1986 Yearbook of Agriculture

Research For Tomorrow

The cover of Research For Tomorrow *visualizes the hand of research working with the double helix of a molecule of DNA (deoxyribonucleic acid)—the basis of heredity in organisms—to shape tomorrow's agriculture and forestry.*

Foreword

USDA's research function is as old as the department itself. It was one of the agency's original functions, and it continues to serve us well today.

In today's complex agriculture, many of the issues faced by producers are nationwide in their impact and demand a national commitment to address them.

In some areas, the research to provide the answers will require such long-term risk and expense that the private sector may hesitate to undertake it. In those cases, there will be a need for concentrated Federal funding.

Once the results of basic research are in the public domain, the private sector can see opportunities to expand and modify them—to put them to work to improve the quality of life by developing new uses and new markets for farm products, improving farm efficiency, and strengthening farmer profitability.

The basic impetus behind agricultural research is not simply to increase production—it is to find answers to the challenges society and agriculture face today—and will certainly confront tomorrow.

Our current challenge in agriculture is to remain competitive in the world market. U.S. producers must be able to produce their crops at a price that will allow them to be marketed successfully in this global economy. Research will help us discover more efficient and more cost-effective means of doing this.

Agriculture is a dynamic industry, and that dynamism is fueled by research. Dedicated men and women all over the United States—in the Federal Government, the vast network of State Experiment Stations, and private industry—are part of a common effort to seek answers that will ultimately benefit all of us.

The excitement and the rewards of their work are evident in the 1986 Yearbook of Agriculture. "Research for Tomorrow" pays tribute to the vital role research plays in enabling U.S. agriculture to be a strong world-class industry.

RICHARD E. LYNG
Secretary of Agriculture

Preface

John J. Crowley, *Yearbook Editor*

This is not the ultimate book on agricultural research. Not even close.

It is, we hope, an enlightening glimpse into just a few aspects of the research generated by or involving dedicated people in the U.S. Department of Agriculture (USDA) and the 56 State Agricultural Experiment Stations, as well as many others, including scientists in the private sector.

From the beginning, the choice of subjects to be included in the book has been controversial—perhaps inherently so. It is not easy, pleasant, or perhaps even rational, to leave out research into soil and water conservation, aquaculture, farm management, irrigation, marketing, tillage, traditional plant and animal breeding, plant and animal production, traditional pesticides, rural development, transportation, and economic consequences—to name just a few subjects in a very broad spectrum—and still maintain that this is a book about agricultural research.

Yet the committees and advisers that selected the subjects in *Research for Tomorrow* saw value in presenting just a few subjects in some depth. They hoped the book would help increase understanding of at least some significant aspects of modern agricultural research.

At the same time, they said that the dissemination of research results needed to be covered in the book, as well as the land-grant system which not only houses much of today's important research but also trains our youth for the challenges of tomorrow.

Without this infrastructure, there would be far fewer seeking answers and too few benefiting from those answers.

My warm thanks go out to all those who helped make this Yearbook possible. Many of them are named in the Credits at the end of the book. USDA is especially grateful to the authors, who took time from research and administration to provide the benefit of their knowledge and insight.

I'm confident that the readers will find their efforts valuable.

Contents

Continuing strong support for our nation's science and technology has been and will continue to be a policy of this Administration. The goals of this support are enhanced national security, improved quality of life, and increased national competitiveness. Today, more than ever before, we must use our technological resources aggressively in order to retain international leadership.

—President Reagan,
1986 State of the Union Address

Agricultural Research

Role of Research in Agriculture

Orville G. Bentley, *Assistant Secretary for Science and Education*

Several factors have been involved in establishing the productive capacity of U.S. agriculture, and high on the list are research and technological innovations. Past investments in research have produced hybrid crop and animal strains, labor-saving equipment, improved cultural practices, animal disease control, and availability of chemicals to enhance growth and protect plants from pests. The use of these technologies has resulted in a higher standard of living for both consumers and producers. A wide variety of wholesome food can be purchased at lower relative prices than at any time in the past, and most farm families enjoy a level of living that was not available to earlier generations.

Despite past successes in productivity gains and industry well-being, global economic changes of the past 5 years have resulted in a considerable decrease in demand for U.S. exports. These developments have had a reverberating impact on rural America resulting in a considerable reduction in land values and financial hardship for many farmers and ranchers. Recent changes in macro-level influences, however, suggest that future opportunities should be brighter:

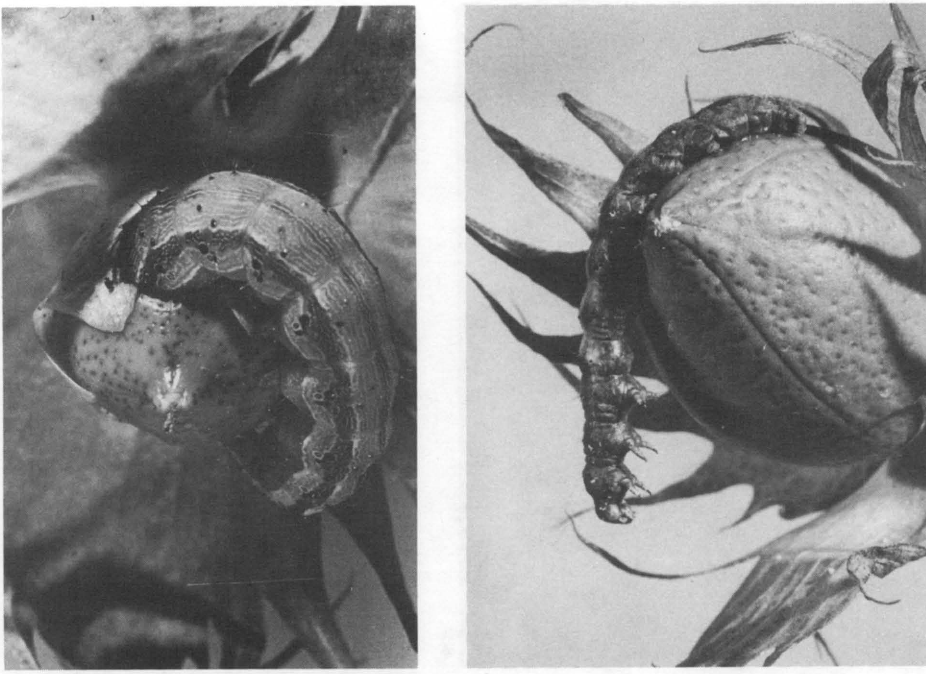
- In recent months the value of the dollar has declined 20 to 30 percent as compared to other currencies. This change reduces the costs of U.S. goods in foreign markets.
- Intense negotiations are under way with our trading partners to encourage exchange of goods on a more level playing field.
- Interest rates and energy costs have come down, easing two of the major expenses of modern-day agriculture.

These positive trends should improve the competitive position of U.S. agriculture. But changes in the rest of the world's ability to produce agriculture products will challenge U.S. access to global markets. In January 1986, Dennis T. Avery, senior analyst with the U.S. Department of State, reported: "annual world production of grain and oilseeds has jumped by 213 million tons in the last four years, while world consumption has increased only 153 million tons. The largest share of the increase in crop output has been in the Third World. Better farm technology, due to increasing human knowledge and broader world communication, has been the single most important factor in this progress." Technology that allowed the United States to develop a productive agricultural industry is now being adopted much quicker by other countries.

What unique strengths does the United States possess to compete effectively in domestic and foreign markets—remaining a net exporter of food and fiber, rather than an importer? Two important strengths are: 1) A strong commitment to the role of science in our national well-being and 2) an entrepreneurial spirit—freedom of economic oppportunity to explore new markets.

The future role of research in agriculture was outlined effectively by Vernon M. Ruttan in an editorial in *Science*, February 21, 1986:

> The capacity of American agriculture to expand its foreign markets and retain its domestic markets depends on continued declines in the



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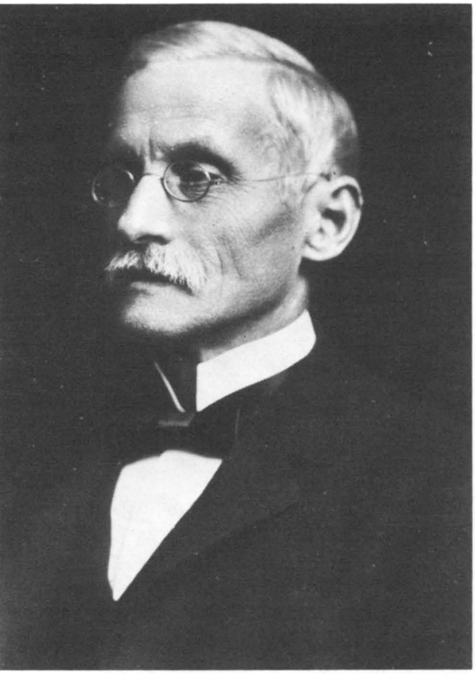
Left: A cotton bollworm eats its way into an unprotected cotton boll. Right: Overcome by a viral insecticide, a cotton bollworm hangs from the boll of a viral-protected cotton plant. At the slightest touch the caterpillar will rupture to release billions of virus particles that could spread to protect other plants.

real costs of production. American agriculture has achieved its preeminence in the world by substituting knowledge for resources. This knowledge, embodied in more productive biological, chemical, and mechanical technologies and the managerial skills of farm operators, has given the United States a world-class agricultural industry at a time when many other sectors of our economy are losing their preeminent position. A necessary condition for U.S. agriculture to retain its status is enhancement of both public and private sector capacity for scientific research and technology development. The costs, to both consumers and producers, of failure to maintain and enhance our efficiency in production would greatly exceed the adjustment costs resulting from abundance.

Beginnings of Agricultural Research

Agricultural experimentation took place in the first permanent English settlements in what is now the United States. The first settlers at Jamestown and Plymouth learned, with Indian aid, to grow corn. In 1613, John Rolfe of Jamestown experimented with Orinoco tobacco and developed our first export crop. The leaders of a settlement in Georgia in 1733 not only established an experimental garden, but hired a botanist to collect plants in the West Indies and Central and South America. During the 18th century, other efforts, in-



USDA

Samuel W. Johnson, 1830–1909, America's first advocate of agricultural research. His efforts led to the establishment in 1876 of the Connecticut Agricultural Experiment Station—first in the United States.

spired in part by the agricultural revolution under way in England, were made to improve agriculture.

George Washington created a veritable experimental farm at Mount Vernon. He worked to conserve his soil and diversify his crops, and pioneered in using new machinery. He was America's first mule breeder and greatly improved his sheep.

President Washington made the first formal proposal for the establishment of a Federal Agency devoted to agriculture, Later, the president of Norwich University asked Congress to appropriate funds from land sales to be distributed to the States for establishing institutions to teach agriculture. During the 1840's and 1850's State legislatures, farm leaders, the editors of agricultural periodicals, farm organizations, and professional and philanthropic societies, urged Congress to act on both of these proposals.

In 1839, Congress appropriated $1,000 of Patent Office funds for collecting agricultural statistics, conducting agricultural investigations, and distributing seeds. Opposing groups said this action was inadequate and represented Federal intervention. The matter was settled on May 15, 1862, when Abraham Lincoln signed into law legislation creating the U.S. Department of Agriculture (USDA). The Act was part of an agrarian reform package offered to the voters by the Republican party.

The Morrill Act of 1862 was the foundation legislation for the land-grant colleges. The primary focus of this Act was not research but to provide the common man with an opportunity for higher education. But the emphatic assignment of a teaching mission seemed to overshadow any research authority and prompted the first generation of college administrators to doubt that the Act authorized the colleges to experiment, except as an aid in the instruction of students.

At the 1871 Convention of Agricultural Editors, University of Illinois President John M. Gregory called attention to the seemingly incidental role the Morrill Act had allotted to research. In an urgent tone, Gregory noted the need for a well-developed system of research had become a serious practical question. Farmers, faced with problems they could not solve, were bringing to the college staff questions that could be answered by astute, continuous, and productive experimentation.

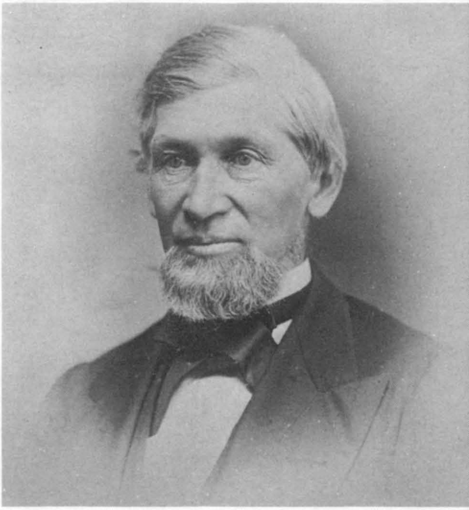
After considerable discussion in the press and at public meetings about State versus Federal responsibilities, the science and education leaders of the time convinced Congress of the need for Federal funding of agricultural research. The result of all this discussion was the Hatch Act of 1887 which celebrates its 100th anniversary in 1987.

The purpose of the Hatch Act was to establish agricultural experiment stations in connection with the land-grant colleges authorized in 1862. These experiment stations were to conduct scientific investigations and experiments that would provide practical and useful information. The Act specifically mentioned original research and verified experiments. Research topics included physiology of plants and animals, diseases of plants and animals, crop rotation advantages, chemical composition of plants at different stages of growth, analysis of soil and water, chemical composition of manures, digestibility of different kinds of foods for animals, and scientific and economic questions about the production of butter and cheese. The 1887 Act also indicated the need for publishing bulletins or reports of progress.

A second Morrill Act was passed in 1890 specifically to support the predominantly black land-grant institutions. These 16 institutions, plus Tuskegee University, are called the 1890 institutions. Subsequently, the Adams Act (1906) and Purnell Act (1925) provided for additional Federal investment in State experiment station research.

The post-World War I depression in agriculture, surplus production, and the migration of rural people to urban areas led to a realization that research to generate new production technology was not adequate by itself. Economic and sociological investigations also were needed. These were provided for by the Purnell legislation.

In 1914, the Smith-Lever Act authorized USDA to provide, through the land-grant colleges, instruction and practical demonstrations to help people identify and solve their farm, home, and community problems.


USDA

John M. Gregory, 1822–1898, first regent of Illinois Industrial University (now the University of Illinois) and eminent leader in agricultural education.

In 1935, the Bankhead-Jones Act increased suppport for research, extension, and teaching activities. It also required Federal funds to be allocated to each station in relation to the relative importance of the rural population of the State and required the State to match the Federal funds received to support research. In 1946, the Act was amended to provide for research to improve and facilitate the marketing and distribution of agricultural products.

In 1962, the McIntire-Stennis Act recognized the scientific and technological needs in the Nation's forests. It authorized cooperative forestry research between USDA and State universities. The 25th anniversary of this legislation is 1987.

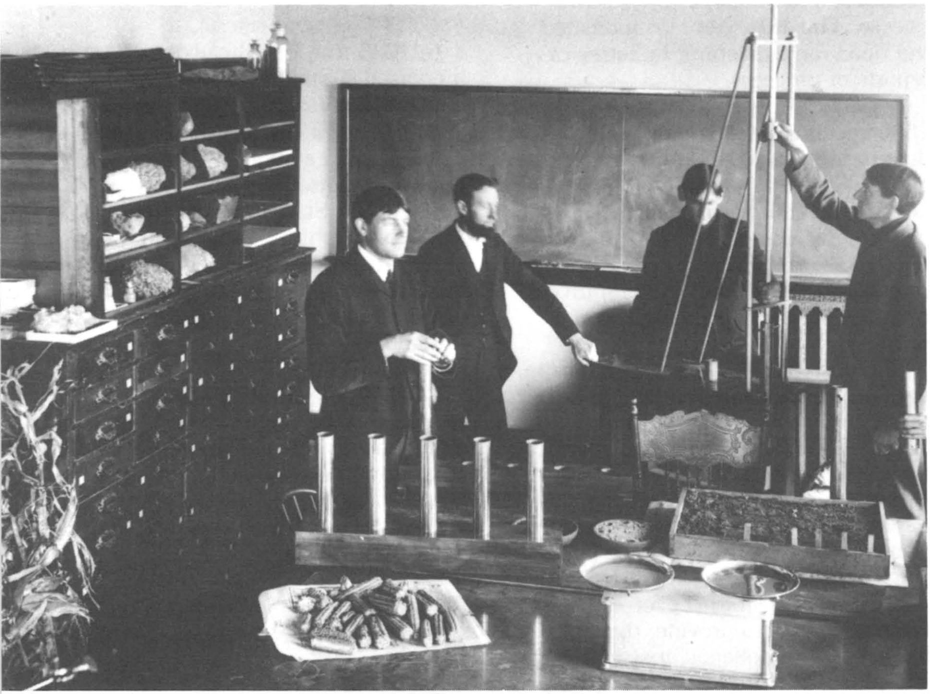
Performers of Food and Agricultural Research

The United States is fortunate to have a unique system of agricultural research and education that has proven its ability to respond quickly and effectively to society's needs. It is a three-faceted system consisting of higher education, research, and extension of knowledge to the public. One of its strengths is its diversity.

The higher education system includes community colleges, land-grant universities, other public universities and colleges, and privately financed institutions of higher education in every State.

Research related to agricultural production and marketing is conducted by the 56 State Agricultural Experiment Stations including departments of forestry, colleges of veterinary medicine, and home economics; by 16 separate schools of forestry, Tuskegee University and sixteen 1890 colleges. Federal funds for these facilities are channelled through USDA's Cooperative State Research Service. The main internal performers of research in USDA are the Agricultural Research Service, Forest Service, and Economic Research Service. The Office of International Cooperation and Development has the responsibility for coordinating the Department's international science programs. In addition, there is considerable research and development activity occurring in the private sector.

Research findings are transmitted to ultimate users by an Extension education system unique to the United States. Organization of this Extension system begins at the county level, making it truly a "grass roots" organization. Cooperative Extension has staff located in nearly every county nationwide. Extension has programs



Students study agronomy at the University of Rhode Island Agricultural Experiment Station in 1902.

for farmers and ranchers to demonstrate new and improved production and marketing technology; seminars on innovative marketing techniques for agribusiness and producer cooperatives; and even courses emphasizing basic nutritional needs for homemakers and families.

In addition there are programs in resource management, energy conservation, and health and safety, as well as those designed to help 4-H Club youth develop leadership skills and explore careers and other developmental activities; demonstrate to homeowners lawn and garden care, the use of pesticides and herbicides, and ornamental horticulture; and assist community groups and local officials in analyzing needs and resources for community development.

Recent Legislative Developments

The passage of the National Agricultural Research, Extension, and Teaching Policy Act in 1977, amended in 1981, resulted in significant management and program changes. This Act firmly established the USDA as the lead Federal agency for food and agricultural sciences. Before this Act, agencies conducting federally supported research were established at different times in response to different needs, and their work was not fully coordinated. Further, it established an assistant secretary of agriculture for Science and Education to carry out the responsibilities of the Act.

To provide for better cooperation and coordination in the performance of agricultural research by Federal departments and agencies, State Agricultural Experiment Stations, colleges and universities, and user groups—two advisory bodies were authorized.

The National Agricultural Research and Extension Users Advisory Board was established to incorporate the views of users. It makes annual recommendations on budgets, program priorities, and agency operations.

The Joint Council on Food and Agricultural Sciences was established to provide better cooperation and coordination among Federal and State interests. Its most important activities have been reported in four document—Needs Assessment, 5-Year Plan, Priorities Report, and Accomplishments Report—that are being used extensively by legislators, administrators, and scientists.

The top five national priorities selected for special emphasis by the Joint Council in 1987 were: 1) Agricultural profitability issues; 2) water quality and management; 3) biotechnology research on plants, animals, and microbes; 4) scientific and professional human capital development; and 5) human nutrition and diet and health relationships.

The long (20 years) and mid-term (5 years) needs and objectives are addressed in the Needs Assessment and 5-Year Plan. The accomplishments report highlights the annual results of these research and education activities.

Congress recognized that the food and agricultural sciences needed extra effort in the basic sciences to achieve breakthroughs in knowledge that could support innovative food and agricultural technologies. The 1977 Act, as amended in 1981, established a program of grants for high-priority agricultural research to be awarded on the basis of competition among scientific research workers at universities, Federal agencies, private organizations, and individuals not associated with any institution. The Competitive Research Grants Office was established to implement this legislation. It adopted most of the same procedures used by the National Science Foundation. Also, a program of education grants and fellowships was established to

Computers monitor physiological and behavior reactions to milking and other functions of the animal.

strengthen training and research programs in the food and agricultural sciences.

The 1985 Food Security Act reiterated the importance of research to the economic viability of U.S. agriculture. Some highlights in the act include: an expanded research and development program on new uses for farm and forest products; development of appropriate controls for biotechnology research and its products; dietary assessment; and increased effort in helping financially depressed farmers.

Future Agricultural Problems

Great and exciting opportunities lie ahead. A core of excellent scientists are using cutting-edge scientific techniques to resolve agricultural problems. Examples of the major problems and the challenges they offer follow.

New Scientific Tools. Improvements in modern computer systems and the development of biotechnology have created exciting opportunities in agricultural research. The technology for gathering, analyzing, and disseminating information is advancing rapidly. Modern computer technology and telecommunications offer great potential for increasing agricultural productivity by improving efficiency of information exchange between and among scientists, Extension specialists, producers, and consumers. Electronic mail will enable scientists to make daily contact with colleagues throughout the world who are working in the same research area.

Because of the discovery of the chemical structure of the genetic code of life some 30 years ago and the development of gene-splicing techniques in the past 10 years:

- living organisms can be harnessed for the production of large quantities of specific biological products;
- sexual reproduction can be bypassed in the transfer of specific desired traits between plants, animals, and micro-organisms; and
- DNA, that master molecule of heredity, can now be studied close up in ways not imagined only a few years ago.

These new abilities, along with other advances in such areas as microculture, cell fusion, and regeneration of plants from single cells are creating vast new opportunities all across the agricultural sciences.

Assuring the Security of Renewable Resources. Despite scientifically and technologically enhanced production capacity and the current surplus of food, uncontrolla-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To increase the amount of rubber in guayule plants, a chemist sprays them with bioregulators.

ble climatic conditions could rapidly eliminate food reserves and cause food shortages. This underscores the irony that scientifically sophisticated agriculture is still at nature's mercy. The decisive factor in assuring the security of our renewable resources will be the abilities of our farm people and technological progress.

To assure food security, production systems must be developed that are more sophisticated and efficient with better control of weeds, diseases, and pests and less dependent on weather. Transportation systems will be developed to move raw agricultural commodities and finished products to consumers more efficiently. New technologies in processing and packaging will insure the continued availability of a low-cost, year-round food supply. Storage technology will allow storing new varieties of commodities and controlling insects and bacteria that have become increasingly resistant to current control methods.

Because of changing political and economic circumstances worldwide, the Nation is giving increased attention to assuring domestic production of needed agricultural industrial materials, as well as food and fiber, wherever it might be economically and technologically feasible. Research has shown that plants can supply numerous industrial raw materials, such as fats, oils, waxes, and natural rubber used in enormous quantities by industry. Of the 14 crops that have been identified and can be grown domestically, two will be discussed here.

Crambe, a member of the mustard family of Mediterranean origin, has a seed oil containing 55–60 percent erucic acid and could replace all imported rapeseed oil. Derivatives of erucic acid are used to make plastic sheets of film slip one over another without sticking; as a fixative for perfumes and fragrances; in nylons for use in manufacturing molded and extruded items such as gears, fasteners, and tubing and coatings, adhesives, films, and fibers.

Guayule is a drought-resistant shrub which grows wild in semiarid regions of North America. In the early 1900's, guayule provided 10 percent of the world's natural rubber supply. After World War II, the plant was abandoned in favor of synthetic rubber. Recent improvements in agronomic and processing technologies suggest that it may once again be a competitive source of natural rubber. Natural rubber is preferred for certain applications such as bus, truck, and airplane tires; fan belts; surgical rubber; and hydraulic hoses. In addition, having a domestic source of natural rubber is an important security issue.

Assuring Protection of Nonrenewable Resources. Average Americans often take their relationship to the natural environment for granted. The importance in absolute terms of the environmental resources, however, grows steadily with each passing year. There is great concern about the adequacy of the U.S. natural resource base to sustain continued expansion of agricultural and forestry production.

The farmer of the future will concentrate heavily on the efficiency of resource use, reducing production costs as a means of improving profitability. Many technologies will be needed to enhance crop yields and reduce their variability from year to year. Water management and conservation technologies such as drip or trickle irrigation and surge-flow irrigation will produce water savings over conventional practices. Laser leveling of land will prepare it for more effective water usage. Infrared guns will measure plant temperatures and indicate water stress. Field conditions will be monitored by sensors and tied in with weather satellite forecasts to aid irrigation scheduling. Our limited energy resources will be used more efficiently. Introducing nitrogen-fixing capabilities into nonleguminous plants will dramatically reduce the cost of using nitrogen fertilizer and ease the pressure on natural resources. Air quality will be improved to prevent atmospheric deposition which affects crop yields, tree growth, lake ecology, and fish and wildlife habitats.

Enhancing International Competitiveness. "The two most important elements of a national research strategy for the United States are (1) education and (2) mechanisms for bringing scientific discoveries from the laboratory to the marketplace. The application and development of scientific innovations in this country have traditionally been a source of unique strength. Today, this is an area that requires material improvement if we are to retain our commanding lead in international technological competition."

This statement by John Diebold in the Spring 1986 *Issues in Science and Technology* is a truism of immense importance. In the past, agriculture has been cited as the outstanding example of transferring scientific knowledge into useful applications. This past success will not automatically continue into the future unless the science and education system in agriculture adjusts to changing conditions. For example, an improved understanding of changing foreign and domestic markets is needed.

Enhancing World Peace and Supporting Foreign Policy. The United States has a long and enviable record of sharing its resources and knowledge with other countries in a continuing effort to promote economic stability, reduce poverty, and solve world food problems. U.S. agriculture has the basic ingredients to assure a role of leadership in this international arena. It has a strong and viable agricultural science system; a solid and proven research, Extension, and teaching system; an effective partnership with the private sector; policies that articulate and emphasize scientific cooperation; and experience in a wide range of international cooperative activities. Exchanging knowledge and training programs provides a foundation for better training partnerships and a better understanding by the peoples of one country of the needs and customs of peoples of another. It can go a long way toward supporting foreign policy and enhancing world peace.

Improving the Quality and Safety of Food and Fiber. Through research, the United States will develop agriculture products that are more appealing to consumers and more nutritious. Not only will techniques be developed that will detect the smallest amounts of agricultural, industrial, or natural toxicants in foods, but production techniques will assure these harmful substances do not get in our food.

Improving Human Nutrition, Health, and Well-Being. Americans have access to more high-quality, moderately priced, safe and nutritious food products, than any other people in the world. The metabolic relationship between nutrient intake and physiological response needs to be better understood. Adequate nutrition and proper dietary practices will reduce the risk of various diseases such as cardiac disease, diabetes, and some forms of cancer. A better understanding of the needs of pregnant and lactating mothers and newborn infants will reduce infant disabilities and mortality. We will have a better knowledge of the relationships between nutrient quality and human genetic potential and will have the ability to alter naturally occurring food ingredients via biotechnology. The opportunities are limitless.

