild, A. H. W., and F. L. Bryan. 1980. Estimate of cases of food-and waterborne illness in Canada and the United States. Journal of Food Protection, 43:435–440.

Institute of Food Technologists. 1988. Special Report: The Growth and Economic Impact of the Food Processing Industry. Chicago: Institute of Food Technologists.

International Life Sciences Institute. 1987. Review of Research Activities to Improve Risk Assessment for Carcinogens. Washington, D.C.: International Life Sciences Institute.

Leopold, A. 1968. A Sand County Almanac. London: Oxford University Press. (Reprint of the 1949 edition.)

Miller, L. A. 1988. Continuing the Momentum: History, Growth, and Future Challenges. Washington, D.C.: U.S. Department of Agriculture.

National Academy of Engineering. 1989. Technology and Competitiveness. Washington, D.C.: National Academy Press.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 1988. Federal Science and Technology Priorities: New Perspectives and Procedures. Washington, D.C.: National Academy Press.

National Agricultural Chemicals Association. 1986. Industry Profile Survey, 1986. National Agricultural Chemicals Association, Washington, D.C. Photocopy.

National Agricultural Research and Extension Users Advisory Board. 1987. Appraisal of the Proposed 1988 Budget for Food and Agricultural Sciences: Report to the President and Congress. Washington, D.C.: National Agricultural Research and Extension Users Advisory Board.

National Agricultural Research and Extension Users Advisory Board. 1988. Appraisal of the Proposed 1989 Budget for Food and Agricultural Sciences: Report to the President and Congress. Washington, D.C.: National Agricultural Research and Extension Users Advisory Board.

National Center for Health Statistics. 1988. Monthly Vital Statistics Report, Vol. 37, No. 1, April 25. Washington, D.C.: National Center for Health Statistics.

National Institutes of Health, Division of Research Grants. In press. NIH Data Book 1989. Washington, D.C.: National Institutes of Health.

National Research Council. 1969. An Evaluation of the Salmonella Problem. Report of the Committee on Salmonella, Division of Biology and Agriculture. Washington, D.C.: National Academy of Sciences.

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

National Research Council. 1983a. Report of the Briefing Panel on Agricultural Research. Washington, D.C.: National Academy Press.

National Research Council. 1983b. Risk Assessment in the Federal Government: Managing the Process. Washington, D.C.: National Academy Press.

National Research Council. 1985a. Meat and Poultry Inspection: The Scientific Basis of the Nation's Program. Washington, D.C.: National Academy Press.

National Research Council. 1985b. Report of the Research Briefing Panel on Biotechnology in Agriculture. Washington, D.C.: National Academy Press.

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

National Research Council. 1987b. Improving Research through Peer Review. Washington, D.C.: National Academy Press.

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

National Research Council. 1988b. Educating the Next Generation ofAgricultural Scientists . Washington, D.C.: National Academy Press.

National Research Council. 1988c. Expansion of the National Seed Storage Laboratory: Program and Design Considerations. Washington, D.C.: National Academy Press.

National Research Council. 1988d. Understanding Agriculture: New Directions for Education. Washington, D.C.: National Academy Press.

National Research Council. 1989a. Alternative Agriculture. Washington, D.C.: National Academy Press.

National Research Council. 1989b. Diet and Health: Implications for Reducing Chronic Disease Risk. Washington, D.C.: National Academy Press.

National Research Council. 1989c. FOCUS 1988: Proceedings of a National Symposium Honoring USDA Food and Agricultural Sciences National Needs Graduate Fellows. Washington, D.C.: National Academy Press.

National Science Foundation. Various years. Federal funds for research and development, detailed historical tables: Various fiscal years. In Federal Obligations for Total Research and Development by Major Agency and Performer: Various Fiscal Years. Washington, D.C.: Division of Science Resources Studies, National Science Foundation.

National Science Foundation. 1988a. Budget Summary FY 1989. Washington, D.C.: National Science Foundation.

National Science Foundation. 1988b. Characteristics of Doctoral Scientists and Engineers in the United States. NSF Report No. 88-331. Washington, D.C.: National Science Foundation.

National Science Foundation. 1989. An Assessment of the Impact of Recent Leveraged Buyouts and Other Restructurings on Industrial Research and Development Expenditures. Washington, D.C.: National Science Foundation.

Office of Management of Budget. 1989. Budget of the United States Government. Special Analysis J. Washington, D.C.: U.S. Government Printing Office.

Pardey, P. G., and J. Roseboom. 1989. Agricultural Research Indicator Series: A Global Data Base on National Agricultural Research Systems. Cambridge: Cambridge University Press.

Pray, C., and C. Neumeyer. 1989. Trends and Composition of Private Food and Agricultural R&D Expenditure in the United States. New Brunswick, NJ.: Department of Agricultural Economics, Cook College, Rutgers University.

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

Thurow, L. C. 1989. GATT Is Dead. Background Paper for the World Economic Forum, Davos, Switzerland.

U.S. Congress. 1988. Congressional Record, 100th Cong., 2d sess., pp. H8487–H8494, September 18, 1988. Washington, D.C.

U.S. Congress, House. 1988. H.R. 100-658 on H. Con. Res. 268. 100th Cong. 1st sess.

U.S. Department of Agriculture. 1988. Agricultural Statistics. Report No. 001-000-04532-6. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Agriculture. 1989a. 1990 Budget Summary. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1989b. Performance Report: Natural Resources and Environment Policy and Program Area: 1981–1988. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Agricultural Research Service. 1983. Agricultural Research Service Program Plan. Miscellaneous Publication No. 1429. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Agricultural Research Service. 1985. Agricultural Research Service Program Plan: 6-Year Implementation Plan, 1986–1992. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Cooperative State Research Service. Various years. Inventory of Agricultural Research, Various Fiscal Years. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Economic Research Service. 1987. Farm Sector Review. Report ECIFS 7-4. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Economic Research Service. 1988a. Food Consumption, Prices, and Expenditures, 1966–87. Statistical Bulletin No. 773. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Economic Research Service. 1988b. Income distribution by type of farm, 1985–1986. In Economic Indicators of the Farm Sector: Farm Sector Review, 1986. Report ECIFS 6-3. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Economic Research Service. 1989. The ERS in 1989. April. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Agriculture, Joint Council for Food and Agricultural Sciences. 1980. Five-Year Plan for the Food and Agricultural Sciences: A Report to the Secretary of Agriculture. Washington, D.C.: U.S. Department of Agriculture.

U.S. Department of Health and Human Services, U.S. Public Health Service. 1988. The Surgeon General's Report on Nutrition and Health. U. S. Public Health Service, U.S. Department of Health and Human Services Publication No. 88-50210. Washington, D.C.: U.S. Government Printing Office.

U.S. General Accounting Office. 1987. Agricultural Competitiveness: An Overview of the Challenge to Enhance Exports. Washington, D.C.: U.S. General Accounting Office.

White, F. C. 1987. Distribution of agricultural research impacts. Pp. 111–121 in Evaluating Agricultural Research and Productivity: Proceedings of a Symposium. Miscellaneous Publication No. 52-1987. Minnesota Agricultural Experiment Station. St. Paul: University of Minnesota.