Need for Trained People. The new opportunities in science require trained people. Many agricultural scientists received their formal education 20 to 30 years ago and are reaching retirement age. Areas of importance are molecular biology, systems analysis, and international marketing. These shortages were highlighted at a conference held in 1984 on "Brainpower for Agriculture"—cosponsored by USDA and the National Academy of Sciences. In addition to a continuing funding problem in higher education, the traditional images of agricultural fields need modification so that talented students will more objectively evaluate career opportunities in the agricultural sciences.

Jonathan Baldwin Turner—Evangelist of the Land-Grant University Movement

Patricia B. Lewis, *public information consultant, New Jersey Agricultural Experiment Station, New Brunswick*

With the livid language, sonorous prose, and grand manner of 19th century oratory, Jonathan Baldwin Turner devoted his life to the idea of general, practical education for the masses.

Turner was an evangelist of ideas in the three areas that consumed him—religion, politics, and education. In all three, his views were unorthodox and brought him severe criticism and some personal abuse. Still he would not modify his stands, and finally it was the melding of religious fervor with political skill that allowed Turner's educational philosophy to become the law of the land.

Ideas developed by Turner spread far beyond Illinois where he honed them and came to encompass the entire United States through the land-grant university movement. With the missionary fervor of a John the Baptist, Jonathan Turner never missed an opportunity to advance his ideas. He fought relentlessly for education for the sons and daughters of the working class; an education "suited to their aptitudes, interests and careers."

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It was his philosophy that the "industrial universities" should exclude "no species of knowledge" whether practical or theoretical; unless, "those specimens of organized ignorance found in the creeds of party politicians and sectarian ecclesiastics should be mistaken by some for a species of knowledge."

Although described by his daughter, Mary Turner Carriel, as "sweet of temper" with a "mildness of manner," Turner was known to be brusque, direct to the point of offensiveness, and keenly sarcastic in dealing with the "evils of public affairs." In an 1873 address he remarked, "I have often thought, and sometimes said, that I can see no way by which the farmers of the West can get rid of the evils that now oppress them until we can contrive to get up several thousand first-class funerals of old judges, legislators, lawyers, editors, etc., etc. with a sprinkling of divines sent along with them to act as chaplains . . ."

A complex man whose ideas were a good 50 years before their time, Turner was unorthodox and imaginative. He was known beyond educational circles for his work with the mentally ill, the sick, and for his unique contributions to horticulture.

A native of Massachusetts, educated at Yale, and for years a professor at Illinois College, Jonathan Turner was constantly engaged in one revolutionary movement or another. From his challenge to the conventional wisdom of his religious demonization to his opposition to slavery, Turner never took the easy path.

Turner's influence among his students at Illinois College was strong, and through them he had still greater influence on leaders of that period. In writing about her father's life, Mary Turner Carriel says that among Turner's students were William G. Green and his brother, sons of a widow living in Menard County, Illinois. At the end of one school term, they walked home, and found that their mother had hired a tall, thin man with a rustic manner to help with the harvest.

After supper, the man asked the boys what they had learned at school and if they would show him their books. They told him about college, showed him their books, and he selected one on English grammar. Every night for weeks he studied that book, sometimes asking questions which the boys answered as best they could, always citing as their authority Jonathan Baldwin Turner, Professor of Belles Lettres, Latin and Greek at Illinois College.

The man was Abraham Lincoln. Years later when he and Turner had become well acquainted, President Lincoln would say to Turner, "My only instruction in the English language has been from you," referring to the Green brothers of Tellula, Illinois, while they were students at Illinois College where Turner taught and [Lincoln] was a hired hand on their mother's farm.

No doubt the Lincoln-Turner association helped the land-grant university movement. Before the campaign of 1860, Professor Turner had talked with Lincoln at Decatur, Illinois. Turner told Lincoln that he would be nominated by the Republicans and that he would win the election.

Lincoln is said to have responded, "If I am, I will sign your bill for State Universities."

No doubt that made Turner happy, but the story goes that he had further reason for jubilation. A little while later on a train to Peoria, Turner met Stephen A. Douglas. Douglas is said to have remarked, "If I am elected, I will sign your bill."

Turner understood the need for bipartisan support and whichever way the country voted—Republican or Democrat—he would realize his dream. It mu st have been a real cause for celebration by Turner who had witnessed 10 years of Congressional maneuvering and a veto by President Buchanan.

Despite Turner's association with Lincoln, Douglas' support of the land-grant university concept was not idle. He had said, "This educational scheme of Professor Turner's is the most democratic scheme of education ever proposed to the mind of man!" And in June 1861, Douglas wrote Turner requesting a copy of his plan for an industrial university and its history. Douglas wanted to introduce the bill himself.

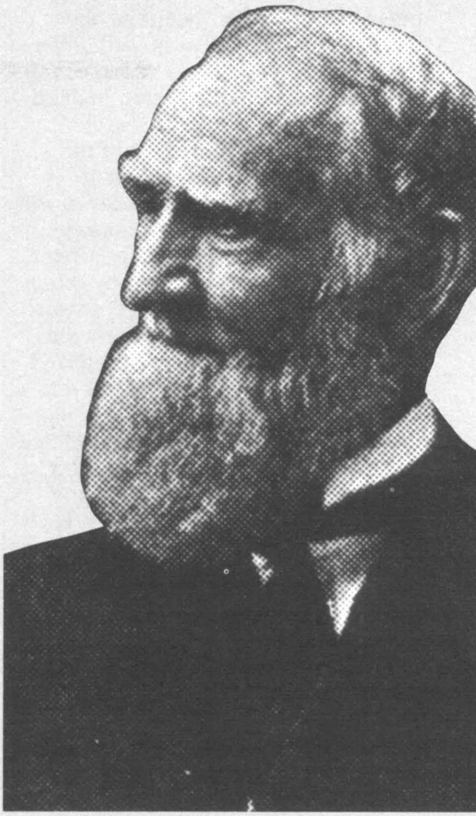
Turner complied, but, when his son delivered the materials to the post office, he found a telegram saying Douglas had died in Chicago. In grief and disappointment, Turner threw everything in the trash. The disappointment was short lived, because Justin Smith Morrill, a senator from Vermont whose earlier attempt at getting land-grant university legislation into law had failed, reintroduced the measure which President Lincoln signed July 2, 1862.

And so Jonathan Baldwin Turner, whose full flowing beard and stately appearance resembled the prophets he often called upon in making his point, had seen a vision realized.

It was a vision of which Dr. S. A. Forbes, while Dean of the College of Science at the University of Illinois, said, "That reaching upward of the masses for more power and light, spreading eastward, gave us later the long line of land-grant colleges, and gives us now the State experimental stations also, as a sort of second growth from the seed first sown, through recognized acceptance of the natural sciences as a necessary part of the course study in a true people's school . . ."

With his missionary mind, Jonathan Turner no doubt would have seen the creation of the State Agricultural Experiment Station system as a type of Second Coming. This movement, which celebrates its 100th anniversary in March 1987, gained its urgency from yet another man from Illinois. University of Illinois President John M. Gregory at an 1871 convention of agriculture educators called attention to the seemingly incidental role the Morrill Act had allotted to research.

Gregory said farmers, beset with problems they could not solve, were bringing questions to the college staff that could be answered only by astute, continuous, and productive experimentation.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Jonathan Baldwin Turner, 1805–1899, agriculturist and early advocate of vocational education.

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Agricultural Research: Who Pays and Who Benefits?

John E. Lee, Jr., *administrator, and* Gary C. Taylor, *agricultural economist, Economic Research Service*

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Contrary to the forecasts of 18th century doomsdayers, agriculture production has increased faster than global population, to the extent that more of the past century has been characterized by food gluts than by food shortages, especially in the industrial economies.

Chronic food shortages, where they exist in the world, are now recognized to be matters of policy, economic development, and, perhaps, distributive equity, because resources and the technology to use them are known to be more than adequate to eliminate the shortages.

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Research has made a major contribution to modern agricultural technology. In the United States, research—together with the teaching and extension of agricultural sciences—has enabled us to 1) produce and deliver to consumers a greater variety of higher quality products for a declining portion of their incomes; 2) improve food safety and quality;

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Research has made a major contribution to modern agricultural technology. In the United States, research—together with the teaching and extension of agricultural sciences—has enabled us to 1) produce and deliver to consumers a greater variety of higher quality products for a declining portion of their incomes; 2) improve food safety and quality;

3) reduce adverse effects of the food system on the environment; and 4) dramatically reduce human drudgery. In varying degrees, similar progress has been made in other countries, especially the developed countries.

Who Pays for Agricultural Research?

Agricultural research has been funded for well over a century by the Federal and State Governments and by privately owned companies who sell their products to food and fiber producers, processors, and consumers. So, the general answer to the question of who pays for agricultural research is fairly straightforward. The funding comes from Federal and State taxpayers and the incomes of agribusiness companies.

In the United States, there has long been a mixture of publicly funded and private research, but, until recent decades, publicly funded research was predominant. Public research funded by tax revenues is conducted in Federal agencies, State agencies, universities, and a host of other public and private institutions. Public funds spent on agricultural research increased persistently, especially after World War I, reaching about $2.1 billion by the mid-1980's.

Farmers and other agricultural interests, including researchers and their administrators, present the case for agricultural research before State and Federal legislatures and executive branches. Some might suggest that farmers basically pay for public research with their tax dollars. Since farmers, however, pay a relatively small part of total tax revenues, agricultural research is funded by the larger public.

Some agricultural research has always been privately funded and conducted, but in the past two decades research funded by private companies

Medical technologist inspects a veterinarian pathology slide at Montana State University.

has increased dramatically, reaching an estimated $2.1 billion by the mid-1980's, equivalent to public expenditures.

Who Benefits from Agricultural Research?

The question of who benefits, directly and indirectly, is much more interesting and complex.

Farmers. Since farmers lobby for public research funds, one would suppose they are major beneficiaries. This is partly true. Technology stemming from research has greatly reduced farm drudgery. Labor-saving technology makes it possible for one farmer to manage a large enough set of resources to increase family incomes. Technology also has helped farmers cut costs and reduce losses from insects, disease, and spoilage.

The benefits of technology to producers are not distributed evenly. The initial gainers are the early adopters, usually the most progressive farmers. As adoption continues and the increased supplies lead prices to fall, the nonadopters are forced to adopt new technology to remain competitive, or they quickly become marginal operators and may drop out of farming.

At this point in the adoption of most new technologies, most of the benefits have been passed on to consumers as lower prices. The rapid development and adoption of new agricultural technology, especially since World War II, has meant relatively cheaper food and fiber for the consumer, and the disappearance of thousands of smaller farmers who were marginal producers unable or unwilling to adopt to maintain competitive costs of production and adequate family incomes.

Society Major Beneficiary. The general society has been the major beneficiary of agricultural research. These benefits accrue in the forms of lower food and clothing costs, improved standards of living, economic growth, improved variety and quality of foods, and improved competitiveness of U.S. farm products in world markets.

The decline in the real price of food has been dramatic. Available data for the period 1888 to 1891 indicate that consumers spent an average of about 40 percent of their income for food. From 1930 to 1960, the food expenditure proportion of consumer incomes ranged from 20 to 24 percent. In the seventies, the proportion of total disposable personal income spent for food dropped to a range of 16–17 percent. By the mideighties, that proportion for the average family had dropped to a record low 15 percent.

Improved standards of living and economic growth result from research-generated technology because

The consumer benefits from lower food prices as new technologies help farmers cut costs and reduce losses.

a declining portion of our Nation's resources are required to provide basic food and fiber needs. The excess resources are released to produce other goods and services that we associate with a rising standard of living. Their production has been a major source of economic growth.

Research has produced more sophisticated food processing methods and systems for protecting, preserving, and delivering our food. Today between 11,000 and 39,000 food items are available to consumers in typical supermarkets, compared with only 1,500 items as recently as 1941. Further, these food items have likely never been safer and more nutritious.

Research generates improved technology which, in turn improves the productivity (efficiency) of the farm sector, lowering costs and improving the competitive position of U.S. agricultural products in world markets. The standard of living improves for the overall society as the United States specializes in producing and exporting what it produces relatively more efficiently and imports what others produce best. Consumers have access to more goods with a given income.

Are the Benefits Worth the Costs?

Since the 1950's, a number of economic studies have measured the benefits of agricultural research and extension relative to the costs. The resulting benefit/cost ratios vary greatly, but most fall in the range of $30 to $50 of benefits for each dollar spent. None of the studies found negative benefits from research. For these studies, benefits were defined as those benefits accruing as higher incomes to producers or passed on to consumers in the form of lower food prices.

Adjustment Costs. The costs included in these studies often are only the direct public or private expenditures for research. The costs of adjustments required by technological change are generally not included. For example, the technology that revolutionized food production and marketing required the movement of millions of farm families and thousands of grocers and associated people to other jobs. In the majority of cases, the new jobs were, in fact, better opportunities, and society in general was greatly benefited. But for some the changes were not an improvement. The costs of progress are borne disproportionately by those who must make the personal adjustments.

Increased Benefits to Consumers. The consistently high returns from agricultural research argue for greater amounts of Federal and State funding to increase benefits to the society at large. One reason this has not happened is a lack of understanding about the dispersion of

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Shoppers in Manila select U.S. produce.

benefits from agricultural research and the general perception that agricultural research is a farmers' program with major political support limited to agricultural commodity producers.

One of agriculture's best kept secrets is that agricultural research programs that lower production costs to farmers primarily benefit U.S. consumers by bringing about lower prices.

New technology has important impacts on the price and cost structure throughout the food and fiber system. This system is characterized by a large number of firms and a high degree of competition. The total quantity of food and fiber that will be used domestically is limited. Therefore, new technology that increases output and lowers costs causes lower consumer prices.

Benefits of research accrue to the total society provided that the benefits are not captured by a few either because of monopoly control of the research results or because markets are not allowed to operate to effectively disseminate the benefits.

Benefits Higher for Low-Income Families. The ratio of research benefits to taxes paid is higher for low-income families than for high-income families because low-income families tend to spend a higher percentage of their income on food and a lower proportion on taxes.

An analysis by the Congressional Office of Technology Assessment showed that the average benefits for families with incomes more than $20,000 were nearly twice as high ($31 for each $1 invested in research) as for families with incomes under $5,000 (16 to 1).

But if the taxes paid by consumers to support agricultural research are apportioned among income classes, the ratio of benefits to tax payments is 10 times higher for the lower income group (12.4) than for the higher income group (1.2). The results of this analysis indicate that public expenditures for agricultural research tend to modify existing income distribution in favor of the lower income population.

Why is Public Agricultural Research Being Questioned?

Questions are being raised today regarding publicly funded agricultural research. Some reasons cited or implied, by both friends and critics, include:

- Recognition that public funds are limited relative to the demands for them. In times of tight Federal and State budgets, all public activities come under more careful scrutiny, and research is no exception.
- In light of tight budgets, the high benefit/cost ratios of public expenditures on research which seem to beg the question of whether given levels of expenditures can be used even more effectively by improved research management and targeting activities more selectively.
- Also, in light of tight budgets and the need to use available dollars more effectively, the rapid growth in privately funded research which has raised questions about the proper balance and complementarity between public and private sector research.
- Concern from farmers that more research simply means larger surpluses and lower prices. In fact, some farmers now express the view that research works against them, and that farm incomes would be higher without productivity-increasing research. Again, this point ignores the very high return to the larger society of investing in agricultural research.

Considerable debate has centered on the issue of private versus public agricultural research.

Maintaining a strong agricultural base improves the U.S. position in world markets while meeting basic food and fiber needs.

Distribution of Benefits. Public policies that determine how the benefits of research are distributed are critical. There has to be the right balance between incentive for private initiative and occurrence of public benefit.

Patent laws and plant variety protection laws are examples of public policy attempts to deal with that delicate balance. Little incentive exists for private investment in research if there is no way to capture some economic rent from that investment.

But the benefits to society are lost if ultimately the information generated by research is not broadly accessible and if the competitive forces are not at work to assure that the information gets incorporated into products and services that improve standards of living and quality of life.

The design and administration of public policies to assure adequate incentives to private research and technology development, while also assuming that these investments ultimately benefit the larger society, is a delicate balancing act.

Public Research Benefits. The "internal rate of discount" for private research may be different from that designed for the broader long-term benefit to the larger society. The public can invest in research whose benefits may not be realized in the timeframe necessary for private investment. Also, the public can invest in research where the benefit risks are higher. The latter point is important to generating fundamental knowledge (basic research) which is the foundation of applied or problem-solving research and development.

The results of public research are made widely available. This has two benefits in addition to the ones mentioned previously: the results are available to other researchers for further discovery (major surges of new technology tend to be the synergistic result of many individual research efforts and discoveries); and the benefits of research are prevented from being captured for the prolonged profit of a few and so are of value to the larger society.

Public research also accommodates "institution building" to enhance future scientific capacity by training scientists in what is known, enhancing what is known, preserving the knowledge base, and maintaining teaching and training institutions.

Research Still Important

In the face of growing concern about excess supplies and challenges to publicly funded research, there are strong arguments in support of Federal and State Governments continuing to invest in maintaining a strong agricultural science and technological capacity. They include:

- *Maintaining productivity growth.* Growth in productivity and efficient use of resources are the primary means of improving the benefits to society. Increased productivity assures more output from available land, water, and other resources. If demand is not growing fast enough to absorb productivity gains, resources can be transferred from food production to other uses. By using fewer resources, costs and the proportion of society's income required to meet basic food and agricultural needs will be lower.
- *Improving competitive position in world markets.* The competitive position of U.S. farm products in world markets is influenced by changes in the productivity of U.S. agriculture relative to other sectors of the U.S. economy and relative to agriculture in other countries.
- *Coping with declining supplies and rising costs of fixed-supply resources.* The supplies of many resources including fertilizer, minerals, ore, petroleum, and nonrechargeable ground water pools, are fixed. Eventually, agriculture must adjust to the loss of some of these resources or to their increasing costs as supplies dwindle.
- *Developing renewable raw mate-*

Chemist at ARS's Agricultural Research Center studies retention of nutrients and storage stability of processed fruits and vegetables to increase the nutrient value of food products.

Price in Minutes of Work of Selected Foods

Food[1]	Amount	1930	1950	1970	1980	1985
	Units	Minutes				
Round steak	1 lb.	48.4	43.8	28.8	29.4	23.0
Potatoes	10 lb.	40.9	23.3	20.7	22.1	16.9
Bacon	1 lb.	48.3	29.8	21.0	15.5	15.8
Eggs	1 doz.	50.6	28.3	13.6	8.9	6.5
Bread	1 lb.	9.8	6.7	5.4	5.4	4.5
Butter	1 lb.	52.7	34.1	19.2	20.0	17.3
Milk	1 qt.	16.0	9.6	7.3	5.6	4.6
All the above	1 ea.	266.7	175.6	116.0	106.9	88.6

[1]Price of food relative to manufacturing wage rate after taxes and employee social security contributions.

rials. Another side to the depletion of stock resources is the possibility of developing new uses for agriculture's productive capacity. One prospect is using agricultural products as renewable resources. Biomass fuels, such as ethanol, may eventually become more economical, and industries could turn to agriculture for other renewable raw materials. Agriculture could become proportionally less of a food industry and more a supplier of industrial raw materials. Such developments provide new opportunities for farmers and a way for the world to adapt to limited supplies of some stock resources. Agricultural research will need to play a lead role in the development of these new products.

- *Improving the quality of products and processes.* With food and fiber in plentiful supply in developed countries, there is an opportunity to shift the focus of some research to the quality of production, including efficient use and conservation of resources. Other examples include increased energy efficiency; less ecologically damaging technology; techniques that make more efficient use of water, mineral nutrients, and other limited resources; and foods that are tastier, more nutritious, and safer for human consumption.
- *Meeting the food needs of developing countries.* Despite excess supplies in most developed nations, many countries still suffer food shortages. The developed world has a vested interest in assisting the developing countries. Stronger economies for many of these nations, including their agricultural sectors, could improve chances for global political stability and provide greater market potential for the growing agricultural capacity of developed countries.
- *Maintaining flexibility to deal with an uncertain future.* Considerable uncertainty surrounds the scenario of plentiful food supplies, especially beyond the next decade or two. Unforeseen natural, economic, or political shocks could change the outlook. The margin for error is indeed slight when the food supply of a whole region of the world can be brought into question by something as localized as a nuclear accident near Kiev in the U.S.S.R.

Without ongoing investment in science and education, continued productivity growth cannot be assured. With food security, it is preferable to err on the side of surplus rather than shortage.

II
Biotechnology: An Overview

Biotechnology Policy—Public Perception, Participation, and the Law

Judith R. Curry, *attorney, Arlington, VA*

Biotechnology is not new. In its broadest sense, the term simply means the application of living organisms to improve, modify, or produce industrially important products or processes. Micro-organisms have been used for centuries in the production of foods, beverages, and other fermented substances. In the past century, they have been used to produce antibiotics, enzymes, and amino acids. And genetic engineering, the biological technique which includes artificial selection for desired traits in plants and animals, has been in use in agriculture since the turn of the century. Beginning in the 1950's, research in biotechnology led to the development of techniques such as artificial insemination, superovulation and embryo transplant in animals, and hybridization in plants. All were valuable contributions to the advance of agricultural science.

It is only in the past 10 to 15 years, however, that the discovery of techniques such as rDNA (sometimes referred to as genetic engineering) and cell fusion have provided the tools to manipulate organisms at the molecular and cellular level, improving the ability, speed, and efficiency of producing desired alterations in hereditary traits. In addition to helping to answer questions about basic biological functions, the new developments in biotechnology are expected to increase productivity of plants and animals significantly and to lower costs of production.

At the same time, biotechnology—and particularly genetic engineering—has the capacity to arouse considerable tension and divergence of viewpoints on issues of ethics, health, and environmental safety. Public participation through regulatory efforts and litigation, as well as less visible involvement, has played a significant role in shaping governmental policies relating to research in biotechnology. This article discusses the causes of some of the public concerns surrounding biotechnological research and the governmental and judicial responses to the causes and concerns.

Public Perception of Biotechnological Research

National surveys were conducted in the early 1980's with the objective of ascertaining the public perception of biotechnology. Cambridge Reports, Inc., reported the following results of surveys conducted in 1982 and 1983:

- About one-half of the people surveyed either hadn't heard the phrase genetic engineering or wouldn't guess what it meant.
- Of those who had heard of private corporations getting into the field of genetic engineering or biotechnology (roughly 40 percent), and who were willing to take a position as to whether this was good or bad, positive sentiments outweighed negative by almost two to one.
- Respondents with higher income levels and higher levels of education, were more likely to expect major benefits from genetic engineering than those with lower incomes and less education.
- When respondents were asked what they thought of when the term DNA was mentioned, 63 percent didn't know; 2 percent gave

an accurate definition; and 2 percent said it was "poison."

Also in 1982 and 1983, Yankelovich, Skelly, and White surveyed the general public with regard to perceptions about genetic engineering. The results showed the following:

- The percentage of the general public believing that the benefits of genetic engineering outweigh the risks increased from 31 percent in 1981 to 39 percent in 1982.
- Sixty-two percent of the public were very or somewhat concerned about genetic engineering in 1982.

In January 1986, Cambridge Reports, Inc., again conducted a survey asking whether respondents had heard or read anything about rDNA or genetic engineering. Fifty-one percent of those surveyed responded that they had heard or read something; 46 percent had not heard or read anything; and 4 percent were not sure. Of those who had heard or read something, only 5 percent were very familiar with the terms and 19 percent were somewhat familiar. Those respondents who had heard or read something about rDNA or genetic engineering were asked whether they agreed or disagreed with the following statement: The development and use of genetically altered organisms create a potentially serious environmental and public health threat that outweighs the social and economic benefits such organisms may produce. Forty-one percent of the respondents agreed with the statement; 34 percent didn't know; and 25 percent disagreed.

This survey data suggests several things: 1) Real public concerns about biotechnological research, particularly in the area of genetics, persist today; 2) a relatively small fraction of the American public is fully informed about genetic engineering in particular, and about biotechnology in general; 3) public knowledge of biotechnology has increased little since the early 1980's; and 4) the more informed the public, the more likely it is to view genetic engineering favorably rather than unfavorably.

Factors Influencing Public Perception

Terminology. While the public is somewhat better informed about biotechnology than it was a decade ago, there still exists a vast comprehensibility gap between laboratory scientists and the average U.S. citizen. This is due, in part, to the complex and technical nature of the subject itself. But it also may be attributed to the use of imprecise terminology by scientists and research administrators when addressing the public on issues about biotechnology and science in general.

It is important for scientists and technicians to understand that certain words or phrases they use every day may have certain science fiction-like connotations for the average person. After all, it has not been such a long time since the idea of cloning was considered by the average American to exist only in the imaginations of science fiction writers and movie producers. For them, the cloning of genes, a basic technique of rDNA technology, can be confused with the cloning of individual human beings. Because language influences perception, the problems caused by multiple connotations attached to terms used by scientists are significant.

News Media. The news media have consistently and enthusiastically reported developments in biotechnology—often with front page stories. One positive result is that the public has become increasingly aware of activity in this area. But journalists, however objective, must be selective in deciding which stories are reported and in determining which facts are newsworthy. News reports that

Public interest has helped shape guidelines and policies relating to research in biotechnology.

emerge from this editing process necessarily present only part of the picture. In addition, the need to generate interest in reading the story or watching the newscast may, to some degree, override the journalist's concomitant dedication to objectivity and comprehensive reporting. Consequently, the general public's understanding of the phenomena described in these reports may be somewhat limited.

Religion and Ethics. Finally, religion and ethics play an important role in determining the acceptability of biotechnology by the public. This is true particularly when genetic engineering of higher life forms such as animals is at issue and, to a much larger degree, when the question of manipulation of human genes is involved.

One reason that the technology has aroused such strong emotions in this area is that the capability to alter the hereditary material of animals and human beings implies a responsibility which, it is argued, was heretofore entrusted to someone with greater reliability than human beings. This issue, of course, could be discussed without end; here, however, only a few comments are offered.

First, there are inherent difficulties in distinguishing between that basic research in genetic engineering conducted for future application to animals and that for application to humans. Because genetics is basic to all living organisms, techniques applicable to lower forms of life are theoretically applicable to higher forms as well, including human beings. For example, in vitro (outside the body) fertilization and embryo transplants were used and perfected in farm animals long before application to solve the reproductive problems of humans. Basic techniques, such as gene isolation, provide the basis for genetic research both in animals and human beings.

Likewise, it is not always possible to distinguish between research aimed at productivity and research for health and medical purposes. The same techniques which allow genetic transfer for the purpose of selecting for desired traits such as high milk production, rapid growth, and low fat content in animals have led to such discoveries as vaccines for foot-and-mouth disease in livestock and coccidiosis in chickens. And these techniques are crucial parts of the effort to understand the genetic bases for such human diseases as cancer, Tay-sachs, and sickle-cell anemia. Consequently, an overlap in productivity and disease research at the laboratory level causes great difficulty in any argument that fundamental human values would allow such research in lower animals but not in human beings and for medical or health purposes but not for productivity.

This does not imply that it is not possible to distinguish between lower life forms and humans in the *application* of research findings. Distinctions and decisions regarding application can and must be made if biotechnology is to be harnessed to the needs of society. RDNA technology may hold the key to finding cures for cancer, leukemia, and a number of other diseases thought to be inheritable. The ability to implant specific genes directly into germ cells and to stably integrate them into the chromosomes so that they are expressed in future generations creates boundless possibilities for treating genetic diseases once the genes responsible for their occurrence are isolated. Few people, regardless of their feelings about the use of genetic engineering to create more productive plants and animals, for example, would argue that genetic engineering should not be used to find cures for life-threatening diseases affecting animals and humans.

There is, nonetheless, a fear expressed by some that our society's technological capabilities have moved "out of phase with our capacity to understand and direct their development, to humanize and contain their impact, and to integrate their evolution with our cultural and social values."[1] It must be recognized, however, that the capability to change things is, in fact, an inextricable part of evolution. If society abdicates its responsibility to make reasoned decisions about research which should be conducted and applications which should be made because of a lack of understanding of the science, then the fear will become a self-fulfilling prophecy. To prevent that, it is essential that there be a continuing dialogue between scientists and the public so that the public may be as educated and informed as possible about technological developments, and scientists may understand the ethical and social concerns of the public.

The imperative for the public to take responsibility for technology and its progress has been recognized by religious leaders and theologians. Robert T. Francoueur has written:

> It is obvious we do not, and never will, have all the foresight and prudence we need for our task. But I am also convinced that a good deal of the wisdom we lack could have been in our hands if we had taken seriously our human vocation as transcendent creatures, creatures oriented toward the future (here and hereafter), a future in which we are co-creators.[2]

While religion and ethics will always play an important part in the public's perception of the permissibility of genetic manipulation of life forms, neither can be relied upon categorically to abdicate the responsibility for making decisions in this important area.

Public Involvement

Peer Concern. Somewhat ironically, given the opinion expressed by many that scientists should not regulate their own efforts in biotechnological research, it was the scientists themselves who actually expressed initial concern about genetic engineering. In 1970, when Stanford scientist Dr. Paul Berg first began to attempt to insert DNA from a tumor virus into a common bacterial virus, a number of his colleagues raised questions about the wisdom of carrying out such experiments. They were concerned that the bacteria carrying the virus might pose a health hazard for laboratory workers or that, in a worst-case scenario, the bacteria might escape into the general environment.

Dr. Berg decided to defer his experiment, but as others continued and rDNA techniques became more refined and application more imminent, debates about safety increased. The debates ultimately culminated in the landmark conference at Asilomar, California, in February 1975, where a number of prominent international scientists convened to discuss the risks involved in this newly emerging technology. This meeting followed a letter which the scientists had written to the National Institutes of Health (NIH) calling for a voluntary moratorium on all rDNA research until an assessment of the risks could be conducted. At the Asilomar Conference, however, the group decided that the moratorium should not continue for most work in rDNA if appropriate safeguards in the form of physical and biological containment were established and followed.

At the same time, NIH made efforts to set up an advisory committee and to establish guidelines such as those called for at Asilomar. In October 1974, the Director of NIH, with the authority of the Secretary of

Health, Education, and Welfare (now Health and Human Services), established the rDNA Molecule Program Advisory Committee. It was later renamed the rDNA Advisory Committee and commonly referred to as the RAC.

rDNA Guidelines. At this point in the development of decisionmaking mechanisms for rDNA research, it can truly be said the public became involved in a significant way. The issue of public participation on the RAC was first raised in 1975, when NIH made an effort to recruit nonscientists. Two nonscientists became members of the Committee in that year.

In February 1976, NIH held public hearings on proposed guidelines for rDNA research. The hearings lasted 2 days and were attended by scientists, physicians, lawyers, philosophers, public interest advocates, and other interested individuals. On January 23, 1976, the Guidelines for Research Involving rDNA Molecules were published. The Guidelines were mandatory for institutions and individuals receiving funding from NIH for rDNA research, but did not apply to private research. Soon after the publication of the Guidelines, all other Federal agencies funding rDNA research, including the U.S. Department of Agriculture (USDA), adopted the Guidelines as mandatory for research funded by their agencies. The Guidelines contained safety standards to be followed by researchers with regard to physical and biological containment.

The first official provision for public representation on the RAC came in September 1976, when the RAC charter was amended, increasing its membership from 16 to 20 members—4 of whom were to be "from other disciplines or representatives of the general public." The new Guidelines, published in December 1978, following public comment and hearings, contained several significant provisions for public participation in the decisionmaking process. The provisions are retained in the current version which appears at 49 Federal Register 46,266 (1984), *as amended* by 50 Federal Register 9,760 (1985).

First, 20 percent of the membership of the Institutional Biosafety Committees (IBC), the committees responsible at the research institution level for approving experiments and assuring compliance with the Guidelines, must come from the general public and may not be attached to the research institution. Second, most IBC records about approval of experiments and compliance with the Guidelines must be made available to the public on request. Third, major actions to approve experiments otherwise prohibited by the Guidelines have to be announced by publication in the Federal Register, followed by a period for public comment.

Finally, the new Guidelines provided for an important change in the composition of the RAC. Membership was increased from 16 to 25 persons—8 of whom must be molecular biologists and 6 of whom must be from other fields of science. At least six of the remaining are required to be drawn from the combined fields of law, public policy, environment, and public or occupational health.

The stated purpose of these amendments was to "provide the opportunity for those concerned to raise any ethical issues posed by recombinant DNA research." From all apparent evidence, the public has been satisfied with the role it has been encouraged to play in the decisionmaking process. During the time that the RAC has been in existence, meetings have been well attended. Publication in the Federal Register of case-by-case approval of experiments has generated moderate public response. Initial fears of potential hazards of rDNA research has dissipated at least to the extent that research which adheres to the NIH Guidelines for physical and biological containment no longer gives rise to serious public concern. The few exceptions are discussed later with regard to litigation of health and safety issues.

Risk Assessment. While the intensity of public concern is low at present, it is possible that, as research emerges from the laboratory and greenhouse and is applied in the environment, the level of public interest will rise again. Industrial applicatiion of important agricultural inventions will be preceded, in most cases, by field tests. For example, deliberate releases of genetically engineered organisms may be engendered by the creation of new plant varieties which are resistant to pests and climatic extremes. Although the field tests will be quite different, the same is true for genetically altered animals. The extent to which an increase in public interest occurs because of these applications will depend, in large part, on the public's perception of the adequacy of measures taken by industry and the government to protect against adverse effects to the public health and environment.

Under the NIH Guidelines, the RAC must review for approval deliberate release experiments on a case-by-case basis. Such review is necessary because, in each case, the risk is necessarily dependent upon the specific organism to be released, the source of DNA, the host-vector system, containment requirements, and the environmental site conditions to which the organism will be applied.

The task of risk assessment is not a simple one. Estimating the probability that an organism released into the environment will adversely affect that environment is quite different from estimating the probability that an organism will escape from a laboratory. In the latter case, NIH Guidelines have set out specific containment levels for categories of organisms, based on the known potential for multiplication, infection, and movement. In the former, risk assessment requires the application of ecological principles of dispersal and persistence which many argue are not adequately developed at present.

Predictive capabilities are, however, becoming more sophisticated. For example, scientists in Scotland have just announced the approval of a field test in which a genetically engineered virus, known to infect the Pine Beauty moth, which has been devastating Scotland's forests, will be released into the environment. The virus has been engineered to include genetic material traceable by gene probe, with the result that the virus can be identified and its persistence and movement monitored.

As predictive capabilities are improved and stabilized by ecological research such as the experiment in Scotland, it should be possible to develop models generally applicable to categories of organisms to be field tested. When models are available, it will be possible to determine risk by the classification of the organism in much the same way that laboratory research is assessed today. In the interim, approval for field tests will have to be given on a case-by-case basis after careful consideration of all known and foreseeable risks.

Even with the capability of measuring risks apparent today, in the final analysis, not all consequences which may flow from the application of genetically engineered organisms can be foreseen. There is the anomalous result that a cost benefit analysis must be made without the benefit of knowing all the possible costs.

Some argue that genetic research should proceed at any cost and others say that it should not proceed unless the risk of adverse consequences is nonexistent. Neither extreme is likely to gain acceptance by the majority of the public. But past experience does indicate that the public will accept reasoned application of the scientific knowledge available to approve releases on a case-by-case basis by persons competent to make such assessments, as long as public information and opportunity for public participation is sufficient.

NIH's Role in Regulation

NIH Guidelines expressly are not regulations; they are mandatory only for government-funded research. The Guidelines, however, provide for voluntary registration of projects by private industry; registering companies agree to abide by the Guidelines' containment standards. The majority of all privately conducted rDNA research today is, in fact, registered with NIH.

Several Federal Government agencies have used their regulatory authorities to require compliance by private industry. For example, USDA requires compliance with the Guidelines as a condition of obtaining a license for veterinary biological products derived from rDNA technology. The Food and Drug Administratiion (FDA) has a similar requirement for products it regulates. So, while the agency cannot directly prohibit or regulate the research, it can theoretically prohibit entry of the genetically engineered product into the market.

During the late 1970's, several attempts were made to enact legislation which would give the RAC the authority to regulate all private research in rDNA, as well as government-funded research. Momentum dissipated when scientists called to testify before Congressional committees reported that, after risk assessment based on experimental work, the techniques of genetic engineering did not substantially increase the risks to human health and the environment caused by the use of infectious agents in research.

The consensus which emerged in the scientific community and which exists today is that, in any contained research, it is not the technique of rDNA or genetic engineering which determines risk, but rather the infectious capacity of the organism or organisms. So NIH Guidelines, which establish containment levels based on the characteristics of the organism to be used as a source of DNA or in the host-carrier system, are deemed adequate to prevent adverse consequences to the public health and environment.

Contained Research. The Guidelines distinguish between contained research conducted in a laboratory and research involving the release of organisms into the environment such as the field testing of a micro-organism or plant. For contained research, the Guidelines specify requirements for physical and biological containment commensurate with the level of risk because of the source of the DNA and the pathogenicity of the host-carrier system. The level of risk also determines the notice and approval procedures.

At the highest risk level, the appropriate IBC assesses the risk, approves containment standards, and submits the research proposal to NIH for approval. In an intermediate area specified by the Guidelines, IBC approval is sufficient. This is generally true where the experiments are covered by containment levels specified in the Guidelines. Other experiments with rDNA that are considered to pose minimal risk may proceed upon notification of the IBC or are exempt.

IBC's are responsible for ensuring that the research is carried out in conformity with the provisions of the Guidelines and approved procedures. After approval, NIH does not become involved unless a specific issue is raised with respect to compliance. Although some agencies require that firms comply with the Guidelines as a condition precedent to the grant of licenses, no regulation by any Federal agency other than NIH covers basic, laboratory-contained research.

Deliberate Release Experiments. The Guidelines as originally issued prohibited the deliberate release of genetically engineered organisms into the environment. The 1978 revision kept that prohibition, although such release may be approved on a case-by-case basis by the entire RAC and NIH on a finding of "no significant risk to health or to the environment." Certain plants also may be released after review by the RAC Plant Working Group and the IBC. Experiments requiring NIH approval because they involve deliberate release may, as well, be reviewed by the Federal agency advisory committees with expertise in that particular science. For example, USDA's Recombinant DNA Advisory Committee reviews all research proposals submitted to NIH about whole plants or other organisms to be applied in agriculture.

Although several deliberate releases have been approved, none have proceeded to field testing. One such approval for field testing, ice nucleation bacteria, is the subject of protracted litigation.

Other Regulators of Deliberate Releases

In discussing regulatory authorities in the context of deliberate release experiments, it is important to distinguish between the regulation of research and the regulation of the products of biotechnology. NIH has no jurisdiction over the regulation of the products of biotechnology. Other Federal Government agencies, such as the Environmental Protection Agency (EPA), FDA, and USDA operate in this sphere. Jurisdictional problems have arisen with regard to the oversight and approval of research activities such as field tests which occur somewhere between contained research and approval of products for marketing.

Because of the increasing number of applications for field testing and the diverse organisms and purposes for which the organisms are developed, the question has arisen whether NIH should continue to have exclusive responsibility for approving all deliberate releases involving rDNA. Indeed, NIH itself has announced its intent to defer to the expertise of other agencies in those instances where other agencies assert oversight authority and NIH determines that review by the agencies will serve the same purpose as review by NIH. 50 Federal Register 48,344; 48,349 (Nov. 22, 1985). This gives rise to further questions as to which agencies have authority to regulate specific research applications and whether one agency or reviewing body responsible for all biotechnological research is needed.

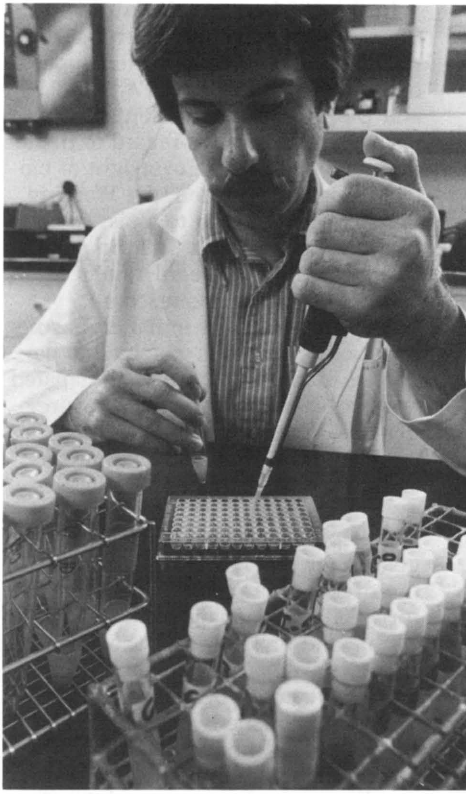
The debate began in 1983 when EPA stated its intention to regulate biotechnology under the Toxic Substances Control Act (TOSCA). EPA based its claims to regulate deliberate releases on its authority under Section 5(a)(1)(A) to require premanufacture notice (PMN) for "new chemical substances." TOSCA defines "chemical substances" as follows: "any organic or inorganic substance of a particular molecular identity including . . . any combination of such substances . . . occurring in nature . . ." It is not clear whether genetically engineered organisms fall within the definition of "chemical substances" contained in TOSCA, but it is arguable that they do not. Moreover, laboratory and "small quantities" of research and development are exempt from PMN. "Small quantities" as defined by EPA regulation would exempt most field testing.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), EPA also has claimed jurisdiction over basic research in the area of pesticides by requiring notification before small-scale field testing of genetically engineered microbial pesticides. 49 Federal Register 40,659 (Oct. 17, 1984). In addition, it has begun reviewing proposals to field test genetically engineered pesticides.

An experimental use permit has been issued to Advanced Genetic Sciences, Inc., to field test a frost resistance bacteria. Monsanto has submitted a request for a permit to test an insect-killing microbe, as has the University of California for field testing the ice nucleation bacteria mentioned. USDA, however, has responsibility for higher plants and animals that are considered pesticides. 40 CFR 162.5(c)(4). For example, a plant which has been modified to produce its own pesticide would presumably fall within USDA's jurisdiction.

These instances are merely a sample of the myriad of definitional and jurisdictional problems that have arisen as biotechnological research has approached commercialization. Acknowledging that some sort of coordination among the four principal agencies (EPA, USDA, FDA, NIH) may be essential if the Federal Government's oversight efforts are to keep pace with developments in biotechnology, President Reagan established an interagency working group under the White House Cabinet Council on Natural Resources and Environment. This interagency group was to study the situation and to coordinate the efforts of the agencies to establish biotechnology regulations or protocols.

On November 14, 1985, the first plan of the Cabinet Council Working Group on Biotechnology was published. The plan called for a two-tier review of biotechnology proposals. The first review would be conducted by the agency-level science advisory committee (for example, USDA's Recombinant DNA Advisory Committee) and the second review by a Biotechnology Science Board (BSB). After receiving comments from the public, the Working Group revised the plan by replacing the BSB with the Biotechnology Science Coordinating Committee (BSCC). (50 Federal Register 47,174, 1985). The BSCC is not recommended to review proposals approved by the agency advisory committees but will coordinate the regulatory efforts of the agencies.



Bob Bjork, ARS

The NIH guidelines prescribe safety standards for DNA research.

In the 1984 notice, the Working Group also published a matrix of the regulatory laws with potential applicability to biotechnology. EPA, FDA, and USDA issued statements setting forth their views with regard to their authorities to provide oversight of biotechnology. Since then, the Working Group has continued to assist them to formulate a clear and uniform policy with respect to the regulation of biotechnology, including research.

The final policy formulation has not been released, but is expected to be published shortly. It is not anticipated that legislation creating any new regulatory authorities will be recommended. Rather, it is likely that the agencies with regulatory authorities over products will be responsible for approving experimental releases of genetically engineered organisms in their respective product areas. Where jurisdictional overlaps exist, it is desirable and probable that the affected agencies will agree upon one agency that will exercise oversight authority. This may be done by implementing memoranda of understanding, such as the memorandum between USDA and FDA regarding responsibility for regulating animal biologic products as biologics under the Virus, Serum and Toxin Act or as drugs under the Food, Drug and Cosmetics Act.

Costs of Delay in Regulatory Approval

Even where jurisdictional disputes can be avoided, the Federal agencies are dealing with products created by new technologies in which they may have minimal expertise. Delay and uncertainty of response can have a tremendous impact on the viability of biotech firms, particularly the small emerging companies that require a much faster return on their investments to remain in business. Industry representatives believe that the uncertainty over future oversight of deliberate releases and other health and safety issues related to the testing of new biotechnological products greatly influence investment in biotechnology.

It also has been pointed out that delays in regulatory approval for field testing of recombinant DNA products could lead to the relocation of firms to other countries that may not have controls or may be further advanced in establishment of testing and other regulatory protocols. Industry has warned that excessive or onerous regulations, such as the regulation by more than one agency, could lead to relocation abroad.

The ability of the Federal Government to respond in an expeditious and effective manner to the need for certainty in the oversight and regulation of research in biotechnology will play an important role in the development of this country's biotechnology industry.

Role of the Courts

National Environmental Policy Act. Perhaps of even greater significance than regulation to the development of biotechnology is the threat of litigation. Court cases filed under the National Environmental Policy Act (NEPA) in the last few years illustrate the importance of risk assessment to the public's perception of the safety of research in biotechnology.

NEPA requires Federal agencies to prepare environmental impact statements for "every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment." 42 U.S.C. 4332 (2)(c). Since NEPA applies solely to Federal agencies, private industry is affected only insofar as it may be the recipient of Federal funds or require the approval of research.

The Act itself gives little guidance

as to which actions of Federal agencies fall within the purview of the statute. The Council on Environmental Quality (CEQ), the agency created by NEPA to oversee its implementation, has issued regulations establishing that, unless the major Federal action falls within an agency's published "categorical exclusions," the agency must, at a minimum, prepare an environmental assessment (EA), a public document which sets forth sufficient evidence of the agency's analysis as to why a proposed Federal action will or will not have a significant impact on the environment. 40 CFR 1501–1508. If a proposal is for a major Federal action as defined by the regulations and the environmental assessment reveals a significant impact on the environment, then the Act requires that an environmental impact statement (EIS) be filed. 40 CFR 1508.18.

Court Cases. Research is not *per se* outside the scope of the requirement that an EIS be prepared for Federal actions significantly affecting the environment. *Scientists' Institute for Public Information* v. *Atomic Energy Commission*, 481 F.2d 1079 (1973). If an agency has published, however, a categorical exclusion narrowly defining categories of actions which, based on past experience, do not have a significant effect on the human environment, and the research legitimately is within the scope of the exclusion, no EA or EIS is required. 40 CFR 1500.4.

In addition, research wholly contained in a laboratory under containment levels established by NIH Guidelines may be exempt from the requirements of NEPA. In *Mack* v. *Califano*, 447 F. Supp. 668 (1978), the District Court for the District of Columbia held that rDNA research in accordance with NIH Guidelines would have no adverse environmental or public health consequences when it appeared that NIH Guidelines would ensure that no recombinant molecules would escape from the laboratory, and the NIH Guidelines had themselves been accompanied by an EIS.

Deliberate releases are somewhat more problematic. The experiment involving ice nucleation bacteria mentioned earlier was a joint venture by the University of California, Berkeley, and a private company, both of which obtained NIH approval for field testing.

The Foundation on Economic Trends (FOET) filed suit in the District Court for the District of Columbia against HEW alleging that NIH had failed to comply with NEPA requirements in reviewing and approving requests for deliberate releases. The District Court issued a preliminary injunction not only prohibiting the field testing of the ice nucleation bacteria by the University of California but also prohibiting NIH from continuing to approve any experimentation involving the deliberate release of rDNA until it developed a programmatic EIS. *FOET* v. *Heckler*, 587 F. Supp. 753 (D.D.C. 1984).

The injunction did not apply to the private company because the Guidelines are mandatory only for government-funded projects. In this case, the firm voluntarily abstained from proceeding with the experiment.

HEW and the University of California appealed to the Court of Appeals for the D.C. Circuit. The Circuit Court upheld the preliminary injunction with regard to the ice nucleation experiment, agreeing with the District Court's finding that an adequate EA must be prepared to assess the possible impacts of the bacteria on neighboring plant and animal life or on weather patterns should the bacteria be carried off site by wind, insects, or birds. With regard to the programmatic EIS, the Court stated that, while it would doubtless be helpful, it was not prepared to agree with the District Court that the absence of an EIS violated NEPA.

The essence of the Court of Appeals decision is that, if HEW gives adequate environmental consideration to each deliberate release experiment, HEW will be in compliance with NEPA.

FOET also has asked the D.C. District Court to enjoin the Advanced Genetic Sciences experiment already mentioned alleging, as in the HEW case, that EPA approval was based on inadequate environmental review under NEPA. *FOET* v. *Thomas* (Civ. Action No. 85-3649, D.D.C. filed Nov. 19, 1985). The Court denied the plaintiffs' motion for a preliminary injunction holding that the case was not likely to succeed on the merits, but has not ruled on the Government's motion for summary judgment.

In another case not involving deliberate release, the same plaintiff brought suit against USDA in October 1984. FOET sought a declaratory judgment that the actions of the defendants in establishing and carrying out an animal breeding research program that allegedly focuses on enhancing size and accelerating and improving reproductivity of animals are in violation of NEPA as well as other Federal laws. *FOET* v. *Block* (Civ. Action No. 84-3045, D.D.C., filed Oct. 19, 1984).

Joined by the Humane Society of the United States, the American Minor Breeds Conservancy, and other individuals who claim an interest in animal rights, FOET asserted that an EIS should have preceded the use of rDNA and other techniques that permit the exchange of genetic material between species to enhance productivity. They wanted the Department to consider alternatives to increasing the meat supply, such as developing a program aimed at changing the U.S. diet to require less meat.

In April, 1986, the District Court granted USDA's motion for summary judgment on the ground that the plaintiffs had not stated any claim cognizable under NEPA or any of the other statutory authorities cited in the complaint.

The allegations of this final complaint are exemplary of how the EIS requirement of NEPA has been used by litigants for purposes that could not have been imagined and certainly not intended by the drafters of the legislation. In fact, the EIS requirement can and probably has, in many instances, been used solely as a delaying tactic. As Senior Circuit Judge MacKinnon stated in *FOET* v. *Heckler*:

> The Foundation's conduct also has delayed this vital experiment for a very considerable period of time. The use of delaying tactics by those who fear and oppose scientific progress is nothing new. It would, however, be a national catastrophe if the development of this promising new science of genetic engineering were crippled by the unconscionable delays that have been brought about by litigants using the National Environmental Policy Act . . .
> 756 F.2d 161 (D.C. Cir. 1985) (MacKinnon, J., concurring).

While the numerous complaints filed by one group of plaintiffs do not evidence a lack of confidence by the general public that government agencies are inadequately assessing environmental, safety, and ethical issues with regard to rDNA research, the legal precedents emerging from the litigation indicate the necessity for agencies approving such research to ensure that these issues have been considered seriously. For the present, when a deliberate release is planned, it will be necessary to require, at a minimum, an EA that has realistically and thoroughly considered the potential for environmental effects.

Future Research and Regulation

The public is interested and fully capable of taking part in decisions affecting rDNA research and its application. The NIH experience is evidence that the public and governmental agencies can work compatibly together to make reasoned decisions about the application of biotechnology. If this cooperation continues, there is no reason to doubt that research will be allowed to move cautiously but progressively forward.

Because no unique risks are posed by genetically engineered organisms, they should be regulated in the same manner and to the same extent as products manufactured by traditional methods. Experience has shown that rDNA research, which is covered by NIH Guidelines, poses no special risk to health, safety, or environment and it should be allowed to proceed without regulation. Adequate EA's and, in some instances, EIS's are essential for deliberate releases, at least until experience allows the development of models generally applicable to categories of organisms to be released.

If such risk assessment is performed conscientiously, it is unlikely that the public will demand regulation of research in biotechnology. The regulation of the products of biotechnology is adequate to protect against adverse consequences to the public health and safety and to the environment. This regulation can be accomplished within the existing framework of governmental authorities.

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[1]Tribe, Laurence H., *Technology Assessment and the Fourth Discontinuity: The Limits of Instrumental Rationality*, 46 *Southern California Law Review* 617, June 1973, p. 621.

[2]Francoueur, Robert T., *We Can—We Must: Reflections on the Technological Imperative, Theological Studies* 33:3, September 1972, p. 429.

Implications of the Biotechnology Revolution for Agriculture

Neville P. Clarke, *director, Texas Agricultural Experiment Station, College Station, TX*

Today, agriculture needs a new infusion of science and technology and new capabilities that will restore and enhance the competitiveness of U.S. agriculture in the world marketplace.

The products of biotechnology offer one of the most exciting opportunities to meet these urgent needs. In the words of Dr. George Keyworth, former Science Advisor to The President, "U.S. agriculture has got to take advantage of new knowledge in biosciences in order to remain the dominant force it is in the world today."

But what exactly is biotechnology? The term *Biotechnology* refers to an array of related basic sciences that have as their centerpiece the use of new methods for the manipulation of the fundamental building blocks of genetic information to create life forms that might not ever emerge in nature—life forms that can expand and enhance the well-being of humans in ways that almost extend beyond the imagination.

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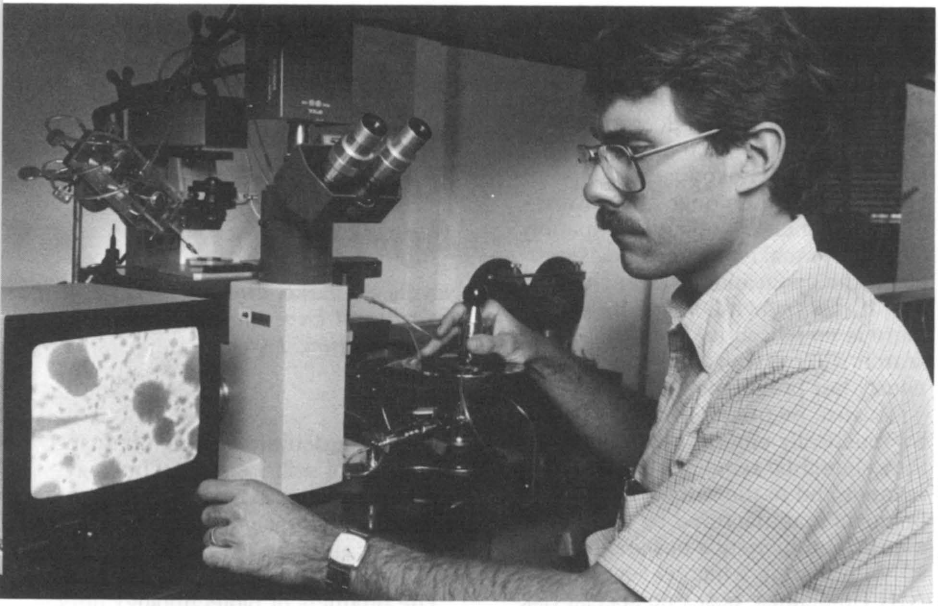


Steve Brown, ARS

With help from a microscope attached to closed-circuit television, a plant geneticist injects a chromosome into a plant cell magnified 15,000 times.

cellular machinery has been termed a biotechnology revolution. It could have as profound an effect on our society as has the information revolution occurring alongside it. Many believe that the impact of biotechnology will be as great or greater in agriculture as in medicine."

Sciences as Base

The biotechnology revolution in agriculture is a part of an overall increasing sophistication of biological techniques for improving the production, processing, and marketing of food and fiber. Biotechnology, for instance, allows an acceleration of the process of selection and breeding that has been under way for over 100 years. While much of the early research in biotechnology addressed the basic biology to solve critical problems in medicine, the opportunities and potential impact of this technology for agriculture make this at least as important an application as medicine. In fact, biotechnology has its broadest applications in sciences that enhance human well-being in the total sense.

In the case of agriculture, biotechnology is built on a broad base of existing and ongoing scientific research that supports and enhances the use of the new methods in genetic engineering and related techniques. This science base helps define what should be genetically engineered and enables the products of fundamental research in the laboratory to be practically applied in the field. The way the pieces fit together and the basic concepts in biotechnology are both exciting and fascinating.

Concepts of Genetic Engineering

Every cell in plants, animals, and microbes contains the genetic information to allow perpetuation of that cell or organism. The study of the structure, chemistry, and function of this genetic material has been the basis of understanding that has enabled the biotechnology revolution to come of age.

This genetic material is arranged in helical strands of amino acids that contain the code for triggering the characteristic functions of that organism in succeeding generations. The discovery of the structure of the DNA helix in the 1950's, the unraveling of genetic code in the 1960's, and the development and refinement of the tools of genetic engineering in the 1970's has caused something fundamentally different to happen in biological science. Using enzymes as "genetic scissors," the genetic structure of cells can be snipped apart and reconstructed in combinations impossible to achieve by natural reproduction. Scientists can not only alter existing genes, but construct totally synthetic genes to cause the organism to perform desired functions.

To make genetic engineering work, methods are being developed to transfer genetic material into plants and animals and to make sure that the function that has been engineered is expressed at the right place and at the right time. But genetic engineering is only a part of biotechnology. The total picture includes understanding the physiology and biochemistry of the function of interest and knowledge of the existing genetic codes that regulate the process. This allows scientists to understand what to genetically engineer to produce a more desirable organism. Once such a product has been created in the laboratory, a variety of techniques such as tissue culture are often needed to recreate an organism that can compete in a practical ecosystem. The techniques of plant and animal breeding and development are used to take the final product back to the field.

Agriculture as a Principal Target

The production of food and fiber is essential to life, and agriculture is the world's largest industry with assets worth well over a trillion dollars in the United States alone. As a biologically based set of industries, agriculture is in the ideal position to reap the major benefits associated with the biotechnology revolution.

In the past, agriculture has been an energy and labor intensive industry. Biotechnology offers the opportunity to reduce both these costs in future operations. Inherent resistance to pests and disease can reduce the use of chemical pesticides, reducing the cost of production and the potentially harmful environmental effects of such practices. The possible uses of biotechnology for agriculture are limited only by imagination and initiative.

The total system for food and fiber production is extremely diverse and multifaceted, providing a broad range of potential applications of biotechnology. Biotechnology is not only enhancing the traditional enterprises in food and fiber production; it also is producing new high technology industries that are in themselves providing new jobs and producing new goods and services. Sometimes thinking of biotechnological applications is limited to production agriculture, where an exciting new array of scientific breakthroughs is being developed. Just as exciting, however, is the new application of biotechnology to food processing and manufacturing, to new methods for ecologically sound disposal of wastes, and to biochemical engineering where totally new products are being produced from agricultural residues using biotechnological tools.

The excitement associated with the biotechnology revolution can be even better conveyed by some specific examples of goals and achievements.

Opportunities and Applications

Biological Factories. One of the early uses of biotechnology has been to use simple organisms such as bacteria and yeast as so-called biological factories to produce biologically active compounds. Genetic codes for these compounds are inserted into the genetic makeup of these simple organisms along with genetic instructions that cause the production of the desired material.

Through these techniques, for instance, human insulin is now produced and is replacing insulin from animal sources for treatment of diabetes in humans.

Interferon, a biological anticancer treatment and antiviral material previously available in only minute quantities, can now be produced inexpensively and in large quantities using biological factories.

Hormones, such as bovine growth hormone, have been manufactured using this method; the product is being experimentally injected in dairy cattle to enhance milk production by some 20 to 30 percent.

Diagnostic reagents and improved vaccines for animal and human disease are being produced using these techniques.

Early progress has been rapid in this area because the genetics of these organisms is relatively simple.

Plant-Water Relationships. In many parts of the world, water is the limiting factor in food production. Biotechnology is being used to greatly enhance the production of plants with high drought-stress tolerance. These plants will maintain yields in environ ments with much less water, and there is the promise of developing plants that can use brackish water. These developments could have a profound effect on stretching water resources and will be crucial as water for irrigation becomes less available and more expensive.

Plant Productivity. Plant growth and development has been the subject of investigation for decades, but until recently remained poorly understood. Biotechnology makes it possible to isolate, characterize, and manipulate specific genes. This new technology provides a powerful tool to understand plant growth and development and a way to directly manipulate the process. Opportunities in this field include altering chemical composition of the plant product, improving processing quality, producing plants resistant to stress or herbicides, altering plant size, and changing the ratio of grain to stalk.

Plant Disease Resistance. Genetic engineering offers an exciting and environmentally sound way of reducing the cost and increasing the effectiveness of plant pest control, through the development of genetic resistance to disease. Because disease resistance is controlled by relatively few genes, this area is among the most favorable candidates for early application of biotechnology to plants.

Nutritional Quality of Plants. Many plant foods are deficient in nutrients or lose nutritional value during storage. Some plants have other features that are not optimum for human or animal health. Genetic engineering can be used to both improve and retain nutritive value as well as to modify undesirable properties of plant products. For instance, through genetic engineering, the composition of dietary fats can be modified to reduce their possible contribution to cardiovascular disease.

Biological Control of Insects. Biological control exploits natural factors in the life cycle of harmful insects as a means of control. Some possibilities include use of highly specific insect pathogens (bacteria, viruses, fungi) to produce insect disease or death or to use unique viruses that interfere with the insect immune system, making it more vulnerable to disease. Also, insect chromosomes or genes with some ability to control population growth are under study as well as methods which interfere with normal growth and maturation. All these processes of biological control are potentially capable of being enhanced through the use of genetic engineering to improve the effectiveness of the crop insect's natural enemy. These processes are highly specific to single insect species and so are highly desirable environmentally as alternatives to chemical pesticides.

Animal Disease Resistance. The ultimate solution to animal disease will be to genetically engineer disease-resistant animals. Recombinant DNA technology has made possible the identification of specific genes controlling disease resistance. The identification, mapping, and cloning of these genes coupled with technical advances in embryo manipulation offer dramatic potential for generating disease-resistant animals through gene transfer.

Animal Production and Development. Thanks to traditional breeding programs, animal food production has more than doubled since 1920, while the number of animals has remained unchanged. Recent components of the success story have been achieved through improved genetics and breeding techniques such as embryo transfer and embryo splitting. As methods for genetic transfer of material in livestock are further developed, it will be possible not only to continue and accelerate the process of improving the productive performance of individual animals, but also to improve the quality of the animal product produced. For instance, future generations of meat animals will be produced with inherently leaner carcasses while maintaining tenderness and flavor desired by the consumer.

Concerns

While the opportunities for using biotechnology in agriculture are truly fantastic, they have triggered public concern and a corresponding need to develop methods to assure that biotechnology is used in an environmentally sound manner. Agricultural researchers are enhancing traditional methods of manipulating plant and animal germplasm used for over 100 years as well as using the guidelines in recombinant DNA studies directed to human applications.

In both cases, there is a sound track record of safety associated with research and its products. Recombinant DNA techniques have been safely employed since the mid-1970's through an essentially self-imposed series of safety guidelines and reviews within the scientific community. Formerly under the aegis of the National Institutes of Health, these safety procedures are now the responsibility of the U.S. Department of Agriculture. Methods and procedures are being completed to assure continued safety in applying recombinant DNA techniques for agricultural research and in producing biotechnology products.

International Dimensions of Biotechnology

Sue Ann Tolin, *professor of plant pathology, Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg*

Biotechnology knows no international boundaries, just as the potential applications of biotechnology to agriculture are boundless. The international dimensions discussed here include U.S. competitiveness in biotechnology research and product development, the guidelines for biotechnology research, and efforts toward international harmonization of regulations.

Competition

The United States is the world leader in biotechnology. The Department of Commerce came to this conclusion in a 1984 report comparing the United States with Japan and five Western European countries—West Germany, United Kingdom, Switzerland, Sweden, and France.

All countries have strong basic research and development programs in biotechnology that provide a substantial challenge to U.S. leadership in many biotechnological fields, particularly pharmaceutical and industrial applications.

Other countries, particularly the United Kingdom and Australia, have met the challenge in plant biotechnology research. Indeed, the science policymakers of most technologically developed countries have targeted biotechnology programs for special support.

Third World countries also have recognized biotechnology as a powerful tool for more rapid development of their agriculture and are anxious to use biotechnological approaches.

Marketable Products. Any assessment of a commercial competitive edge at this time must be recognized as largely speculative since few products of biotechnology are as yet being marketed. Furthermore, all the early products were functional protein molecules purified as products of genetically engineered bacteria or other single cells growing in large fermentation vessels.

For example, human insulin, the first marketed product, was isolated from bacteria into which the DNA that directs insulin synthesis in human cells had been introduced.

Such products should not be fundamentally different from conventional products because they are produced by a more precise, efficient, and perhaps safer process.

Marketable Organisms. Fulfilling the predictions of the benefits of biotechnology for agriculture will require that at least some of the marketed products are living organisms.

The lead nation in the future for agricultural applications of biotechnology is likely to be the nation that is first to recognize that benefits from using genetically engineered organisms outweigh any potential disadvantages of untoward events encountered by introducing these organisms into the environment.

The early experimental field tests with engineered organisms as a part of the research process to demonstrate their safety and efficacy will be the key to establishing and maintaining a competitive position, in much the same way that field experimentation in agriculture and clinical trials in medicine have traditionally been used.

Research

Most of the major scientific discoveries that led to the beginning just over a decade ago of the new biotechnology era of science were made in this country, largely as a result of our long history of funding basic research.

U.S. scientists were the first to recognize and isolate enzymes from bacterial cells that had the power and specificity to cleave and rejoin bits of genetic information from different organisms. This technique became known as recombinant DNA (rDNA) since the DNA comprising the genes was "recombined" in a test tube from organisms not known to combine or otherwise interact genetically in nature.

Question of Safety. U.S. scientists also were the first to express concern over the safety of conducting certain rDNA experiments, since, in theory, a new organism with unpredictable properties could be created.

The National Institutes of Health (NIH) asked a group of eminent scientists, ultimately known as the RAC or Recombinant DNA Advisory Committee, to write a set of guidelines to be followed when conducting research with recombinant DNA molecules so that harm to laboratory workers and the environment could be avoided. The guidelines helped to allay concern and fears and allowed research with certain organisms to proceed in an orderly and safe manner under the continued purview of the RAC.

Although NIH could insist only that their own researchers or grantees comply with the guidelines, other Federal agencies including the U.S. Department of Agriculture were directed by executive order to follow the same guidelines for research that they funded.

Private institutions and industry also widely accepted the laboratory protocols set forth in the guidelines.

After more than 10 years of widespread use of recombinant DNA techniques under the guidelines, no health or safety problems specifically associated with the techniques have arisen.

Research Under Guidelines. With review and approval by either a local committee or from NIH for certain categories of experiments, countless academic, government, and industrial scientists proceeded to conduct research in which they discovered the many potential human, industrial, agricultural and environmental applications of this technology. They also found many unanticipated benefits from basic research discoveries.

Research also proceeded at a rapid rate in other nations. U.S. or similar guidelines for laboratory research were adopted by most nations, but few of them established a body equivalent to the RAC. They recognized that the RAC provided an internationally valid scientific forum for biotechnology and saw little need to duplicate it.

In its scientific and political wisdom, the United States had built flexibility into the guidelines, which permitted experiments to be recategorized as scientific knowledge about the organisms or the procedure accumulated instead of rigid regulations based on an, as yet, inadequate science base. This process helped to give U.S. scientists a competitive edge because approvals for certain types of research projects could be requested by them and quickly incorporated into research programs throughout the country. Other nations could adopt the changes in the U.S. guidelines after they were published in the Federal Register.

The evolution of guidelines for research into a *de facto* regulatory framework, nationally or internationally, could be viewed as either stimulatory, early on or inhibitory, later and currently, to biotechnology research and the development of agricultural applications.

Question of Release. Initially, the guidelines specifically prohibited deliberate release of any organism containing recombinant DNA into the environment. Thus, an Environmental Impact Statement written by NIH concluded that issuing guidelines for conducting research with recombinant DNA molecules would have no significant impact on the environment.

There was the underlying perception that less was known about these organisms than about other organisms in nature, and that because less was known they should not be released. Clearly, the only organisms in the minds of the early RAC members that would contain rDNA were bacterial pathogens of humans. The issues of transgenic plants and animals, of human gene therapy, and even of ice minus bacteria were scientific light-years away.

However, the safety of other techniques used in biology to produce genetically altered organisms, such as cell fusion, induced mutation, directed mutagenesis, somaclonal variation, and conventional plant and animal breeding, was not questioned at this time. Scientists and the public expressed no concern that use of these other techniques could result in any of the hazards initially conjectured for rDNA experiments. In addition, the long experiences with plants and animals in agriculture certainly demonstrated that field experimentation with organisms altered by these genetic engineering methods could be conducted safely.

Eventually, the RAC received requests to release rDNA-modified plants and micro-organisms in controlled field tests. Although the requests were approved because no untoward effects to humans or the environment could be envisioned, the legality of this RAC action was challenged because NIH was not a regulatory agency.

Regulation. When biotechnology moved from the laboratory to the marketplace, and living organism products were ready for testing, other agencies and statutory authorities became involved in the research process. The United States has essentially concluded that the existing framework for regulation of biological and chemical products is adequate to assure the safety of biotechnology. These laws are product specific, rather than process specific, to assure uniformity in product regulation. All research or all commercial products may not need safety regulation, provided the precision of the genetic modification is completely understood and the organism can be managed as it is introduced into the environment.

International Harmonization

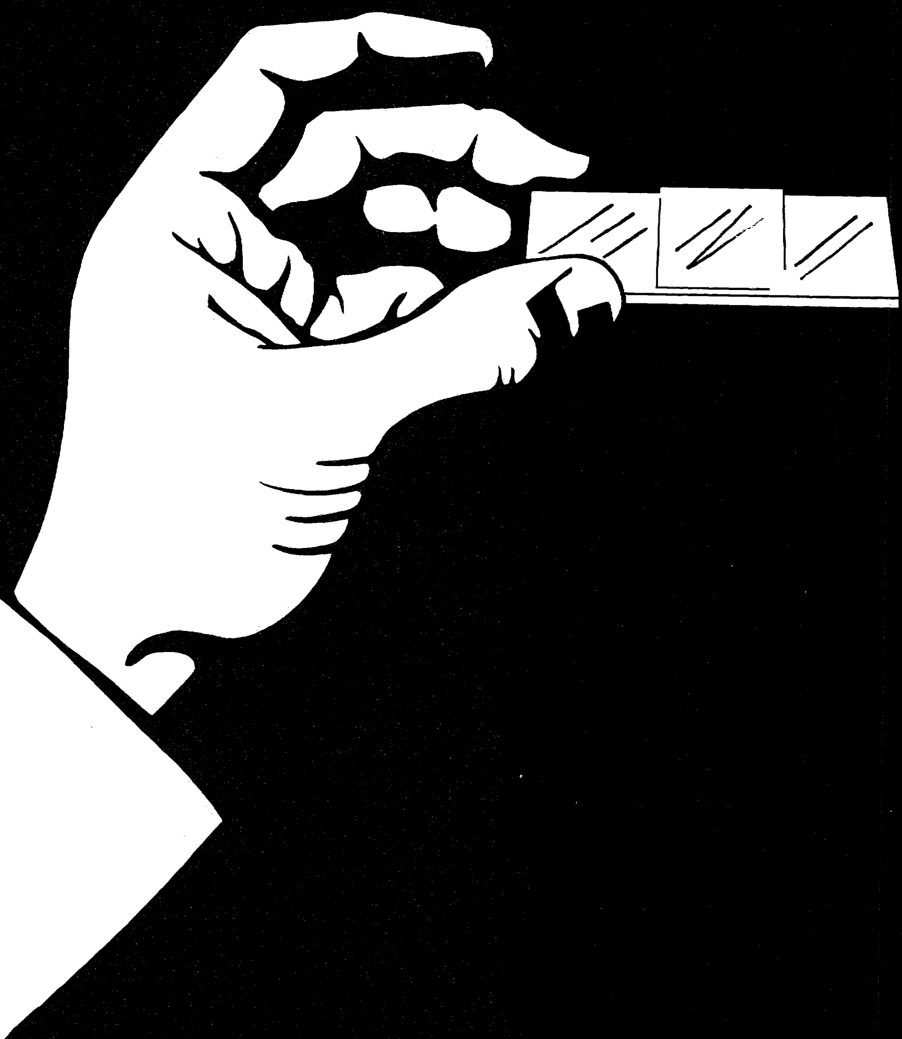
The United States began thinking about both large-scale fermentations and release of organisms at an early stage of biotechnology research and regulation. Other countries have followed our lead, and some have now approved release of rDNA-containing plants in field tests. Many more will soon follow, particularly if the United States releases are blocked by litigation.

Nations have recognized the need, particularly in biotechnology applications, for uniform scientific principles on which to base their decisions. One of the most active international organizations in attempting to arrive at harmonization has been the Organization for Economic Cooperation and Development (OECD). Over the last 3 to 4 years, a special group of scientific experts, delegated by the more than 20-member nations, deliberated on a report entitled *Recombinant DNA Safety Considerations*. The report considers potential benefits and risks of rDNA organisms in industrial, environmental, and agricultural applications, and the extent to which risk assessment of these organisms differs from that applied to conventional organisms. It also identifies general scientific principles for achieving safety in the various applications, and makes recommendations to member countries for both general and specific issues that they can use in formulating their regulations.

The OECD report should provide the basis for an international consensus for the protection of health and the environment, the promotion of technological and economic development, and the reduction of international trade barriers.

III

Biotechnology: Its Application in the Microbial World



Using Biotechnology in Food Processing Today

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Biotechnology has been described as the last great technical innovation of the 20th century, but it has been used to produce food and food ingredients through fermentation for thousands of years.

Biotechnology was largely a practiced art in food processing and not scientifically understood. Now, through recent research in genetic engineering, the understanding of biotechnology's scientific basis has increased. Innovations have followed in process engineering, improvements in products, and cost reduction.

Biotechnology is defined here as the integrated use of biochemistry, molecular genetics, microbiology, and process engineering to commercially produce products of reactions of micro-organisms, cell cultures, or parts of micro-organisms or cells. As research is focused on these and other potential products, biotechnology's role in producing food and food ingredients will increase.

The following sections identify fermentation, separation, and purification operations as major areas of research needed to enhance the use of biotechnology for producing consumer products, including food.

Increasing Efficiency of Fermentation Systems

Fermentation is used to produce alcoholic beverages, bread, and cheese. It is a reaction or series of reactions in which a biocatalyst, usually a microbial cell or isolated enzymes, is used to convert a substrate or chemical constituent into a desirable product. Applications in the food industry include the production of alcoholic beverages, bread and cheeses. In most cases, the transformations of substrates to products are extremely complex and require control of other nutrients, oxygen transfer, and maintenance of the biocatalyst.

In designing a fermentor or bioreactor, the following technical areas must be considered: biological kinetics, piping and equipment design to maintain sterility, fluid hydraulics, mass transfer of substrate materials into the micro-organism, mass transfer of atmospheric oxygen through the bulk liquid and into the micro-organism, mass transfer of product material out of the micro-organism into the bulk liquid, heat transfer for removal of metabolic heat, the control system desired, and scale-up. Intensive research is probing these areas to make such operations more efficient and affordable.

Bioreactors. Bioreactors are classified as batch reactors or continuous reactors. Batch reactors produce a variety of products, such as beer, bread and pickles. They are especially important in facilities producing a wide variety of high-value, low-volume fermentation products. They also are relatively easy to maintain in disease-free condition because the run time is relatively short, 1 to 2 days, compared to run times of several months for continuous reactors. Their main disadvantages are extra operating costs and low productivity.

Continuous reactors fall into three

main groups: 1) chemostats; 2) tower fermentors, and 3) immobilized cell bioreactors. The chemostat is like a batch reactor except it has a continuous feed stream and a continuous product draw-off stream. The volume is maintained constant by matching the feed stream rate to the product stream rate. The main disadvantage is the loss of unconverted feed and nutrient components in the product draw-off stream.

The tower fermentor generally operates by injecting air at the bottom of a tower and relies on the upflow of the gas to provide continuous agitation. The organism is carried around in the fermentor and, as a result, encounters a variety of changing conditions. Placement of feed points, including air inlets, must be designed to minimize these extremes. The product is continuously withdrawn, and the design requires location of the draw-off point to minimize loss of nutrients and carbon source substrate.

The immobilized cell bioreactor, the newest type, traps whole cells in an inert carrier or matrix that allows nutrients and oxygen to enter and products to leave without releasing the whole cell. Individual enzymes also have been immobilized on materials such as ceramic beads of ion-exchange resins and gels with significant success. The most notable commercial application is the production of high-fructose corn syrup.

Several problems must be overcome for a significant expansion of immobilized whole cell reactors, including prevention of clogging of the matrix and maintenance of the cells for extended periods. Immobilized cell or enzyme reactors provide one of the most promising areas for fermentor development.

Scale-up Research. Scale-up is perhaps the most critical issue when a new process is to be commercialized.

University of Minnesota

Research will increase the role of biotechnology in production of food products from animal and plant sources.

This topic is as old as the first entrepreneur who wanted to increase plant production by increasing the size of equipment. The approach to scale-up often used in the past relied on geometric similarity, trial and error techniques, and a "make do" philosophy. With the potential for biotechnology, these techniques are no longer adequate, and scale-up has been a research topic of great interest. Biotechnology encourages a closer examination of all the rate-limiting steps, rather than simply adding physical capacity.

Separation Technologies

Frequently the products of biotechnology remain a part of the product itself as in the case of yeast in bread-making or micro-organisms in cheese. In other cases, the product is removed from the micro-organism or reaction medium by a series of separation technologies. The separation area of a biotechnology plant may be extensive depending on the product and its intended use. It also depends on whether the product is extracellular or intracellular.

Extracellular products are usually proteins or other organic molecules dissolved in the fermentation broth. They are often present in low concentration, and require an initial concentrating step before purification. Extracellular products also tend to be unstable.

Intracellular products are usually large molecules retained inside the organism. Transfer of nutrients into the cell is either by active or passive transport. Passive transport takes place by simple diffusion or osmosis of the substance through the semipermeable membranes of the cell wall. Active transport is a mechanism whereby a substance that cannot penetrate a cell attaches itself to a carrier that has the ability to penetrate and they both go through the cell membrane.

Cell Disruption. Separation of intracellular products begins with cell disruption resulting in release of the desired product. These types of products have become more important with advances in genetic engineering. There are chemical and mechanical cell disruptions. Chemical methods include alkalai treatment, enzymatic detergent treatment and osmotic shock. Mechanical methods include liquid shear, solid shear and agitation with abrasives.

Of these techniques, only liquid shear and agitation with abrasives have the potential for wide use in industry. The homogenizer has been adapted for liquid shear disruptions and is used in well over half of all large-scale installations. The high-speed bead mill was originally developed by the paint industry for grinding and dispersing pigments and has been adapted for cell disruption in about 10 percent of the large-scale plants. The remaining 30 to 40 percent use a variety of chemical and specialized mechanical methods.

Several factors govern the method of choice for cell disruption including characteristics of the micro-organism (e.g. gram-positive bacteria are normally more resistant to disruption than gram-negative bacteria), location of the desired product within the cell, and sensitivity of the product to heat and shear.

Product Separation—Traditional Methods. Once the cell has been disrupted, the desired product must be separated from the cell debris. Techniques for accomplishing this step rely on methods for separating solids from liquids. Requirements for separation usually fall into four categories: 1) separation of whole cells from fermentation broth; 2) removal of cell debris from a homogenate stream; 3) separation of protein precipitates from a supernatant, and 4) separation of solid absorbent from a supernatant. A supernatant is usually the clear liquid overlying material deposited by settling, precipitation, or centrifugation.

Centrifugation and filtration techniques are the practical separation methods for each of these requirements. Both techniques are strongly influenced by size of the particles to be separated. Most biotechnology centrifuges run batch-wise, and the new machines typically develop 14,000–15,000 times the force of gravity.

Filtration techniques have been used in a wide variety of biological separations, and all rely on pressure differentials to overcome the resistance of the filter and accumulated cake (layer of solids) to the liquid flow through the system. Traditional filtration methods commonly used in bioprocesses include filter presses and various types of rotary drum filters.

The filter press is a batch unit with main advantages of simple operation and low cost. Filter cloth is used to retain the solids while the permeate flows through.

Rotary drum filters are continuous and much more complex than the filter press. The most common version uses a vacuum inside a hollow drum that either rotates in a trough containing the feed materials or has the feed sprayed on top. This technique is used to recover yeast and mycelia from fermentation broths. For bacterial fermentation broths, the filter cloth is usually precoated with filter aid, usually diatomite.

Intensive Research on Membrane Systems. The most rapidly advancing area of filtration technology is in membrane systems—microfiltration, ultrafiltration, and reverse osmosis. Microfilters have the largest pore size and will retain particles as small as 0.1 microns. They will not retain soluble proteins. Ultrafilters can retain soluble proteins with molecular weights as small as a few thousand.

Reverse osmosis, often referred to as hyperfiltration, is the highest level of filtration. It retains not only soluble proteins but also dissolved salts and small organic molecules.

Electrodialysis is a membrane process that could see increased application in bioprocessing. The process employs semipermeable ion-exchange membranes that are impervious to water. The separation is electrically driven in contrast to filtration which is pressure driven.

Of the three types of membrane separation processes, ultrafiltration is experiencing the most intensive research and will have the most far reaching impact on biotechnology. Diafiltration, an alternative method of operating ultrafiltration processes, also is of interest. In diafiltration, a solvent, usually water, is added to the feed to wash out contaminants not retained by the membrane.

A severe limitation in application of membrane processes is membrane fouling. Membrane fouling results in a loss of membrane permeability and can arise from a variety of conditions. This is an area of active current research.

Purification Operations

Protein precipitation is one of the oldest methods of recovering and purifying proteins. A wide variety of precipitation methods have been developed, based on adjusting system temperature, ionic strength, acidity, and dielectric constant. These techniques have been used successfully on a large scale to concentrate proteins but are not particularly effective for separating one protein from another.

Purification of biotechnological products is most commonly done using chromotography techniques. Separation and purification are based on molecular properties such as size, net ionic charge, shape or polarity. Chromatography is normally carried out in packed columns where the nature of the selected packing determines which molecular property forms the basis of the purification. Currently, high performance liquid chromatography is receiving considerable attention as a highly efficient, cost-effective method for commercial purification of biotechnological products.

The Future of Biotechnology in Food Processing

Susan K. Harlander, *assistant professor, Department of Food Science and Nutrition, University of Minnesota, St. Paul, and* Richard G. Garner, *food scientist, Cooperative State Research Service*

By the year 2000 the worldwide market for biotechnology-derived food and agricultural products could be valued at tens to hundreds of billions of dollars. The results of the rapid pace of biological research since 1970 indicate that we are only scratching the surface of the potential.

We define biotechnology broadly, as the use of biological systems, including micro-organisms or components produced by micro-organisms, in industrial processes. Micro-organisms have been used in food preparation for centuries to preserve and transform raw agricultural commodities into edible products for human consumption.

Fermentation of milk, meat and fish, fruits and vegetables, and cereal grains by micro-organisms creates products which contribute to the flavor, texture and keeping quality of food, suppress the growth of disease and spoilage organisms, and enhance the nutritional quality of the final product. Fermentation is the use of enzymes produced by micro-organisms to change an organic compound into other substances such as carbon dioxide and alcohol. Fermentation technology also has been used for the microbial production of enzymes, amino acids, vitamins, and a host of other components used as food ingredients, nutritive supplements, and food processing aids.

In essence, the food processing industry was practicing biotechnology long before it was recognized as a distinct and revolutionary scientific discipline.

One facet of biotechnology of particular application in the food industry is genetic engineering. This technique is used in the laboratory to alter the genetic material of living cells so that they can produce more or different chemicals or perform new functions. It will have a profound impact on agriculture and traditional food processing because of the tremendous potential for genetic improvement of plants, animals and micro-organisms.

The interface between biotechnology and food processing was explored

Forecasts on Size of Worldwide Market for Biotechnology Agriculture and Food Processing Products

Source	Year	$ (in millions)
Arthur D. Little	1990	2,000–4,000
Business Communications Co.	1990	430
Policy Research Corp.	2000	50,000–100,000
Predicasts, Inc.	1985	6,200
	1995	101,000
Strategic, Inc.	1990	4,500
	2000	9,500
T.A. Sheets & Company	2000	21,300

in October 1985 at an International Symposium, *Biotechnology in the Food Processing Industry*, cosponsored by the Department of Food Science and Nutrition and the Agricultural Experiment Station at the University of Minnesota, and the Cooperative State Research Service of the U.S. Department of Agriculture (USDA).

Now let us focus on the manipulation of micro-organisms in the production of food additives and processing aids, and their role in the development of value-added technology, improved processing methods, and more efficient use of food processing wastes. Many examples are from the symposium proceedings.

Food Additives and Processing Aids

Some of the products, including enzymes, amino acids, vitamins, organic acids, and certain complex carbohydrates and flavoring agents used in food formulation are currently produced by microbial fermentation. In the future, biotechnology will be used to design micro-organisms capable of producing these high-value additives more efficiently and cost effectively. In addition, advances in large-scale fermentation systems and bioprocess design will optimize recovery and downstream processing of microbial products. All of these will have a profound impact on the food industry.

Some food ingredients are extracted from plant material or synthesized chemically (i.e., gums, flavors, pigments). In the future it will be possible to transfer the genetic ability of the plant to synthesize certain flavors, pigments or complex carbohydrates into food-grade micro-organisms. This transfer will allow commercial production of these high-value food additives via fermentation processes.

Biotechnology Products for the Food Industry

Product	Use
Enzymes	
amylase	High fructose corn syrup
isomerase	
rennet	Cheesemaking
proteases	Meat tenderizer
pullulanase	"Lite" beer
Organic acids	
citric acid,	Acidulant
benzoic, propionic acid	Food preservative
Amino acids	
methionine, lysine, tryptophan	Nutritional supplement
aspartic acid, phenylalanine	Aspartame production
Vitamins	Nutritional supplement
Low calorie products	
aspartame, thaumatin, monellin	Non-nutritive sweeteners
modified fatty acids and triglycerides	Food additives and cooking oil
Microbial polysaccharides	Stabilizers, thickeners, gelling agents
Flavors and pigments	Flavoring and coloring agents
Single cell protein	Animal and human food supplement

Enzymes. The food processing industry is currently the largest consumer of industrial enzymes, making up about 40 percent of a $400 million market. An enzyme is a complex protein produced by living cells that helps a chemical reaction along without itself being changed. Enzymes are added during food processing to control texture or appearance, enhance nutritive value, and generate desirable flavors and aromas.

Future application of biotechnology will involve enzyme engineering—changing the primary structure of an enzyme. Such changes may alter target specificity, acidic condition, or thermostability. Enzyme engineering can be used to "tailor-make" enzymes to function best in commercial food processing systems.

Immobilized enzyme technologies have been developed for the production of high fructose corn syrup, and will have broad application in processing other foods. Immobilization of an enzyme increases its stability, allows easy separation of the product from the enzyme, and so facilitates its recycling.

In the future, immobilized enzymes will replace batch fermentations for producing amino acids, aspartic acid and tryptophan, and the non-nutritive sweetener, aspartame. Immobilization of rennet, the enzyme that coagulates milk during cheesemaking, or lactase, the enzyme which cleaves lactose to glucose and galactose, could speed the development of innovative continuous processing methods in the dairy fermentation industry.

Low Calorie Foods. The current trend toward a more health- and nutrition-conscious lifestyle has encouraged the development of low calorie foods. The non-nutritive sweetener market has been predicted to reach $500 million by the year 2000.

A new class of compounds called taste-active proteins functions as sweeteners and flavor modifiers and includes compounds such as aspartame, thaumatin, and monellin. The gene which codes for the protein thaumatin has been isolated and characterized. Transfer of this gene into bacteria would allow the production of thaumatin via fermentation. If engineered into plants, new and unique foods could be developed.

Another application of biotechnology in low calorie food production is the development of low calorie fats and oils. Genetically inducing the production of shorter chain fatty acids in soybean or rapeseed would speed the development of a low calorie vegetable oil. The market for this oil could reach $2 billion a year by the end of the next decade.

Natural Food Products. Another consumer trend is the demand for natural food products. Natural flavors and colors elicit a higher price than their synthetic counterparts, as the supply of these natural additives is highly dependent upon favorable environmental conditions for growing the plant and efficient and safe extraction procedures. Numerous strains of bacteria, yeast, and mold can produce flavors and colors of interest to the food processing industry. An understanding of the metabolic pathways and the specific proteins and enzymes responsible for the synthesis of these compounds will allow the future development of more consistent and cost-effective production methods.

Value-added Technology and Waste Management

A major concern in the food processing industry is the development of methods to convert inedible plant materials and waste materials into new value-added products. Each year the cheese industry generates billions of pounds of whey that must be disposed of. Ultrafiltration has provided the cheesemaker with a means of concentrating the protein component of whey into a value-added item with significant dollar value. Some solids, however, have a negative market value because it costs money to get rid of them.

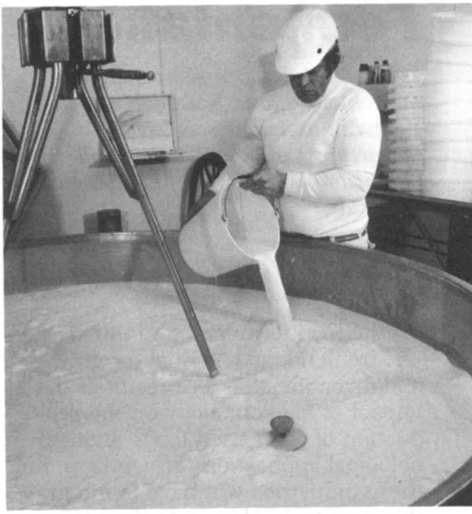
A recently developed bioconversion system employing selected strains of yeast can convert these solids to ascorbic acid with a market value of about $10 per kilogram.

Certain strains of yeast can produce terpenes which impart a characteristic grape aroma and the odor of oils of interest in the wine and food industries. Because these strains use the lactose in whey as a sole carbon source, they could be used in fermentation systems to produce flavor components. The yeast biomass could be dried and used as single-cell protein supplements in animal feed.

Enzymatic treatment of food processing waste streams could produce materials readily metabolized by micro-organisms genetically engineered to produce antibiotics, hormones, or peptides of interest in the pharmaceutical or chemical industries. In the future, environmental and economic concerns will necessitate a reduction of food processing waste, better use of raw materials, and the processing of food residuals to new products that have value.

Rapid Detection Methods

Ensuring the safety of our food supply is an integral part of the food processing industry. Classical microbiological techniques for the enumeration and identification of disease agents and their toxins in foods are not always reliable and are often slow. Foods can already be in the marketplace before results are available. Biotechnology has been used to develop sensitive, reliable, and rapid detection methods to expedite this process.



John Caldwell, Grant Heilman Photography

Cheese plant worker adds rennett to milk; immobilization of rennett could improve cheesemaking methods.

One method involves DNA—deoxyribonucleic acid, the molecular basis of heredity in many organisms. Specific fragments of DNA from disease-causing micro-organisms that code for toxins or virulence factors have been used to create DNA probes which in hybridization analyses can detect those organisms in foods.

Commercial test kits for the detection of *Salmonella* are available and currrently being tested in field trials.

The identification of antigens by using monoclonal antibodies (see other articles in this yearbook) is another valuable tool in the biological monitoring of food. Monoclonal antibodies have been used to detect disease-causing micro-organisms, and they also help detect nonmicrobial components of food.

In the future, bioassays employing DNA probes and monoclonal antibodies will be developed for a host of food-borne disease agents and become a powerful diagnostic tool for the food processing industry.

Fermentations

Larry L. McKay, *professor of food microbiology, and* Kathleen A. Baldwin, *assistant scientist, Department of Food Science and Nutrition, University of Minnesota, St. Paul*

The food fermentation industry has tremendous potential for growth and diversification as a result of the impact of biotechnology on the production of fermented foods. Biotechnological applications are endless, but these industries will have to integrate this new technology into their long-term goals. The impact of biotechnology on the industry will depend, in part, on advances in genetically manipulating the micro-organisms involved in producing fermented foods.

Fermentations

The use of micro-organisms in food fermentations is a significant phase of food production. (In fermentation, an enzyme is used to change an organic compound into other substances such as carbon dioxide and alcohol.) Micro-organisms are directly involved in the successful outcome of numerous food production processes such as brewing, baking, sausage manufacture, fermentation of vegetable material for sauerkraut and pickles, the manufacture of fermented dairy products, and numerous other fermented foods.

In recent years, plasmid biology has become an exciting area of research with respect to those bacteria in dairy, meat, and vegetable fermentation processes as well as those used for silage and for health benefits.

Plasmids can be defined as small, circular pieces of DNA which exist in the bacteria cell and maintain themselves separate from the chromosome. Certain metabolic properties vital for successful dairy fermentations are determined by genes carried on these plasmids. Examples would be the ability to use milk sugar (lactose), to degrade milk protein (casein), to produce butter aroma, to produce antagonistic substances against disease-causing and spoilage bacteria, as well as to resist attack by bacterial viruses.

Genetic Technology

Recent advances in genetic research have received considerable publicity, and companies based on this new technology are springing up worldwide. Prospects are good for major advances in food fermentation technology through the cloning of desirable genes in food fermenting bacteria, yeasts, and molds. The techniques used are highly sophisticated and include a process of enzyme surgery (wherein the genes to be cloned are inserted) into vector DNA, usually a plasmid, which, in turn, is introduced into a host micro-organism to propagate new genes. To apply this concept to food fermentation organisms, we need an indepth understanding of the molecular biology, metabolism, and plasmid biology of these bacteria.

Acquiring New Strains

The potential of a given micro-organism is determined by the nature of the genetic material contained in the individual cells. Access to the large number of possible variations in the expression of the genetic material can be made by several approaches. The first is the isolation and selection of strains from sources in nature—the primary method for selecting strains for food fermentations since the turn of the century. The second is the artificial mutation of the genetic material of existing strains followed by selection of desired mutants.

The most exciting possibility for obtaining new strains for food fermentation processes is the use of recombinant DNA technology to construct an organism for a specific process.

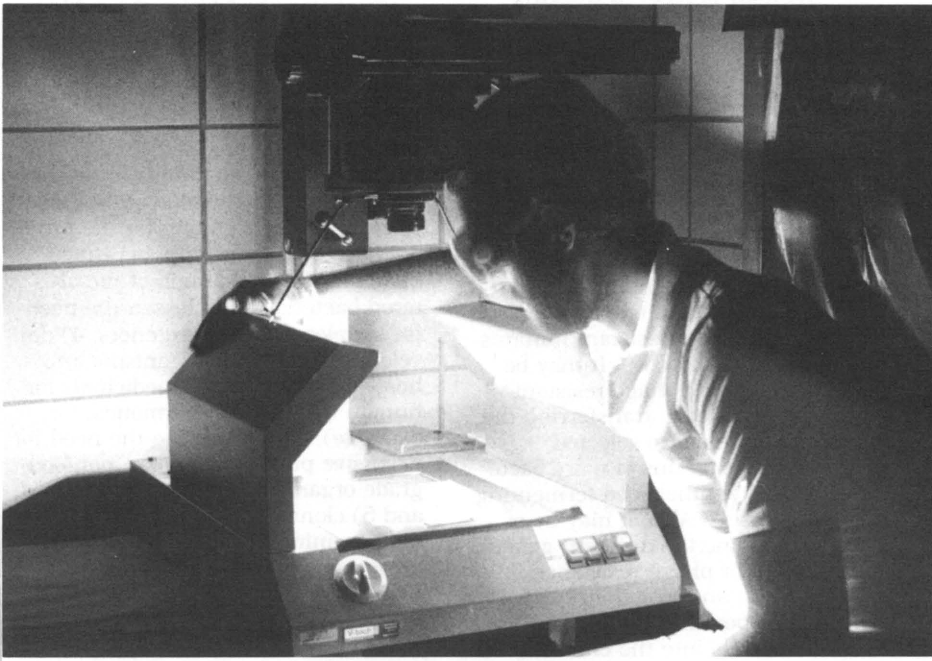
Accelerated Cheese Ripening

The application of genetic engineering techniques, including recombinant DNA technology, to micro-organisms used in food fermentations could improve fermentation efficiency, flavor, texture, nutritive value, or appearance of the final product. Such applications could enhance consumer acceptance or provide economic savings to the manufacturer.

One example would be the ripening of Cheddar cheese in which a storage period of 6 to 12 months is required. Reducing this ripening period, which constitutes a major proportion of the total processing cost of cheese, has long been a goal of the cheese industry. Since milk protein degradation may be involved in cheese ripening and since some of the enzymes used are linked to plasmid DNA, the genes for different enzymes could be exchanged between strains, and the level of their activity controlled through genetic engineering techniques. The manipulation of existing bacterial enzymes or the introduction of new ones from nondairy sources could lead to strains capable of accelerating the ripening of cheese.

Antagonistic Properties

The ability of many food-fermenting micro-organisms to produce antagonistic compounds other than organic acids is well documented. The linkage of the ability to produce some of



An ultraviolet system detects plasmid DNA molecules that control characteristics such as butter aroma or acid production in dairy product fermentation.

these antagonistic compounds to plasmid DNA may lead to the construction of "super"-antagonistic-compound-producing derivatives through the manipulation of existing genes. Such strains may have considerable commercial value. In addition, the ability to transfer the genetic factors controlling inhibitory substance production to other desirable bacteria may ultimately lead to construction of strains with enhanced antagonistic properties against food spoilage organisms and food-borne pathogens. Such strains could extend the shelf life of fermented dairy products as well as other food items.

Bacteriophage Sensitivity

A major microbiological problem facing the dairy fermentation industry is the presence of bacteriophage—viruses normally present in the environment. The isolation and use of phage-resistant mutants as a means of circumventing the problem is now well accepted by the dairy industry. Evidence associating plasmids with phage resistance in dairy bacteria is increasing. Recent developments provide a genetic mechanism to explain the rapid appearance of phage-sensitive dairy bacteria. The manipulation of these plasmids by genetic engineering techniques is one approach for obtaining phage-resistant mutants for commercial purposes. It may be possible to develop phage-resistant strains by genetically transferring the appropriate plasmid to selected phage-sensitive strains of dairy bacteria as well as to other food-fermenting micro-organisms. Also, it may be of value to combine the different genetic components for phage resistance into a single strain and to stabilize the trait by incorporating the phage-resistance genes into the chromosome or into a plasmid present in high numbers in the cell.

Commercial Culture Preparation

Further efforts in applying genetics to dairy bacteria could be helpful in developing strains more suitable for mass-culturing techniques, in obtaining a large number of strains for use in preparing frozen culture concentrates, or in developing strains for use as freeze-dried or spray-dried culture concentrates.

Additional Applications

The development of efficient gene transfer systems in food-fermenting micro-organisms will open new avenues of investigation for the study of gene expression, gene regulation, and plasmid development in these organisms. Some of the more realistic and potentially beneficial applications include: 1) developing naturally produced flavor compounds (pineapple, citrus, grape-like, peach, banana) through the isolation of the responsible genes and transfer of the genes to yogurt bacteria, 2) developing strains capable of converting whey into a marketable end-product through flavor and texture alterations or by conversion into a high value end-product, 3) cloning genes coding for the production of proteins with sweetness qualities so that addition of the altered bacteria would lessen the need for supplementary sweeteners, 4) developing food-grade organisms into hosts used to produce medicinals for human use (growth hormones, for example), circumventing the need for extensive purification when nonfood-grade organisms are used as the host, and 5) cloning genes beneficial to human or animal health, including enzymes and nutritive additives.

Fermentation of Lactose

Lactose is not digested well by a large proportion of the world's population and has low solubility in water, which leads to problems in concentrating whey and in preparation of certain foods. When compared to sucrose, lactose has a relatively low level of sweetness. These problems can be overcome, to a large extent, by breaking down lactose to its simple sugars which are more digestible, sweeter, and more soluble.

The enzyme, β-galactosidase, breaks down lactose to glucose and galactose. Genetic engineering techniques could be used to improve the ability of food-grade organisms to ferment lactose as well as to construct strains which produce greater quantities of the enzyme β-galactosidase, to be used commercially.

Sausage Manufacture

The manufacture of fermented sausage also depends on the proper activity of lactic acid bacteria. The rapid production of lactic acid and resulting increase in acidity is responsible for the characteristic flavor and texture of sausage and, more importantly, the inhibition of spoilage and disease-producing micro-organisms. The genus *Lactobacillus* is one of the primary groups of bacteria used in cured and fermented meats. An understanding of the physiology and genetics of the micro-organisms involved is necessary before developing strains for use as starter cultures. Recent advances in biotechnology have stimulated interest in applying these principles to construct new strains or improve existing strains for sausage manufacture.

Fermentations Using Yeasts

Attempts also are being made to improve the genetic makeup of yeasts in brewing and winemaking, as well as in the baking industry. In brewing, the genetic manipulation of yeast cells has improved their ability to ferment carbohydrates, giving rise to "Lite" beer which is distinguished by its lower carbohydrate level. The mutation of yeasts for winemaking has resulted in strains with increased alcohol tolerance and strains with improved sedimentation properties necessary for facilitating separation of yeasts from wine.

The baking industry also is undergoing technological changes, and yeasts with new properties are now needed for faster fermentation of the dough. These new yeasts with improved biological properties would allow improvements in the baking industry.

Starch Hydrolysis

Strains of lactic acid bacteria that produce the enzyme amylase have recently been reported. These starch-hydrolyzing strains could be essential in improving fermentations, especially in Third World countries, where starch is the primary carbohydrate source. Studies on the genetics and plasmid biology of these strains is urgently needed to improve strains for use in many food fermentation processes throughout the world.

Lactic acid bacterial fermentations also are being extended to nontraditional raw materials for production of animal or human food. These efforts need to continue as they may lead to ways of converting waste material into edible food sources.

In addition, the traditional fermented foods and beverage products produced throughout the world must be studied in detail with respect to the micro-organisms and biochemical changes involved. It is anticipated that these traditional fermented foods will play an increasingly important role in the food supply of Third World and industrialized countries as population levels continue to increase.

Soil Microbes Could Help Clean the Environment

Philip C. Kearney, *research leader, Pesticide Degradation Laboratory, Beltsville Agricultural Research Center, Agricultural Research Service*

Pesticides, nitrites, and soluble salts are all potential ground-water pollutants if not properly managed. Two major sources of ground-water pollution result from the extensive use of these materials.

The first source results from the downward movement of pesticides out of the root zone and through the vadose zone (the area below the root zone and above the water table), eventually moving into ground water. This problem results from the normal use of agricultural pesticides.

A second major source of ground-water pollution results from disposal of pesticide wastewater in unlined soil pits or from any form of ground disposal in an uncontained area.

One of our first needs, therefore, is to identify the contributions that each source makes toward the ground-water problems and take appropriate technological or regulatory actions to alleviate it.

In 1986, trace amounts of 23 different pesticides were detected in ground-water samples from 16 different States. This number probably will increase as further monitoring studies are begun and completed.

Micro-organisms in Cleanup

Soil micro-organisms help to prevent extensive movement of the intact pesticide out of the root zone. But microbes are not infallible; some compounds are not readily degraded because of environmental factors or lack of appropriate genes or enzymes. If carefully manipulated, selected, and engineered, however, micro-organisms could play a major role in solving many waste disposal problems.

Over the past four decades, we have made significant progress in identifying the soil micro-organisms responsible for metabolizing many of the organic pesticides, the microbial enzymes responsible for separating specific bonds in the molecule, and the products resulting from these metabolic reactions. Moreover, with the advent of modern molecular biology, we are beginning to understand the role of DNA in directing the synthesis of specific degradative enzymes.

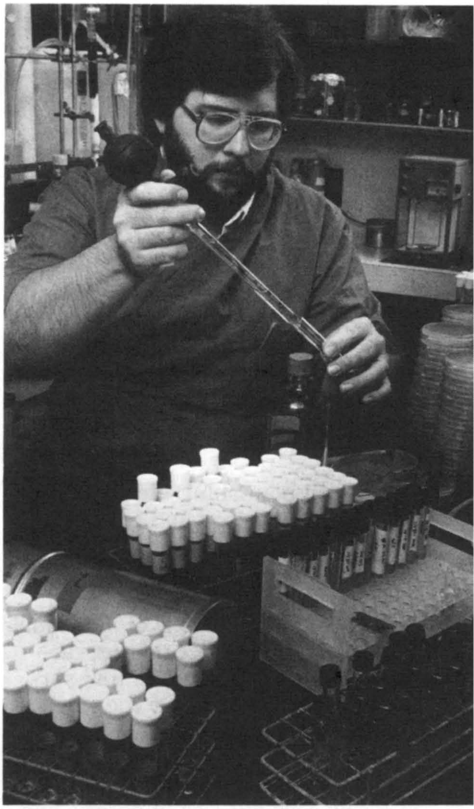
A particular type of DNA, termed a plasmid, has been associated with the metabolism of several specific pesticides. These circular DNA elements are much smaller than the cell's chromosome and carry specialized genetic information for specific biodegradation genes that may not be present on the chromosome genes. Plasmids can replicate independently within the cell but cannot exist outside it. They also can move from cell to cell in certain microbial communities and transfer these genes to other micro-organisms.

Plasmids have been isolated and characterized for the initial metabolic reactions associated with the herbicides 2,4-D and MCPA, the herbicides dalapon and TCA, and the insecticides parathion, diazinon, and coumaphos. New discoveries of pesticide-degrading genes will increase rapidly over the next two decades as we learn more about DNA in the diverse soil microbial flora.

The ability to manipulate these genes and move them into micro-organisms more readily adaptable to the conditions that often make waste disposal difficult holds considerable promise for solving some potential pollution problems.

A Unique Cleanup Situation

The U.S. Department of Agriculture's Animal and Plant Health Inspection Service conducts a tick control program along the U.S.-Mexican border. Cattle are dipped in large vats containing about 3,000 gallons of the tick control compound, coumaphos. About 42 of these vats are refilled with formulated coumaphos annually, so a large amount of pesticide wastewater is generated that must be degraded. Normal soil micro-organisms degrade coumaphos too slowly to be useful. Some classical chemical methods of pesticide disposal also did not provide a simple solution to the problem. But inoculating a very active *Flavobacterium* sp., known to degrade parathion rapidly, directly into the cattle dip solution resulted in a complete loss of coumaphos in several hours. When a field trial was conducted at Laredo, Texas, headquarters for the Tick Eradication Program, 680 gallons of used coumaphos solution were destroyed within 48 hours. The enzyme responsible is parathion hydrolase.



Fred Witte, ARS

Microbiologist studies bacteria that degrade pesticides at the ARS Pesticide Degradation Lab. Researchers have found a way to make it easier for soil microbes to detoxify hazardous wastes.

Future Research

Considerable attention is now being focused on the *opd* gene in the *Flavobacterium* sp. that is responsible for producing parathion hydrolase. Working independently, scientists at the Agricultural Research Service and the University of Texas have isolated and described the gene responsible for the synthesis of parathion hydrolase. What is even more fascinating is that although the two groups worked with different micro-organisms of diverse origin, the gene appears to be the same.

The gene also has been transferred successfully to other bacteria by using cloning vector plasmids as shuttles for moving the gene. The possibility exists, therefore, to move this valuable gene into micro-organisms better adapted to the dip vat environment.

In a larger context, it may be advantageous to move this and other pesticide degradative genes into a variety of soil micro-organisms to clean up existing problems and prevent future pollution of our natural resources.

Biotechnology and Soilborne Plant Diseases

George C. Papavizas, *plant pathologist, and* Joyce E. Loper, *microbiologist, Soilborne Diseases Laboratory, Plant Protection Institute, Beltsville Agricultural Research Center, Agricultural Research Service*

The soil nourishing the crops that provide our food and fiber is a complex environment where microbes live in numbers estimated to reach 2 billion per ounce of soil.

Millions upon millions of individual bacteria and fungi live on root surfaces and the soil particles that surround them. Bacteria are the smallest and the most abundant. The fungi, usually larger than bacteria, are found throughout the world, not only in fertile soils but also in deserts and drylands, in polar lands and mountain highlands, and in forests and marshes.

Beneficial Soil Microbes

Great numbers of soil microbes are beneficial to humans and other animals, and to cultivated plants. They convert atmospheric nitrogen, which plants cannot use, to ammonia or other useful nitrogenous compounds in small nodules on the roots of legumes such as peas, beans, soybeans, and clovers; oxidize chemicals and assist plants in absorbing nutrients and trace elements such as iron, cobalt, manganese, and molybdenum from soil; and decompose plant and animal organic matter into simpler organic products that plants can absorb and use to sustain their growth. Soil microbes also help to form and maintain arable soils rich in complex organic materials through which roots easily grow and absorb water and nutrients. Were it not for microbial activity to transform organic matter released by living animals, plants, and microbial cells and dead organisms, nutrients for plants would be locked away from them in large, unmanageable piles.

Harmful Soil Microbes

Harmful molds and other soil fungi are responsible for many serious root diseases and aboveground diseases of plants. No major economic crop escapes damage from soilborne fungi and bacteria. Root rots, collar rots, wilts, seed decay, seedling blights, fruit rots, root browning, and damping-off take a heavy toll year after year. More than 50 percent of the total estimated annual losses of economic crops due to all plant diseases, or about $4 billion annually in the United States alone, are caused by soilborne diseases.

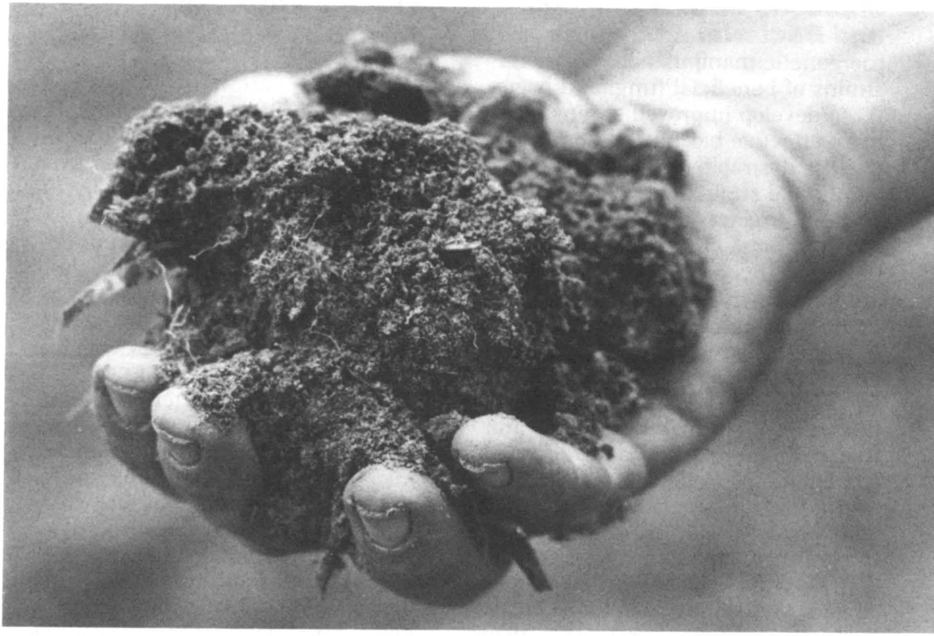
Many plant diseases caused by soilborne plant pathogens (disease-causing organisms) are difficult to control by conventional procedures. Plants with resistance to most diseases caused by harmful soilborne microbes have not yet been developed by scientists. Growers currently depend on pesticides to fight some soilborne diseases. Aside from the environmental damage caused by many pesticides and public pressure not to use them, some of them are expensive, difficult to apply, or not completely effective against soilborne pathogens. Moreover, pesticides may indiscriminately kill both harmful and helpful soil microbes or present a health risk to humans and animals. Cultural control methods such as crop rotation may affect soilborne diseases very little since the pathogens that cause them attack a wide range of crops and can live in soil for a long time.

Biological Control Using Soil Microbes

Fortunately for our crops and soil environment, every ounce of soil harbors numerous species of microbes, including many of the plant pathogens' natural enemies. These natural enemies, which include bacteria and fungi, could be exploited to reduce or curb the diseases caused by plant pathogens. This method of controlling plant diseases biologically is gaining in stature as a feasible technology of the future.

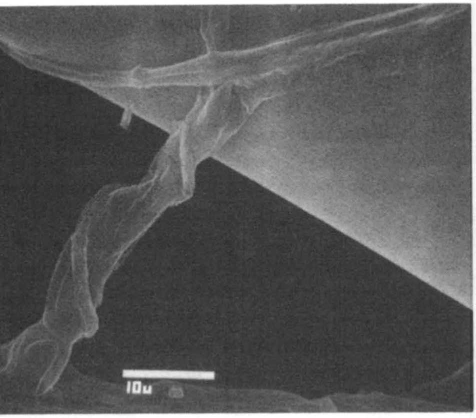
The concept and practice of biological control, or biocontrol, can be advanced not only by discovering and using new disease-fighting microbes, but also by improving their effectiveness with conventional genetics and modern biotechnological approaches such as genetic engineering, and by improving production and delivery systems.

New Strains of Biocontrol Microbes. *Trichoderma* spp. and *Talaromyces flavus* are otherwise harmless soil fungi that attack certain soilborne plant pathogens, reducing plant disease. We developed several new strains of these biocontrol fungi by mutating natural strains with chemicals and ultraviolet light. Some of the new strains tolerate high concentrations of benomyl, a fungicide commonly used by farmers to control soilborne diseases. Some of the new strains also have other desirable characteristics such as increased ability to curb diseases, good survivability in soil, and prolonged shelf life. The combined use of biocontrol microbes with low dosages of pesticides may be an effective integrated control method until purely biological methods are



Murray Lemmon, USDA

Soil microbes help transform organic matter into a form useful to plants.



Jack Lewis, USDA

The thread-like hypha of the beneficial fungus Gliocladium virens *coils around and destroys the* Rhizoctonia solani, *a soilborne pathogen that attacks more than 200 plant species (magnified 2,000 times).*

found. New pesticide-tolerant strains are well suited to be used in combination with various soil pesticides.

Improved Strains of Fungi and Bacteria. Another approach is the genetic manipulation of various strains of beneficial fungi and bacteria to develop improved strains for more effective biocontrol. For example, the desirable characteristics of two fungal strains may be combined by the introduction of DNA from one strain into the other. Spores or the threadlike hyphae of beneficial fungi are treated with enzymes that degrade their cell walls, resulting in protoplasts—individual cells that no longer have cell walls. Protoplasts of two strains with desirable characteristics are brought together to fuse and then examined to find new desirable combinations. Protoplasts also are useful for transformation, a process in which isolated DNA is introduced into a fungal cell.

In the future, genes involved in biological control may be cloned and introduced into fungal protoplasts using transformation procedures. Although application of these techniques to biocontrol fungi may be difficult, their successful use with other fungi justifies considerable optimism for future success.

The tools for the genetic manipulation of bacteria are more developed than those for fungi. These tools, most highly refined for the bacterium *Escherichia coli*, also have been applied to the study of bacterial strains with biocontrol activity against various soilborne and foliar plant pathogens. These biocontrol bacteria represent several taxonomic groups. DNA can be isolated from these bacteria, and specific DNA fragments can be cloned and reintroduced into bacterial cells.

New, improved bacterial strains, with increased abilities to establish large populations on plant roots or with greater antagonism against plant pathogens, may be developed using recombinant DNA techniques.

How Beneficial Microbes Bring About Biological Control

Scientists believe that beneficial fungi and bacteria reduce or curb root injuries and other diseases caused by soilborne plant pathogens either by 1) directly parasitizing the pathogen, eventually curbing its action or destroying it; 2) competing with the pathogen for nutrients or space; or 3) producing enzymes or other substances such as antibiotics which injure the pathogen.

Because of the lack of precise information on the mechanisms of biocontrol action of most of the beneficial microbes, it is difficult to pursue cloning and recombinant DNA research to engineer biocontrol microbes with enhanced biocontrol characteristics, or to produce virulent genes against plant pathogens. If we knew, for instance, that *Trichoderma* breaks down the cell walls of pathogenic fungi with a specific enzyme or destroys a pathogen with a specific antibiotic, we could identify the genes that encode for production of the enzyme or antibiotic. The genetic information could then be transferred to a vector (a transporting agent) and then used to transform protoplasts of strains that possess other desirable characteristics such as tolerance to pesticides, ability to survive in soil, and long shelf life. Research is under way to identify substances produced by biocontrol fungi that may be directly related to their biocontrol action. An antifungal substance produced by the biocontrol fungus *Talaromyces flavus* has already been isolated. This substance appears to be curbing the pathogenic action of *Verticillium dahliae,* one of the world's worst crop pests.

Identifying Biocontrol Mechanisms

The most immediate contribution of biotechnology to biological control is the identification of mechanisms involved in the antagonism of beneficial microbes at the soil-root interface. Scientists can now use a system of single-site mutations and compare biocontrol activity of parent and mutant strains to determine the importance of a single genetic change.

A single-site mutation inactivating antagonism will produce a mutant strain differing from its parent by altering a single gene. The antagonism of this mutant can be compared with that of the parent strain at the soil-root interface, confirming or discounting the importance of this gene in biocontrol. If the mutant is less effective than the parent in biocontrol, the genes can be cloned from the wild type and reintroduced into the mutant, restoring its antagonistic activity, or it can be moved into other strains. Several antifungal compounds have been identified with this type of genetic study.

Other areas of biotechnology provide equally powerful approaches for understanding biocontrol mechanisms. For example, monoclonal antibodies offer a new tool for specifically detecting the presence of antibiotics produced by biocontrol organisms at the soil-root interface.

Understanding the precise mechanisms by which biocontrol agents function in a soil environment is prerequisite to further genetic studies enhancing biocontrol activity. Biotechnology offers promise for identification of the specific genes involved in biocontrol.

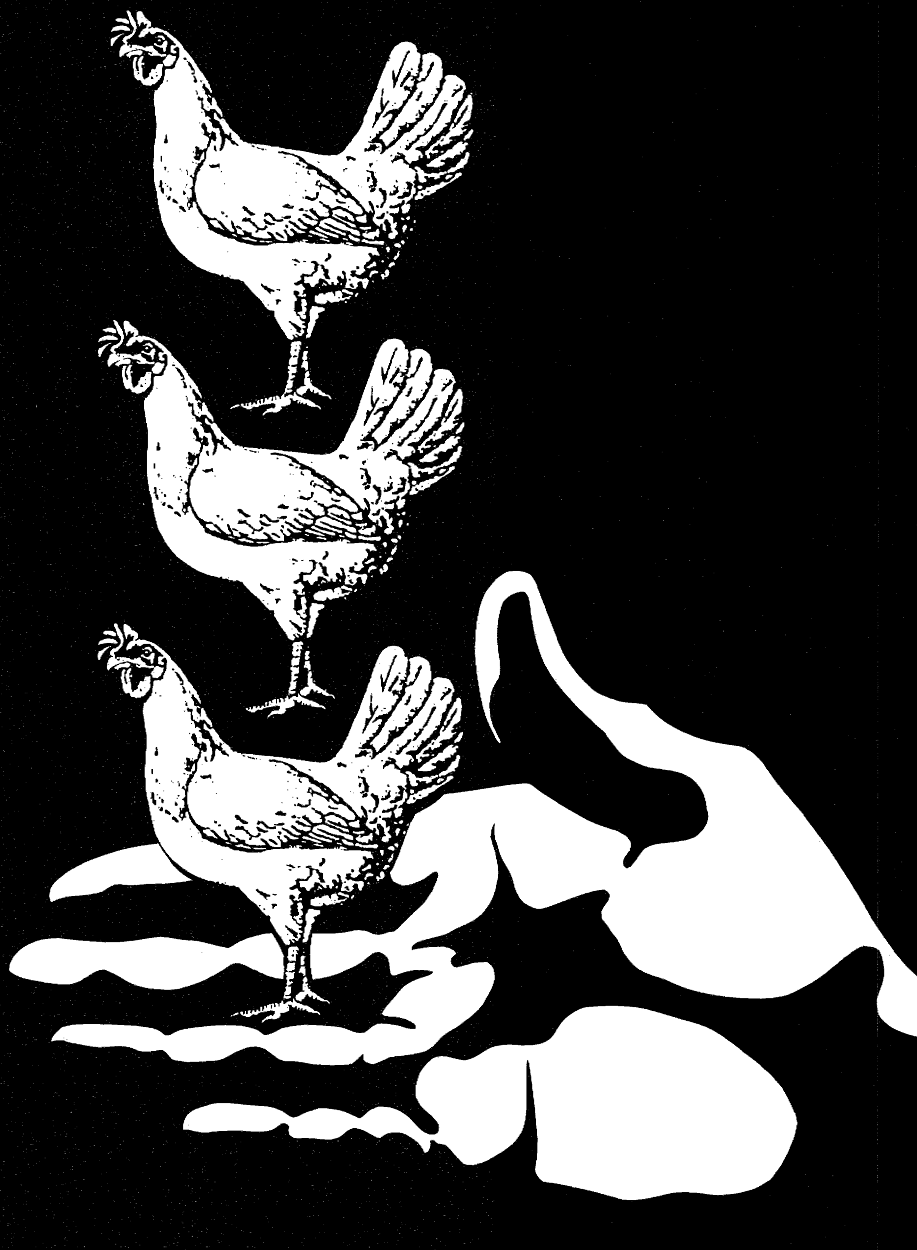
Production and Delivery Systems

The last 30 to 40 years have seen considerable progress in fungal technology for the large-scale production of industrial products. Similar technology for biocontrol microbes is not well developed. If widespread control is to be achieved with beneficial microbes, inexpensive fermentation technology must be developed to mass-produce them.

Recently, we have developed in the Beltsville laboratory deep-tank fermentation for biomass production of biocontrol microbes simulating large-scale industrial production. In contrast to solid fermentation, deep-tank fermentation is the technological approach most likely to be useful in biocontrol.

A recent development in delivery technology that may revolutionize the way to apply biocontrol microbes in the field for control of soilborne plant pathogens involves encapsulation of bacterial cells, fungal spores, or mycelium of beneficial microbes. Scientists are incorporating various biocontrol microbes into alginate pellets or other seed or soil treatments that are compatible with conventional agricultural practices.

IV
Biotechnology: Its Application to Animals



Biotechnology in Animal Reproduction

George E. Seidel, Jr., *professor of physiology and biophysics, Animal Reproduction Laboratory, Colorado State University, Fort Collins*

Gametes, Embryos, and Fetuses

Animals pass on their genetic characteristics to the next generation via cells called gametes, sperm for the male and eggs or oocytes for the female. An embryo is formed when an oocyte is fertilized by a sperm, and development of a new animal begins.

About every 20 hours, embryonic cells duplicate their genes and divide, progressing through the 2-, 4-, 8-, and 16-cell stages, etc. The embryo floats freely in the lumen of the female reproductive tract for the first 1 to 4 weeks depending on the species, and then it attaches to the lining of the uterus, a process called implantation. The embryo is termed a fetus when recognizable organs form such as the brain and heart.

The sperm, the oocyte before fertilization, and the embryo before implantation all can be removed from the reproductive tract for various biotechnological purposes without damaging them. This has led to the development of such techniques as artificial insemination, in vitro (outside the body) fertilization, and embryo transfer, which is the replacement of the embryo into the female reproductive tract for gestation to term.

Availability of Gametes and Embryos

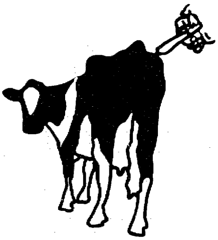
Nature has gone to great lengths to insure that animals reproduce. For example, each male of most farm animal species produces trillions of sperm each year, yet under natural conditions sires only a few dozen offspring per year. Fertilization of each ovum requires only one sperm. Female farm animals usually produce a few offspring (with swine a few litters) in their lifetime, yet their ovaries contain hundreds of thousands of oocytes. The unused oocytes degenerate within the ovaries at a rate of several dozen each day.

One major principle of biotechnology is to take advantage of the huge numbers of sperm and oocytes from genetically superior animals that ordinarily would be wasted by degeneration of oocytes and loss of sperm in urine.

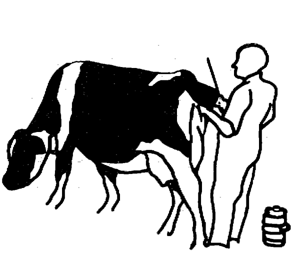
Characteristics of Gametes and Embryos

The oocyte is the largest cell in the body, but a microscope still is required to observe it because it is only 1/200 of an inch in diameter. The sperm is one of the smallest cells in the body, about 1/6000 of an inch in diameter. By the end of the first week of development, the embryo grows to more than 100 cells, but it remains about the same size as the oocyte at fertilization. Thus, the embryonic cells get smaller and smaller during the first cell divisions.

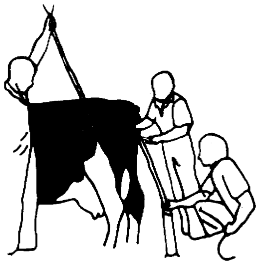
Gametes and embryos are quite resilient to manipulation in vitro provided that a proper environment is maintained. Sperm are kept in vitro for up to several days, and we are slowly learning to keep embryos healthy in vitro throughout the preimplantation period.



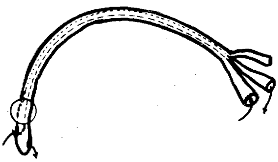
Superovulation of donor with gonadotropins



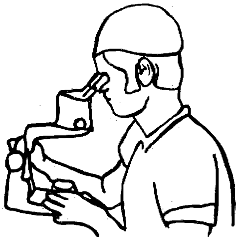
Artificial insemination (5 days after initiating superovulation)



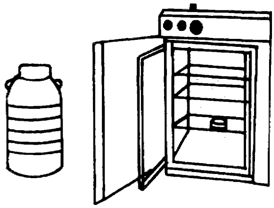
Nonsurgical recovery of embryos (6-8 days after artificial insemination)



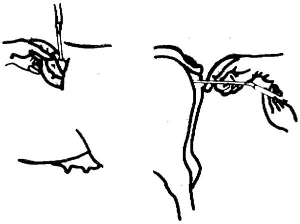
Foley catheter for recovery of embryos



Isolation and classification of embryos

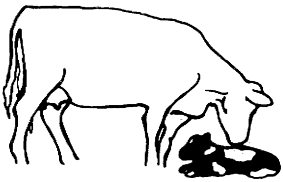


Storage of embryos indefinitely in liquid nitrogen or at 37°C or room temperature for 1 day



Transfer of embryos to recipients surgically or nonsurgically

Pregnancy diagnosis by palpation through the rectal wall 1 - 3 months after embryo transfer



Birth (9 months after embryo transfer)

Colorado State University

Genetically identical twin calves were produced by splitting a single embryo.

Biotechnology Techniques for Gametes and Embryos

Recovery and Transfer. Sperm are collected with a device called an artificial vagina. Depending on the species and other factors, oocytes and embryos are collected and transferred either by minor surgical intervention or by nonsurgical procedures. They are recovered by irrigating the reproductive tract with a medium consisting primarily of salt and water.

Females usually are treated with hormones to cause superovulation, so that more mature oocytes or embryos can be harvested than is normal for the species. Superovulation can be used to amplify reproductive rates of valuable animals because the embryos are transferred to less valuable females for gestation. Embryo transfer is done similarly to artificial insemination; that is, a catheter is inserted into the lumen of the female reproductive tract, and the embryo is expelled in a few drops of medium.

Cryopreservation. One of the most useful biotechnological procedures for both sperm and embryos is cryopreservation. Cooling to the temperature of liquid nitrogen (−320°F) is done in a medium containing chemicals called cryoprotectants. Sperm and embryos can be kept in suspended animation at this temperature for decades, and then thawed, resulting in normal offspring. Storage may be successful at this temperature for hundreds, if not thousands, of years.

Cryopreservation provides great flexibility for various applications. Semen can be stored, eliminating the need to have males in proximity when semen is used. Semen and embryos can be sent from country to country inexpensively.

Strains of animals that are no longer of economic importance can be kept frozen at low cost for a future genetic resource, and animals that have been dead for years can become genetic parents.

Screening for Genetic Disease. Another option with embryos is to examine several cells for genetic characteristics such as sex and chromosomal abnormalities. This is comparable to amniocentesis which is the surgical insertion of a hollow needle through the abdominal wall and into the uterus of a pregnant female to obtain fluid for the determination of the sex of the fetus or chromosomal abnormality. Knowing the sex of the embryo can be useful for commercial as well as experimental purposes.

Splitting embryos. One of the most exciting techniques is the microsurgical division of embryos into two, three, or four groups of cells. This relatively simple procedure frequently results in identical twins, and occasionally in identical triplets or even quadruplets. That this is possible should not be too surprising because identical twins occur quite often in nature—and even identical triplets in rare instances.

Splitting bovine embryos to produce identical twins is fairly simple, and success rates are excellent. Thousands of calves have been produced from split embryos.

The main reason for using this procedure is a commercial one. Pregnancy rates from unsplit embryos frequently are about 65 percent; with split embryos they usually are about 50 percent per half; however, since there are two halves, the net result is 100 percent pregnancy rate on the average, or about one and one-half times as many calves as with unsplit embryos.

Of course, in many cases only one calf is produced after splitting an embryo, and in some cases neither half develops. When both halves result in calves, these identical twins are useful for experimental applications. For example, in certain nutrition studies, about only one-third as many animals are required for valid experiments if identical twins are used.

Cloning. In some respects, dividing embryos to make identical twins, triplets, and so forth is a form of cloning. The resultant animals are genetically identical and, in fact, might be even more identical than offspring produced by transplantation of nuclei into oocytes.

Theoretically, more than four identical copies could be produced by nuclear transplantation, since each cell within the body of an animal has the same genetic material, even though cells of different tissues use different parts of the genetic information available.

In mammals, unfortunately, cloning procedures do not work with nuclei from adult cells, or even advanced embryonic cells. While it should be possible to produce large sets of genetically identical animals eventually, the only practical current method for cloning is dividing embryos.

Gene Injection. Cloning is by no means the ultimate in genetic engineering; it merely results in making a copy of the best animal available.

Some techniques will lead to the production of animals that are better than the best available. One such technique is to inject genes into the 1-cell embryo for characteristics such as resistance to disease and more efficient growth. The advantage of using the 1-cell embryo to introduce new traits is that the embryo duplicates incorporated genes each time the cells divide, and every cell in the resulting fetus has the new genes. Animals produced with genes added in this way are called transgenic animals.

The genes that are injected can come from other animals of the same or a different species. This technology also mimics nature, because genes are constantly being moved around within, and occasionally between, species by some types of virus infection.

Transgenic animals simply represent a more controlled way of moving genes than the random ways of nature. This technology is nothing more than another tool for selective breeding.

Applications of Biotechnology with Gametes and Embryos

Animals have been modified by selective breeding for centuries. One purpose is to develop animals with specialized traits.

Breeds of dogs illustrate this point. Large breeds may be 10 times the size of small breeds; furthermore, dogs come in different personalities, colors, hair styles, and so forth.

In the same way, some cows have been selected for meat production; others for milk. Sheep may be selected for wool characteristics or meat characteristics, or both. Chickens may be selected for efficient egg production or meat production. Those selected for both turn out to be relatively inefficient.

Biotechnological techniques enable changing characteristics of farm animals more rapidly than with earlier methods. The objective is to produce healthier, more efficient animals. Efficiency, for example, can be improved by increasing fertility. Only about 50 percent of dairy cattle and 65 percent of beef cattle end up having calves from a single artificial insemination. If they do not become pregnant, the farmer has to wait another 3 weeks until the next reproductive cycle to try again. It is expensive to feed a cow for 3 weeks, and even more expensive if it takes three or four 3-week reproductive cycles before pregnancy is achieved.

Improved resistance to disease also increases efficiency. Sick animals obviously do not grow, reproduce, or milk well. Furthermore, it is expensive to treat sick animals. Certain breeds of cattle are quite resistant to tropical parasites, but frequently those breeds are not productive. An obvious application of biotechnology is to move the genes for parasite resistance into productive breeds of cattle or vice versa.

Some people believe that a prime objective is to produce larger animals. This is rarely desirable. In fact, the opposite is usually more practiced, because smaller animals need less feed for maintenance. Thus, chickens and pigs have become dramatically smaller in recent years as intense selection programs have increased efficiency. New technologies will be used for similar purposes in cattle and sheep.

Other means of improving efficiency are earlier maturity, improved feed efficiency, less fat and more protein in meat and milk, shortened gestation lengths, and calves shaped for easier birth to minimize calving difficulty.

The new biotechnologies will help accomplish such objectives efficiently.

Gender Preselection in Farm Animals

Lawrence A. Johnson, *research physiologist, Animal Science Institute, Reproduction Laboratory, Beltsville Agricultural Research Center, Agricultural Research Service*

Every living being has a set of paired chromosomes, which carry all the genetic material necessary to maintain life and also to propagate new life.

All but one pair of chromosomes are called autosomes and carry genes for all the characteristics of the body, such as skin, hair and eye color, mature size, and body characteristics. The remaining pair are called sex chromosomes. They carry the genetic material that specifies gender. One sex chromosome is called X, the other Y.

A sperm from the male or an egg from the female contains one of each pair of autosomes; in addition, in mammals the egg always contains an X chromosome, while the sperm always carries either an X or Y chromosome.

When a sperm and egg unite and the sperm carries the Y chromosome, the offspring is male (XY); however, if the sperm carries an X chromosome when it unites with the egg, the resulting offspring is female (XX).

In most animals, including humans, the ratio of males to females is 50:50. Because the determination of sex, or gender, takes place when a sperm fertilizes an egg, preselection of gender by selecting the sperm that fertilize eggs must be done before the sperm are used for insemination.

In all bird species, including turkeys and chickens, the female determines the sex of offspring. In birds, the sex chromosomes are exactly the same in all sperm, so poultry sperm cannot be manipulated to preselect the sex of offspring.

Purpose of Gender Preselection

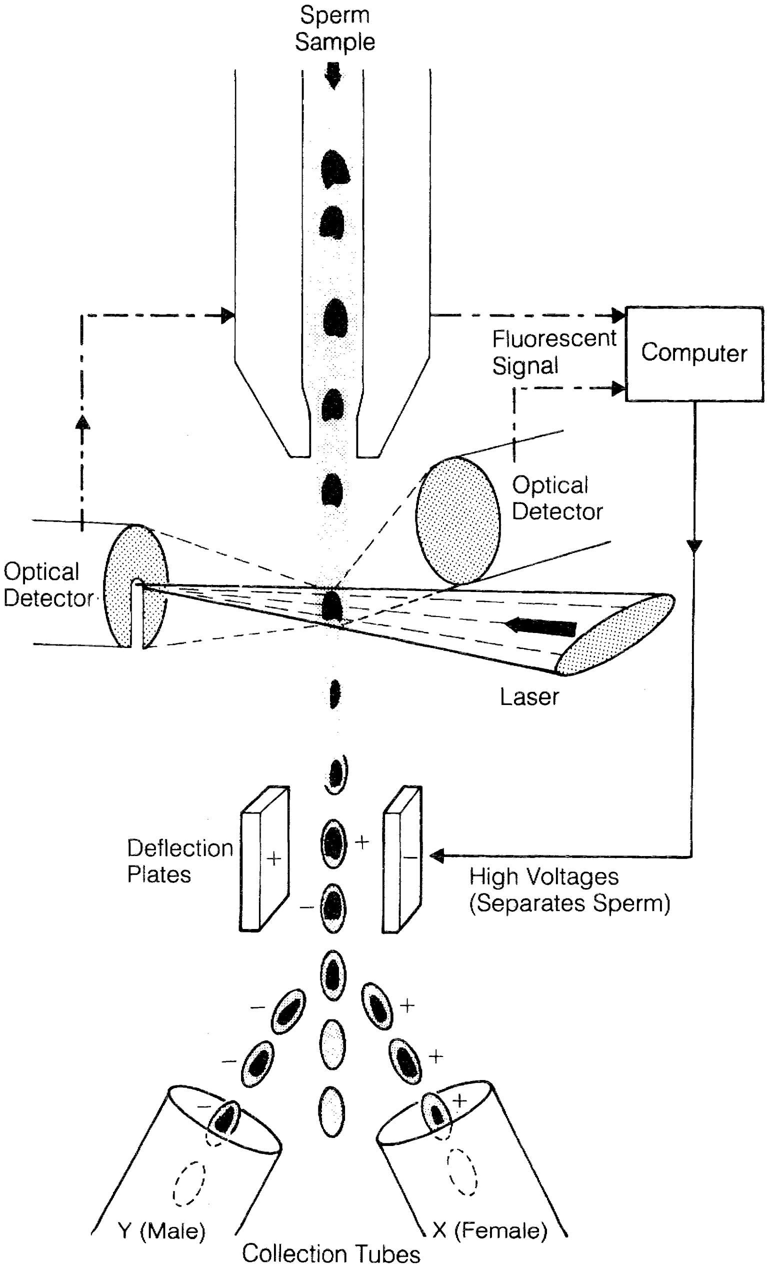
Gender of animal offspring is important to livestock producers. Selection of gender by separating X-bearing sperm from Y-bearing sperm before semen is used in artificial insemination could give farmers the choice of sex of offspring.

Because the dairy farmer has little use for most bull calves, the use of sexed semen to produce only females would make milk production more efficient. Swine farmers would produce pork more efficiently if they were able to market only female swine because females grow faster than males.

In beef cattle and sheep breeds, the male grows at a faster rate than the female and hence is preferred for meat production.

In addition, the ability to specify male or female offspring should shorten the time required for genetic improvements, since desirable traits are often associated with one or the other parent. Planning the sex of cattle offspring is already practiced on a limited basis. This procedure consists of removing embryos from the cow, identifying their potential gender, and re-implanting only those of the desired gender. However, an ability to separate sperm into male-producing and female-producing groups before they are used for artificial insemination could enhance the overall value of offspring produced by embryo transfer.

Cell Separation Process



History of Gender Preselection

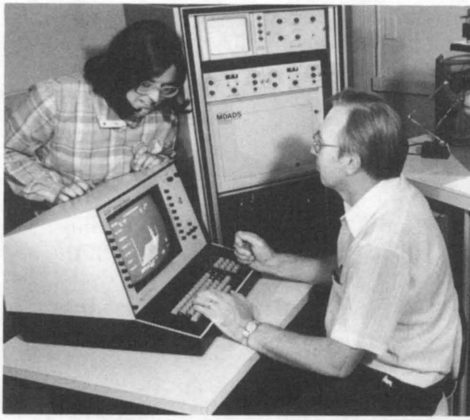
Interest in controlling the sex of offspring dates back at least to Hippocrates (460–377 B.C.). In the 20th century, particularly since 1950, many attempts have been made to determine differences between Y-bearing sperm and X-bearing sperm, particularly with regard to cattle. Most techniques that have been tested have been aimed at distinguishing subtle physical differences, such as swimming ability, size, shape, density, and weight of the sperm. Any such physical differences, however, are small, and the methods used to separate X- from Y-bearing sperm are not sufficiently precise to detect the differences.

Nevertheless, some entrepreneurs have tried to capitalize on the interest in controlling sex by selling so-called "sexed" semen. As one might expect, they fail to follow up to determine the outcome of live births from that supposedly "sexed" semen.

In short, no valid practical method exists today for separating a sample of livestock semen into X-bearing or Y-bearing sperm, and regardless of the claims, no practical method exists for even enriching a sample of livestock semen for either X- or Y-bearing sperm.

Sexing Semen by DNA Content

The only established and measurable difference between X and Y sperm that is known and has been proved to be scientifically valid is their difference in deoxyribonucleic acid (DNA) content. The X chromosome is larger and contains slightly more DNA than does the Y chromosome. The difference in total DNA between X-bearing sperm and Y-bearing sperm is 3.4 percent in boar, 3.8 percent in bull, and 4.2 percent in ram sperm.



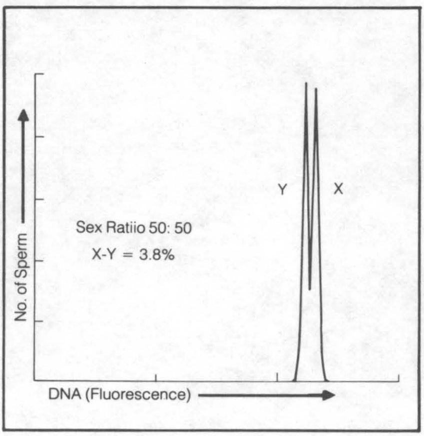
Steve Brown, ARS

Flow cytometers are advanced cell sorters that use lasers to excite fluorescent dye to separate X and Y chromosome-bearing sperm.

The amount of DNA in a sperm cell, as in most body cells, is stable. Therefore, the DNA content of individual sperm can be monitored and used to differentiate X- and Y-bearing sperm.

Instruments to Measure Sperm DNA

Instruments to measure DNA in microscopic particles and cells, such as sperm and blood cells, have been de-



veloped during the past 10 years. These instruments, called flow cytometers, measure the amount of fluorescent light given off when the sperm, previously treated with a fluorescent dye, pass through a laser beam. The dye stains the DNA. The fluorescent light is collected and analyzed by computer. Because the X chromosome contains more DNA than the Y chromosome, the female sperm (X) takes up more dye and gives off more light than the male sperm (Y).

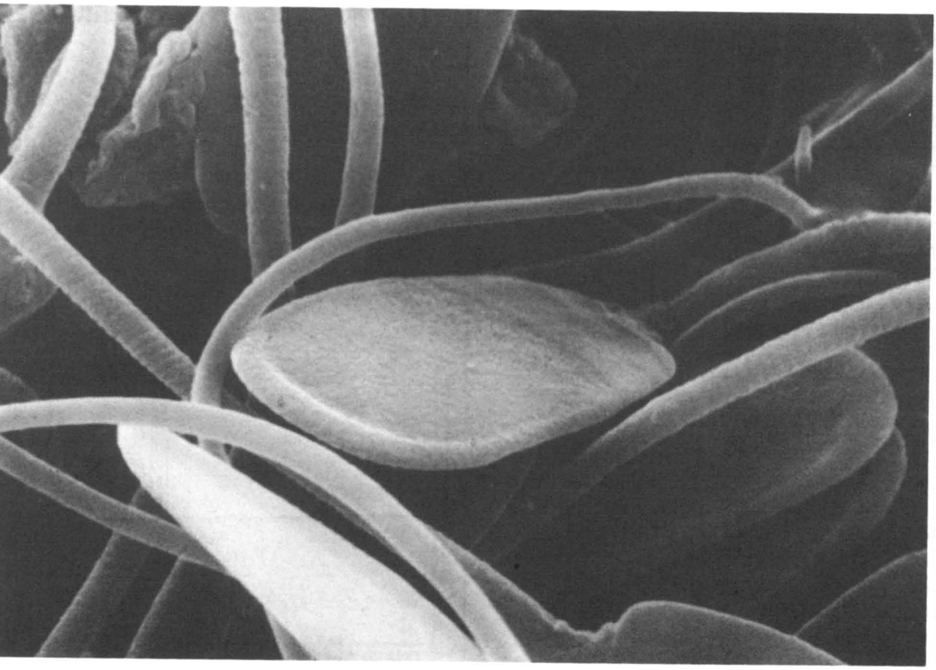
For small differences in DNA to be detected between X and Y, the sperm must pass single file through the laser beam, which measures the DNA content of individual sperm. Hundreds of sperm pass through the beam each second, and 10,000 sperm per sample are routinely analyzed. From this analysis, the ratio of X to Y sperm in a sample of semen can be determined.

Flow cytometric methods can verify any change in the X to Y sperm ratio in a sample of semen. Flow cytometry also is useful in determining whether a particular procedure used in an attempt to change the X–Y ratio is actually changing the ratio. Before the advent of this flow cytometric procedure, the experimental semen had to be used to artificially inseminate many females, and the offspring counted to determine the ratio of males to females. This is an expensive and time-consuming procedure.

Now the potential sex ratio can be determined before the semen is used for artificial insemination.

Flow Sorting of X- and Y-Bearing Sperm

Flow cytometry systems also can be used to separate cells. After sperm pass in front of the laser beam to de-



Spermatozoa from swine, magnified 10,000 times.

termine their DNA content, which takes only a fraction of a second, each sperm can be encased in a droplet of liquid. The droplet containing an individual sperm can then be given either a positive or negative electrical charge, depending on the amount of DNA that was measured (X- or Y-bearing sperm). Next, the droplets pass between two steel deflection plates with high voltage, one positive and one negative. Each plate will attract the oppositely charged (+ or −) droplet, pulling it out of the center stream of droplets and into a tube below.

Using this type of cell sorter, the sperm can be separated into groups containing only X- or Y-bearing sperm. The sorted sperm, however, are not intact; during preparation for DNA measurement, the sperm tails are removed. Only the head of the sperm (nucleus) containing the DNA is passed through the flow cytometry system. So the sorted sperm are not capable of fertilizing an egg. Research is currently being conducted to separate intact sperm capable of fertilizing an egg into X- and Y-bearing groups.

Future Prospects

Once the problems of separating two intact groups of sperm (X and Y) are solved, efforts will be made to identify some other factor on the surface of sperm that can be used to differentiate female from male sperm. Although flow cytometry and cell sorting using DNA as a marker are useful for the numbers of sperm required for research, these procedures are not applicable to separating the billions of sperm required for artificial insemination programs. A surface marker, however, might be used to separate the large numbers of sperm needed for artificial insemination.

Membrane Research: New Approach to Treatment of Gastrointestinal Illnesses

Robert A. Argenzio, *professor of physiology, School of Veterinary Medicine, North Carolina State University, Raleigh*

Diarrhea and other gastrointestinal illnesses cause high livestock mortality rates and result in significant economic losses to the livestock industry. These losses were passed on to consumers in the form of higher prices.

During the past few years, however, research on the function of the epithelial membrane has begun to provide information in both basic and applied physiology. (This membrane of cellular tissue covers a surface or lining of a tube or cavity of an animal, serving to enclose and protect other parts of the body, to produce secretions and excretions, and to function in assimilation. Gut linings are an example.) Studies are leading to new approaches for the treatment of diarrhea and acute and chronic bowel injuries. Significant therapeutic advances based on this new knowledge are now anticipated. Some of these studies will now be discussed.

Membrane Function

The study of epithelial function is especially difficult because of the many different types of cell in the mucous membrane of an animal's gastrointestinal tract as well as the complexity of termine their DNA content, which takes only a fraction of a second, each sperm can be encased in a droplet of liquid. The droplet containing an individual sperm can then be given either a positive or negative electrical charge, depending on the amount of DNA that was measured (X- or Y-bearing sperm). Next, the droplets pass between two steel deflection plates with high voltage, one positive and one negative. Each plate will attract the oppositely charged (+ or −) droplet, pulling it out of the center stream of droplets and into a tube below.

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The study of epithelial function is especially difficult because of the many different types of cell in the mucous membrane of an animal's gastrointestinal tract as well as the complexity of the limiting cell membranes. The functions of cells differ markedly. So we may no longer treat the epithelium as a "black box" if we are to study rigorously the underlying mechanisms and control of ion transport.

Several recent advances in methodology have opened the "black box". It is now possible to separate villous (hairy) and crypt cells in vitro (outside the body) and to make membrane vesicles (pouches) of the two limiting membranes which can be separated by sucrose density gradients. Thus the individual membranes can be studied under conditions of precisely controlled electrochemical and pH gradients. In the past 2 years, these studies have provided sound evidence for the molecular transport characteristics of several membrane transport systems and have elucidated important information on their control.

A second recent development in methodology is the growth in culture media of a colon cancer cell line. These cells can be grown to form a membrane only one cell thick with one surface attached to glass or plastic or a nylon mesh. Transmission electron microscopy and freeze fracture techniques indicate that they form junctional complexes between adjacent cells. Preliminary studies with this system show that they possess many of the transport pathways of intact mucous membranes. Conventional electrophysiological methods such as microelectrode and patch clamp techniques also can be applied to these isolated cells.

The study of intracellular mechanisms in conjunction with transport pathways should be greatly facilitated with this method because the cells are completely isolated from external neuroendocrine influence. Further, such methodology is an alternative to the use of animals in some of these critical areas of research.

Membrane Phospholipids and Hormone Action

It was well established that one group of hormones uses cyclic adenosine monophosphate (cAMP) as an intracellular messenger linking stimulus to response. Recently, studies with several cell systems have shown that a large number of other hormones and neurotransmitters utilize calcium rather than cAMP for their actions. These agents induce a breakdown and resynthesis of a membrane phospholipid known as phosphatidylinositol. This phospholipid turnover may open a calcium gate in the membrane allowing calcium concentrations to increase inside the cell.

In addition, activation of an enzyme known as protein kinase C is linked to this turnover of phospholipids. In several cell types, activation of protein kinase C is a requirement and acts synergistically with calcium mobilization to elicit the physiological response. Recently, studies with mammalian intestines have shown that direct stimulation of this enzyme results in intestinal secretion.

Also involved in this turnover is the release of arachidonic acid, a component of phosphatidylinositol. Arachidonic acid is metabolized by two major pathways in intestinal mucosa to form prostaglandins, which may control blood pressure and muscle contractions, and thromboxanes which regulate cell function. Also formed are compounds known as leukotrienes and other fatty acids. These compounds have diverse and potent actions. They may play key roles in the regulation of ion transport and mucosal defense.

For example, several of the prostaglandins activate cAMP which, in turn, stimulates intestinal secretion. More recently, several products of the second arachidonic acid pathway were shown to cause colonic secretion by a mechanism independent of both cAMP and calcium. The possible interaction between these intracellular messengers makes an understanding of the stimulus-secretion coupling much more complex than was previously imagined. These recent findings will stimulate much needed research in this area for many years to come.

Medicinal Treatment of Diarrhea

This new knowledge in the control of ion transport has already led to advances in the medicinal treatment of diarrhea. For example, agents which inhibit protein kinase C and calmodulin, such as the tranquilizers trifluoperazine and chlorpromazine, inhibit intestinal secretion in experimental systems. These agents also are effective clinically. But the doses required for an antisecretory effect may have undesirable side effects such as sedation.

Nevertheless, it is expected that potent new drugs which are specific for the desired effect will be produced in the next few years.

Similarly, agents capable of inhibiting prostaglandin production seem to be effective in some types of diarrhea. The recent findings that lipoxygenase products of arachidonic acid also may be capable of causing intestinal secretion opens yet another avenue for pharmacologic intervention.

Basic knowledge in the control of ion transport by neurotransmitters and hormones has led to studies using agonists or antagonists of these agents. Recent animal studies indicate that these compounds may prove to be effective in the treatment of certain types of diarrhea.

Mucosal Defense

In recent years, it was found that prostaglandins were capable of protecting gastric and upper small bowel mucosa from serious injury caused by certain damaging agents. Further studies have established that these prostaglandins stimulate mucous and bicarbonate secretion, a mechanism which protects the mucosa from back diffusion of gastric acid and disruption of the "gastric mucosal barrier."

Careful studies of the time course of mucosal injury and its protection by prostaglandins show that the proliferative cell zone is completely protected during an acute injury and therefore can initiate rapid repair of damaged surface epithelium. Proliferative activity itself seems to be at least partially controlled by metabolites of arachidonic acid. These findings have great potential in the therapy of gastric and duodenal ulcers.

Other potent and diverse effects of these metabolites are regulation of mucosal blood flow, epithelial ion transport, and chemotaxis. Further study in this rapidly expanding area may unravel the mechanisms by which these agents are involved in mucosal injury, defense, and repair.

The Body's Army—Its Immune System

Gary A. Splitter, *associate professor, Department of Veterinary Science, University of Wisconsin-Madison*

Daily warfare rages between invaders and defenders within our bodies. The body's army—its immune system—patrols for unfamiliar shapes using special troops—immune cells—whose origin is in the bone marrow but whose final maturation may occur elsewhere in the body. A system of communication and specialization of duties allows these cells to act most effectively.

The immune system's purpose is to recognize itself from everything else, especially bacteria, viruses, and parasites. It helps that each cell in the body has a distinct shape on its surface that distinguishes it from foreign invaders. And every foreign invader has hundreds of components, termed antigens, that can be recognized by immune cells as foreign. The two branches of the immune system—cell-mediated and humoral immunity—work together in responding to invaders.

Cell-mediated immunity refers to the direct response of immune cells to the foreign antigen.

Humoral immunity refers to the production by immune cells of antibodies that circulate in the blood in response to the foreign antigen.

Principal Cells

Principal cells of the immune system are T and B lymphocytes and macrophages. These cells reside in organized tissues and organs, including the lymph nodes, spleen, tonsils, thymus, and bone marrow. In addition, a substantial fraction of the lymphocytes and macrophages comprise a recirculating pool of cells found in the blood and the lymph. Lymphocytes in both lymphoid organs and in the circulation provide the body's immune army with fortified garrisons and patrol missions to seek out foreign invaders.

Individual lymphocytes are committed to respond to a limited group of structurally related antigens. This commitment, which exists before the first contact of the immune system with a given antigen, is expressed by the presence on the lymphocyte membrane of receptors specific for the antigen. Characterizing these antigen specific receptors at the genetic level and determining the mechanisms of cell stimulation and activation of these receptors are areas of intense present study. One set, or clone, of lymphocytes will differ from another set, or clone, in the structure of the antigen-combining region of its receptors and, thus, the range of antigenic substances that may stimulate it to respond. A large number of separate sets of lymphocytes, each bearing receptors specific for distinct antigens, enables the body to respond to virtually any antigen.

As a result, lymphocytes are an enormously heterogeneous collection of cells. Although exact figures are not available, the number of distinct antigen-combining sites of lymphocyte receptors present in an adult animal exceeds one million. That is, over a million different lymphocytes, each specific for a different antigen, exist. In actuality, there are more lymphocytes because many of them have already recognized their specific antigen either through vaccination or natural exposure and produced multiple daughters.

T and B Lymphocytes. Lymphocytes differ from one another not only in the specificity of their receptors but also in their functional properties. Two broad classes of lymphocytes are recognized: T, or thymus-dependent lymphocytes and B lymphocytes, which are precursors of antibody-secreting cells.

T lymphocytes consist of a series of subtypes. Some mediate important regulatory functions, such as the ability to help the development of immune responses. Other T lymphocytes suppress the development of immune responses. Both helper and suppressor T cells regulate antibody production. Additional T lymphocytes (cytotoxic T cells) are involved in producing soluble products that start a variety of inflammatory responses, or directly destroy agents bearing antigenic substances (killer function).

Precursors of T lymphocytes originate in the bone marrow but are required to travel to the thymus for final maturation. On completion of intrathymic maturation under the influence of thymic hormones and education of self-recognition, thymic lymphocytes join the peripheral pool of T lymphocytes.

Several distinct peripheral T lymphocyte groups can be identified because they express characteristic molecules on their membranes. These molecules that distinguish different T lymphocyte groups have only recently begun to be characterized in domestic animals. To date, molecules on helper and cytotoxic lymphocytes have been described, but those that characterize suppressor lymphocytes have not been identified.

Identifying and characterizing molecules specific for each lymphocyte group will provide methods to isolate different cell groups and to study the response of each cell group to different bacteria, viruses, and parasites. Also, the relationships that different cell groups have to pathologic lesions in infectious diseases can be identified in diseased animals. Knowing the types of cells that respond to infectious agents, it may be possible to augment the function of cells with biological response-modifying factors produced by similar kinds of cells grown in the laboratory.

A recent advance has been the production of monoclonal antibodies to the immune cells of domestic animals. Monoclonal antibodies produced specifically for the molecules for each of the body's army cells have helped in identifying the cells of the immune system. In the future, the role of all of the different cell populations in the animal's response to disease-producing agents will be defined.

Killer Cells. In addition to the major T and B lymphocyte classes, lymphocytes that are large, possess cytoplasmic granules, and mediate certain nonspecific cytotoxic responses have been identified. These include natural killer (NK) cells that kill certain tumor cells using recognition systems which may be quite different from those used by T or B lymphocytes. Another type of nonspecific killing of target cells is antibody-dependent cellular cytotoxicity (ADCC), where a lymphocyte or macrophage is capable of killing antibody-coated cells after recognizing the constant portion of the antibody bound to that cell. The role of these types of immune cells in response to bacterial and viral infections in domestic animals has not been well defined. But the response to herpes virus infections by these immune cells in cattle has been shown in the laboratory.

Macrophages. Macrophages are the third type of cell involved in the development and expression of humoral and cell-mediated immune responses. These cells, which function in a nonspecific manner to remove foreign matter, are located throughout the body at fixed sites as well as wandering freely through blood and lymph. When a bacterium or virus enters the body, it is usually first ingested by a macrophage. Macrophages participate in the immune response by 1) killing micro-organisms, particularly intracellular micro-organisms, by the release of toxic chemicals; 2) functioning as scavengers to remove damaged or dying cells and sequestering nonmetabolizable inorganic materials; 3) functioning in bidirectional cellular interactions with lymphocytes; 4) serving as an important secretory cell in the production of bioactive materials (cytokines) that regulate other cellular functions; and 5) playing an important cytocidal role in the control of cancer.

Cell-Cell Interaction in Response to Viruses or Bacteria

An immune response to *Brucella abortus* illustrates the interaction of macrophages with T lymphocytes. Macrophages engulf foreign material and process the bacterium. Processing involves digesting the complex bacterium into small fragments that are more easily recognized by lymphocytes bearing receptors specific for antigens on these fragments. The actual processing events are not fully understood, but most of the bacteria are destroyed inside the macrophage, and only a few are processed into an immunogenic form recognized by lymphocytes.

The many bacterial antigens are expressed on the surface of the macrophage in association with a self-molecule. The self-molecule is a product of the macrophage's genes located in the major histocompatibility complex (MHC). This complex is a genetic region found in all mammals whose products are primarily responsible for the rapid rejection of grafts between individuals, and which function in signaling between lymphocytes and cells expressing antigen. The MHC segment responsible for this function is termed the class II region. This complex of genes has not been thoroughly characterized at the molecular or functional levels in domestic animals. In mice and humans, the MHC consists of a tightly clustered series of genes that code for protein molecules on the cell surface called MHC class I and II molecules. MHC class I molecules are present on all cells of the body, while MHC class II molecules are found on only select cells such as macrophages. T lymphocytes with receptors for both the bacterial antigen and the self-molecule interact with the macrophage expressing this complex.

This complex of bacterial antigen associated with the MHC class II self-molecule constitutes the first signal of activation of the T lymphocyte. Animals possessing different MHC genes have different levels of immune response to a number of foreign antigens. Ultimate survival of an animal may depend on its particular MHC genes and how well antigens are associated with MHC self-molecules. Characterization of the MHC in domestic animals is a promising area in investigating the contribution of these genes to an immune response.

A second signal is provided by the macrophage in the form of a soluble cytokine termed interleukin 1. After the T lymphocyte receives this second signal, the lymphocyte undergoes cell division. Classically, these T lymphocytes are helper T cells and secrete a variety of soluble products, termed cytokines or more specifically lymphokines. These lymphokines have specific functions that affect selected cell groups. However, in domestic animals lymphokines have only been studied recently. Examples of lymphokines are: interleukin 2, T cell replacing factor, B cell growth factor, and gamma interferon.

Soluble Communication Signals

Interleukin 2 serves to clonally expand the foreign antigen-activated T lymphocytes. As a result of increased numbers of lymphocytes specific for the organism, the immune response is enhanced. The greater the number of specific lymphocytes, the greater the opportunity to encounter the organisms. Also, the expanded number of antigen-specific lymphocytes provides a mechanism for memory of the immune system. On a second encounter with the organism by an animal, there are more bacteria-specific lymphocytes and so the response is more rapid. Interleukin 2 binds to a specific receptor on T cells that is expressed at only certain times during the cell cycle.

Studies completed point to a hormonal-like mechanism responsible for the target-cell specificity of interleukin 2 and that interleukin 2 functions at low concentrations. These data indicate that lymphocytes communicate among themselves by producing polypeptides (molecular chains of amino acids) that express characteristics identical to hormones and neurotransmitters. Another way of expressing this aspect of lymphocyte biology is that lymphocytes, especially T cells, are disaggregated, recirculating glands.

The magnitude of T-cell clonal expansion is one of the attributes that determines the extent of the immune response. Also, clonal expansion determines the cellular basis for at least one aspect of immunological memory (i.e., each reintroduction of the same antigen results, through clonal expansion, in the accumulation of exponentially greater numbers of antigen-specific cells). Lymphokines, as hormones that are targeted for other lymphocytes, play critical roles in regulating the animal's immune system.

Because interleukin 2 induces the proliferation of antigen-activated T lymphocytes, this concept has been used to produce clones of antigen-specific T lymphocytes. Large numbers of identical, functional cells can be derived from normal T cells and can be maintained indefinitely outside the body. This accomplishment is even more remarkable since less than 25 years ago, it was generally considered impossible to grow lymphocytes in culture—indeed, their true function was not even known. The discovery of interleukin 2, formerly called T cell growth factor, made cloning of T cells possible. Clones of T lymphocytes can now be developed, and the antigens of the bacterium, for example, responsible for cell-mediated immunity can be determined.

Determining specific bacterial or viral components that produce a T cell response and lead to protective immunity would aid in the development of synthetic vaccines.

Further, synthetic vaccines combined with the proper delivery of interleukin 2 would produce the rapid expansion of relevant T lymphocyte clones, thereby enhancing cell-mediated immunity. Determining the soluble lymphokines produced by these T lymphocyte clones may be useful in characterizing the T cell response to the disease-producing agent.

T cell replacing factor, another lymphokine produced by activated T lymphocytes, serves as a second activating signal for B lymphocytes. B lymphocytes have surface receptors that specifically recognize foreign antigens like those present on *Brucella abortus*. B lymphocyte antigen-specific receptors, however, are known as immunoglobulin molecules and are molecularly different from the antigen-specific receptors present on T lymphocytes. In fact, these receptors are coded for by genes different from the ones that code for the T cell receptor for foreign antigens.

Monoclonal antibodies have been produced that are specific for the different immunoglobulin classes found on B lymphocytes in domestic animals. These B lymphocyte immunoglobulin receptors bind foreign antigens as a first signal of B lymphocyte activation. A second signal is usually required for B lymphocyte activation and is provided by the T cell replacing factor. Having received both signals, the B cell can undergo cell division.

An eventual end line result of B lymphocyte activation is their conversion to plasma cells. The function of plasma cells is to produce and secrete into the blood large amounts of immunoglobulins, approximately a million immunoglobulin molecules per minute. These immunoglobulins are specific for the particular foreign antigen that initially triggered the B lymphocyte and are called antibodies. The antibodies circulate throughout the body providing a soluble defense system separate from cells. When antibodies bind foreign antigens, they immobilize the antigen and/or activate an enzyme system in the blood called the complement cascade system whose end result may be the production of lytic holes in the wall of the foreign organism.

B cell growth factor, similar to interleukin 2 which clonally expands antigen-activated T lymphocytes, clonally expands antigen-activated B lymphocytes. The long-term growth of B lymphocytes occurs without restimulation of surface immunoglobulin antigen receptors suggesting strongly that the trigger for B lymphocyte division occurs independently from antigen-activating signals.

Despite initial encouraging findings, the long-term culture and clonal derivation of B lymphocytes has not come into widespread use, primarily because optimal growth conditions have yet to be identified. The exception to the problem of B lymphocyte growth *in vitro* (out of the body) is the use of hybridomas which result from the fusion of normal antibody-producing B lymphocytes with a tumor cell.

Gamma interferon is another soluble lymphokine produced by activated T lymphocytes that has a direct effect on macrophages. Gamma interferon can enhance macrophage processing of foreign antigens. Similarly, gamma interferon increases the expression of MHC self-molecules on the macrophage surface. These two events, increased processing and increased MHC molecule expression, allow for better lymphocyte-macrophage communication in response to foreign antigens. This finding demonstrates the bidirectional role of T lymphocytes in the function and regulation of macrophages. Other factors produced by activated T lymphocytes have been identified but are poorly characterized.

Cytotoxic T Lymphocytes.

During the identification of self from nonself cells by lymphocytes, cytotoxic T lymphocytes seek out virus-infected cells and kill the infected cells. Products of the virus are expressed on the surface of virally infected cells. Cytotoxic T lymphocytes specific for the virus must recognize the viral antigens in combination with MHC class I self-molecules. Since all cells of the body possess MHC class I molecules, cytotoxic T cells have the potential of recognizing all cells that might become infected. Interleukin 2 also serves as a soluble communication factor to increase the numbers of cytotoxic T lymphocytes specific for a current virus infection, thereby enlarging the repertoire of cells capable of killing virally infected cells and halting the spread of the virus. The mechanism of killing appears to be the injection into the virally infected cell of a toxic signal contained in small granules from the cytotoxic T cells.

Regulatory Lymphocytes.

What keeps the immune response under control? In theory once the immune system has responded to a foreign invader, T lymphocyte division and antibody production by B lymphocytes could continue without end. One mechanism to control the immune response is a check-and-balance system of help provided by helper T cells and suppression provided by suppressor T cells. Suppression of an immune response involves a number of internal feedback and amplification loops of cells constituting a highly complicated regulatory system termed the immune circuit. Some of the effects have been shown to be mediated by soluble factors with or without antigen specificity and MHC involvement.

Given the complexity of the system, there are some controversies over the precise roles and types of cells of the suppressor circuit. Extensive work remains to be done to adequately define how regulation of the immune system occurs. There appears to be, however, a series of cell types that interregulate one another with the final purpose of influencing helper T cells and ultimately antibody-producing B lymphocytes.

Future Control of Disease Agents

The immune system consists of many different cell types, some of which are more defined than others. As the mysteries of the cells of the immune system are identified, we will be able to determine how each cell, or troop of cells, can be manipulated by clinicians to improve the health of sick animals. Also, components of bacteria and viruses that produce the optimal immune protection can be determined. Communication signals in the initial triggering of the body's army of immune cells, or the expansion of selective troops of antigen-specific immune cells, can be genetically engineered to produce large quantities for vaccination programs or treatment therapies.

Finally, it may be possible to genetically alter the cellular army so that specificity of the immune response to a disease-producing agent is more likely assured, or the animal is more resistant to disease agents indigenous to a geographic region. Unravelling the interactions of immune cells in response to disease-producing agents is a central factor in controlling infectious diseases of domestic animals.

Genetically Resistant Animals

Lyman B. Crittenden, *research geneticist, Regional Poultry Research Laboratory, Agricultural Research Service, East Lansing, MI*

The production of high-quality animal products depends on healthy animals that thrive and produce. Animals need to be protected from infection by pathogens (disease-producing organisms) or from their effects. This is usually done by eradication of the pathogen, by vaccination to induce protective antibodies, or by chemotherapy.

Since animals can inherit the ability to resist disease and to improve response to the usual methods of control, recent developments in genetics research have exciting implications for breeding more disease-resistant animals.

Genes can influence resistance at many levels in the cycle of infection, immune response, and disease development.

An animal can passively resist infection if the pathogen cannot enter the body, organ, or cell, or is inactivated by some body fluid that is present earlier. Alternatively, an animal can respond actively, often through its immune system, to develop resistance to the pathogen and eliminate it.

Therefore, genetic resistance, even to a single disease, is usually a complex trait controlled by many genes. However, single genes have been found that block infection or a single step in the origin and development of a disease. Such genes, however, often prevent only a specific disease.

Over the years, animal breeders have selected animals for breeding if the animals' relatives survived well under farm conditions.

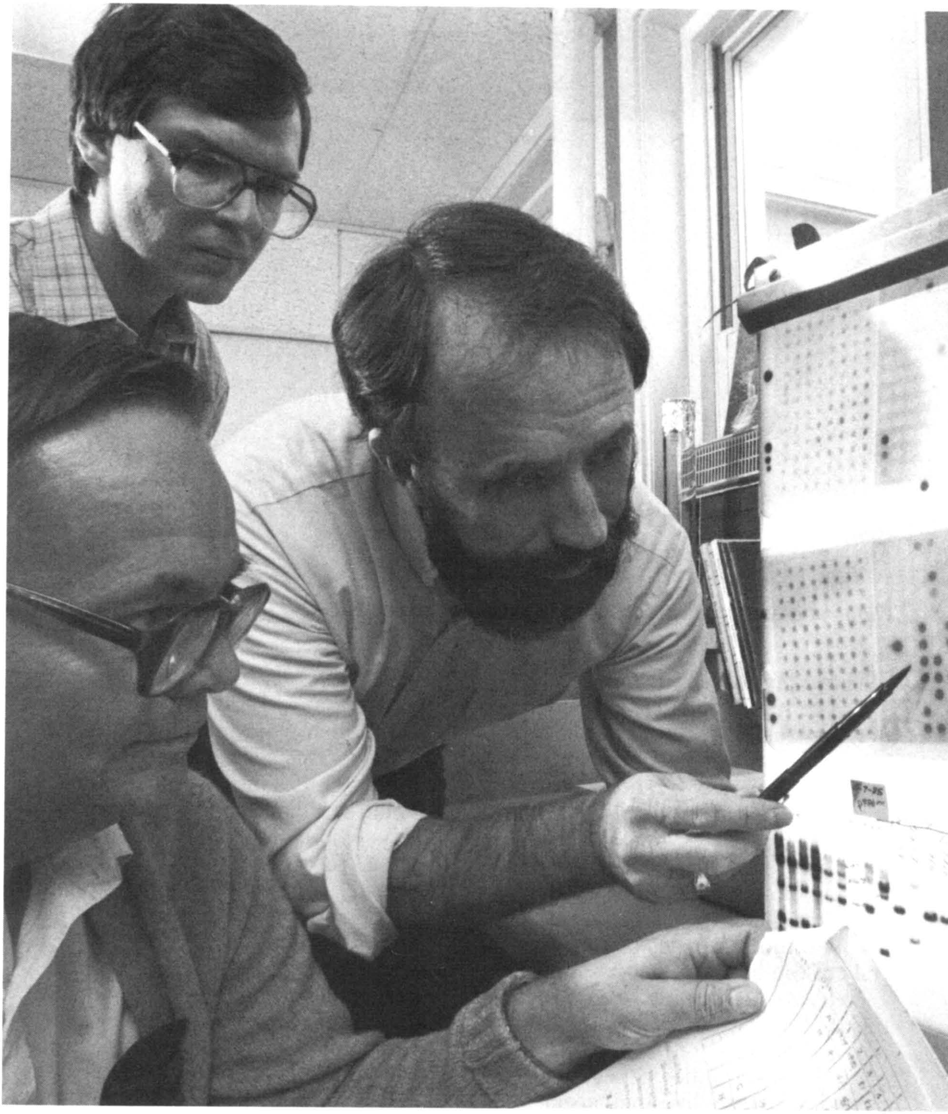
Some animals, particularly in poultry, are selected for breeding based on the ability of their relatives to survive after artificial exposure to a specific pathogen. This selection is usually made only when an epidemic is causing severe economic loss and there is no alternative method of control. This is because selection for resistance to a specific disease reduces the ability of the breeder to select for other traits of economic importance, such as growth rate or egg production.

Conventional, nongenetic, methods of control have been effective for many acute infectious diseases that have troubled livestock in the past. But as such diseases come under control, genetic resistance will become more important for the control of chronic diseases. An important research goal is to find ways to select for genes that impart general resistance to a variety of diseases so that the breeder will need to select for only a few additional traits to improve resistance.

Gene Identification for Disease Resistance

The classic method of gene identification is to look for differences in a trait or characteristic, mate animals that have different characteristics, and describe the variation observed among the progeny for the next few generations. By such observations the geneticist can determine whether a few or many genes control the trait. This approach depends on the identification of genetically controlled variation in an observed trait or in a chemically defined gene product.

With the advent of molecular cloning technology, a single gene can be isolated from an animal, spliced into a microbial vector (carrier), and then replicated in large amounts in this new form of DNA (deoxyribonucleic



Researchers evaluate autoradiograms of chicken blood in research aimed at identifying chickens with avian leukosis virus genes.

acid). These manipulations enable the gene's coding sequences to be read—even though chemical variation in the product is not recognized. Once the isolated DNA has been characterized, genetic variation can be sought at the DNA level and used by the breeder. The use of molecular cloning methods has greatly increased understanding of four multigene families which regulate the immune systems of mice, humans, and farm animals.

W. S. Payne, ARS

Wings of day-old chicks show short feathers on males and long feathers on females.

These families are:

1) the major compatibility complex that controls both tissue transplant rejection and the level of immune response to a variety of antigens (substances that stimulate production of antibodies);

2) the genes that control the production of specific antibodies;

3) the T-cell receptor genes that regulate the responses of specific cells of the immune system; and

4) genes for soluble factors that are released by certain cells having immune functions.

As these and other genes are cloned in several livestock species, they will become raw material for selection, and gene transfer to other animals. They also will be sources of DNA that can be used as molecular probes, for identifying a related gene in an animal as a way to search for genetic variation in their own and other species. Some of these genes may be valuable as regulators—in a general way—of the immune response in an animal. Some particular problems may be solved by an understanding of genes at the DNA level.

Hatcheries selling day-old egg-producing chicks discard male chicks which are identified as such by experts who charge about 3 cents per chick. To cut these costs, some breeders have introduced a gene for slow feathering in male chicks so that even unskilled hatchery workers can easily identify and discard the males. Half the egg-producing chickens in the United States are feather-sexed. Male chicks have short wing feathers and females long wing feathers.

Many breeders who have introduced this gene, however, have noticed some flocks that do not lay the expected number of eggs. Also, such flocks have unacceptable rates of mortality with lymphoid leukosis, a virus-induced lymphoid tumor, as well as other diseases. This called for further investigation. Further experiments showed that the slow-feathering gene was located near another gene on the sex chromosome which increases a chicken's susceptibility to attack from the leukosis virus. Actually, these endogenous leukosis virus genes interfere with the development of antibodies to the invading, disease-causing virus, crippling the chicken's ability to fight back. Now, using similar methods, breeders can look for new sex-linked slow-feathering genes that are not associated with the leukosis virus gene.

So new developments in molecular genetics can help animal breeders identify and characterize general classes of genes for disease resistance as well as help solve particular disease problems.

Gene Manipulation

Since the domestication of animals, their genetic traits have been manipulated to select animals with desirable characteristics for reproduction. In the last few years, it has become almost routine to manipulate genes artificially by inserting cloned genes into the genetic material of mice to achieve changes in their characteristics rapidly. We are just learning to transfer genes in farm animals.

Gene transfer provides new sources of genes because genes can be transferred between any species even though natural mating between the species is impossible. In addition, a beneficial gene can be introduced into a highly productive strain of animals without introducing other harmful genes.

To achieve permanent change in a strain of animals, the genes inserted must be stably inherited through succeeding generations. They must be in the right configuration and location so that the characteristic governed by the gene is expressed in the appropriate tissue at the correct stage of development.

Extensive research in the mouse is under way, using gene transfer, to understand the factors that are important in gene regulation. Such experimental work in mice and other laboratory animals will pave the way for successful application to farm animals.

The first gene-insertion studies in the mouse were discouraging because the inserted genes, although stably inherited, were expressed in unexpected organs and sometimes at the improper stage of development. More recently, single-cloned genes from some of the multigene families that regulate immune response have been inserted and have been expressed properly.

For example, a class-I gene from the major histocompatibility (state of mutual tolerance that allows some tissues to be grafted effectively to others) complex of swine has been introduced into an inbred strain of mice that ordinarily accepts skin grafts from other members of the same strain. Skin from mice carrying the gene from swine was rejected by unmanipulated mice from the same strain. This showed that the new gene was expressed as a histocompatibility antigen.

These exciting results not only indicate that it will be relatively easy to introduce active genes that can alter the immune response, but also show that transferring a single-cloned member of a complex gene family can lead to proper expression in the absence of other genes of that family.

Some viruses insert an antigen into the membrane of the infected cell, and this antigen interferes with further infection by the same or related viruses. If one could introduce the viral gene for the interfering antigen into the genetic material of the host and it were expressed in the host cell membrane, then it should act as a gene for resistance to the virus.

Since only the gene for the interfering antigen would be introduced, the infectious virus could not be produced by the host.

Also, one might introduce a gene for the immunizing portion of a disease-causing agent or vaccine into the chromosomes of the host in such a way that it is expressed at the time that vaccination would ordinarily take place. Such a gene would then become an inherited vaccine—each animal, in a sense, would have its own built-in vaccination shot—eliminating the need to vaccinate every animal.

Prospects for Application

These are exciting prospects. But the animal breeder must consider how to integrate these new methods into a breeding program aimed at improving the whole animal and not just a specific trait controlled by a single-cloned gene.

Probably the first applications will be to introduce genes that will control specific diseases that cause severe economic loss. Theoretically, this can be done without altering the other important genes carried by a highly productive strain of animals. The breeder, however, must test carefully the altered strain of animals to determine if some undesirable side effect has been introduced, as was done by introducing sex-linked slow feathering into egg-production crosses of chickens by conventional breeding methods.

Animal breeders in collaboration with molecular geneticists will conduct basic studies on gene identification and cloning, on gene regulation after transfer, and on the effect of transferred genes on productivity. These studies will provide the basis for using these new methods to augment conventional breeding programs aimed at providing healthier and more productive animals.

A Revolution in Immunology—Monoclonal Antibodies

Richard A. Goldsby, *professor, Department of Biology, Amherst College, Amherst, MA*

The construction of antibody-secreting cell lines—hybridomas—by fusing antibody-secreting lymphocytes with appropriate tumor cell lines—myelomas—has forever changed immunology. Indeed, the monoclonal revolution has spread far beyond the shores of its mother discipline and now laps the coasts of biochemistry, neurobiology, developmental biology, agriculture, medicine and toxicology.

This article will describe the technology of hybridoma production. A companion piece by David Snyder tells how monoclonal antibodies are used to solve many problems.

Hybridoma technology, like recombinant DNA technology, is rooted in basic biology and is the capstone of years of basic research in cell fusion. It is a procedure in which two different kinds of cells are artificially caused to fuse to form a single hybrid cell. Such hybrids are particularly interesting because they incorporate the genetic potential of both parent cells. This technique has made it possible to construct and study the properties of cell hybrids made from such combinations as normal cells with cancer cells, mouse cells with human cells, and even human cells with those of mosquitoes.

Early Research

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Early Research

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Plant virologist checks the temperature of liquid nitrogen storage tanks in which hybridomas are preserved.

Chicago's LaRibida Institute, were the first to produce antibody-secreting hybridomas by fusing normal antibody-producing human cells (B lymphocytes or B cells) to antibody-producing mouse tumor (myeloma) cells. Their hybridomas displayed the capacity for unlimited growth in culture characteristic of the myeloma parent while retaining the antibody-producing characteristics of the normal B cell.

But it was George Kohler and Cesar Milstein who devised and demonstrated a deliberate and rational strategy for the construction of continuous cell lines which secrete monoclonal antibodies of a desired specificity. In 1975 they fused a mouse myeloma cell line with lymphocytes from mice that had been previously immunized with a particulr antigen. They then screened the resulting hybridoma clones to identify those that were secreting monoclonal antibodies specific for the immunizing antigen. Their success, which has been widely reproduced, revolutionized immunology and created an industry.

Polyclonal Antiserum

The power of hybridoma technology can be appreciated by examining the contrasts between monoclonal antibodies and antibodies produced the traditional way. Most antigens of practical interest display many distinct antigenic determinants. Indeed, a bacterium, virus, or foreign-tissue graft presents the immune system with an extraordinarily complex "forest" of highly immunogenic antigens. Typically, many determinants in the complex antigen mixture trigger the activation of one or more of the animal's B cell clones to divide and differentiate into antibody-secreting populations of cells. In the body, the monoclonal antibodies characteristic of each activated B cell clone pool, and, consequently, the serum harvested from the animal is an intimate polyclonal mixture of many different antibody molecules. Furthermore, the composition of this polyclonal mixture will change from day to day and from animal to animal. Thus, polyclonal antisera, even when prepared by well-standardized procedures, tend to differ from batch to batch. While sometimes purification procedures can be devised that specifically isolate those members of the serum's antibody population which bind to the immunizing antigen, such procedures succeed only in producing a mixture of structurally distinct antibodies which share a capacity to bind to some of the determinants presented by the antigen.

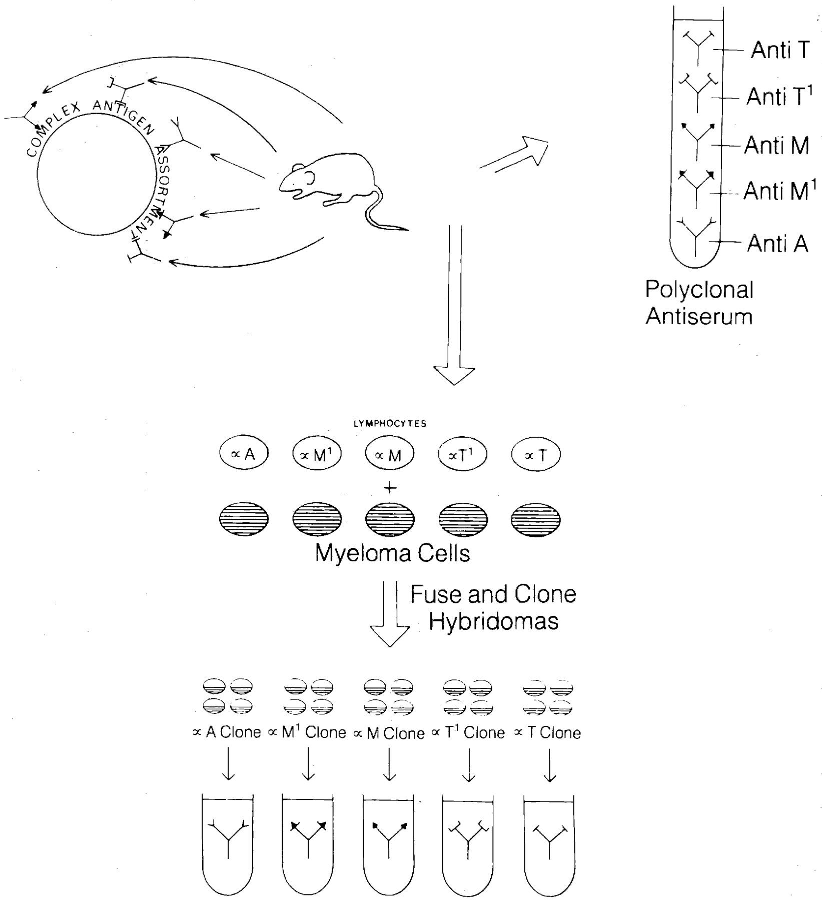
Monoclonal Antibodies

A different state of affairs results by harvesting lymphocytes from recently immunized animals, constructing hybridomas by cell fusion, and isolating those that secrete monoclonal antibodies to the immunizing antigen. Each of the selected hybridomas produces an antibody that recognizes only a particular determinant of the assortment presented by a complex antigenic mixture. Using the mouse system, it has been possible to produce hybridomas secreting antibodies to antigens as diverse as viruses, bacteria, and bacterial toxins, cancer-associated antigens, and to a long list of hormones, enzymes, and drugs. This method also has been applied to the production of human, bovine, porcine, and sheep monoclonal antibodies. This pinpoint technology offers several advantages over conventional polyclonal antisera.

Advantages of Monoclonal Antibodies

- Once stabilized, hybridomas can be frozen and stored for weeks, months or years, until they are

Polyclonal Antiserum Versus Monoclonal Antibodies



needed. Thus, they provide a perpetual source of well-defined, homogeneous monoclonal antibodies.

- Large amounts (grams, even kilograms) of a particular monoclonal antibody can be obtained with a relatively modest investment of resources and personnel.
- Monoclonal antibodies specific for a particular target antigen can be obtained even when the antigen is grossly impure or present only in trace amounts.
- Monoclonal antibodies react with determinants in an all or none fashion, so there is no need to resort to absorption to improve specificity.

For these reasons, monoclonal antibodies have had an enormous impact on experimental biology and biotechnology. More and more, monoclonal reagents are replacing useful, but undefined, polyclonal antisera. Increasingly, hybridoma technology will provide the standard analytical and reference reagents for the fields of food technology, veterinary medicine, and agriculture.

Improving Animal Health Through Monoclonal Antibodies

David B. Snyder, *assistant professor, Virginia-Maryland Regional College of Veterinary Medicine, University of Maryland, College Park*

Wouldn't it be nice if cattle producers could choose the sex of their next calf? Wouldn't it be nice if poultry producers could instantaneously identify the exact cause of the disease that was affecting their flock? Wouldn't it be nice if the horse industry could determine in minutes whether a mare was ready to breed or that she was already in the early stages of pregnancy?

Wouldn't it be nice if milk producers could within minutes quickly assure that milk from each cow was free of contaminants? And, what if a veterinarian could vaccinate an animal without using a vaccine?

Better yet, what if a veterinarian could successfully locate and destroy tumors in valuable animals without using surgery, irradiation, or chemotherapy? These are only a few of the probable applications that monoclonal antibodies will soon bestow on the animal world.

What Are Monoclonal Antibodies?

Antibodies are proteins produced by white blood cells in response to the presence of a foreign substance in the body, such as viruses and bacteria. Antibodies can bind to and inactivate cells of the foreign substance but will not harm other kinds of cells.

Until recently, the primary source of antibodies was blood serum from animals. Now, to produce large quantities of a single antibody, scientists use a technique called monoclonal antibody production. By fusing a cancerous cell with a cell that produces an antibody, scientists create a hybridoma, which produces large quantities of identical or monoclonal antibodies in a pure, highly concentrated form. The use of these new reagents has become widespread in both applied and research settings.

New Field Created

The 1984 Nobel Prize in Medicine was awarded to Kohler and Milstein, the scientists who originally described the method for generating immortal hybrid cells which secrete the almost magical monoclonal antibodies. The method they described showed researchers how to dissect a complex antibody response against a foreign substance or antigen into its individual component parts. The monoclonal antibodies which result from this proportioning have many unique and highly useful properties that sharply separate them from the group from which they were derived.

Since the original discovery of monoclonal antibodies in 1975, a new field has been created. This new field inspired by the utility of these highly useful probes has exploded, revolutionizing nearly every area of the concurrent biotechnological movement. Monoclonal antibodies have been prepared for nearly every imaginable purpose, bringing about major advances in many diverse fields where conventional, mixed antibody reagents often have limited the scope of what could be achieved. (See previous article by Richard A. Goldsby for additional details about monoclonal antibodies.)

When cultured in an artificial environment, spleen cells consisting of various white blood cell groups and antibody-producing B lymphocytes normally have a short life span. However, a biotechnological process known as somatic cell hybridization permits the fusion of antibody-secreting B cells with nonantibody secreting myeloma cells that have an infinite life span. The hybrid cell types produced by the process are called hybridomas. They combine the most desirable characteristics of both the parental cell types: antibody production and immortality. Individual hybridoma cells can be selected and cultured to yield a group of cloned cells that all produce and secrete large and unending quantities of identical monoclonal antibodies.

Antibodies themselves are serum proteins produced by individual B lymphocytes. Normal animals respond to infection by an organism or to injection of a foreign substance (antigen) by producing a mixed group of specific antibodies that are then secreted into the host's serum. Traditionally, the antibody containing serum (antiserum) from animals which have been deliberately exposed to various antigens by vaccination has been used in many diverse applications, most notably in veterinary diagnostics.

Since each antigen has many unique binding sites, different antibodies are produced by individual B cell clones that are specific for each of the attachment sites (epitopes). Hence, antibodies that are found in serum and were formed against each separate binding site, or epitope, on an antigen may be considered custom blends of different monoclonal antibodies. These blends of antibodies are produced by as many as one million different B cell clones. But they may be singled out and immortalized into monoclonal antibody-secreting clones by somatic cell hybridization.

Just as the right key will turn the correct lock, antibodies are able to bind specifically and firmly their inducing antigen. Like guided missiles, antibodies find their targets, bind to them, and neutralize or kill their activity. In this way, antibodies serve as a highly selective defense mechanism for animals and thereby ease the removal of foreign substances from the body.

Uses of Monoclonal Antibodies

Monoclonal antibodies are not used extensively in the animal world. They are employed in the process of genetically engineering an animal vaccine. In this process, several fundamental things must be known before an attempt to produce a recombinant vaccine is made.

Producing Vaccines. Viruses, such as foot-and-mouth disease, are composed of large and complex proteins, all of which have many antibody binding sites. Since only antibodies specific to a few of these binding sites are able to kill or neutralize the virus, monoclonal antibodies are important for identifying which sites are involved in virus neutralization and on which protein they reside. With that fundamental information, the gene which encodes this protein may be isolated, and a recombinant protein having the amino acid sequence for the neutralization site may be produced.

While monoclonal antibodies identify gene products (proteins) that are important in the genetic engineering process, their utility does not stop at the first stage. After the potential recombinant vaccine has finally been expressed, the same monclonal antibodies are often used in quality assurance procedures. These procedures seek to assure that the pertinent neutralization sites on the new recombinant protein have not been altered.

Finally, the monoclonal antibodies can be used to purify selectively the recombinant protein for use as a subunit vaccine. It is doubtful that genetically engineered or certain kinds of synthetic vaccines would be as possible without monoclonal antibodies.

Therapeutic Role. Another use of monoclonal antibodies is a potential therapeutic role in preventing certain infectious diseases. One example is the use of monoclonal antibodies that bind to the antigen of certain strains of intestinal bacteria, such as Escherichia coli, or *E. coli.* This passively immunizes calves and pigs against neonatal diarrhea.

In this particular scheme, monoclonal antibodies against the antigen with hairlike binding sites are fed to newborn calves or pigs. In the gut, the antibodies attach to the binding sites, or pili, of the toxic strain of *E. coli.* But the toxic bacteria need these hairlike structures to attach to the gut wall. Even as these "bad" bacteria are unable to colonize because the monoclonal antibodies have blocked their attaching ability, other less pathogenic strains of *E. coli* then colonize the gut. This reduces the severity of the disease.

This process is favored over costly vaccination of pregnant cows that must be vaccinated annually or semiannually to provide similar natural protection through their colostrum and milk.

"Magic Bullet" Concept. Monoclonal antibodies specific for some tumor antigen or viral antigen can selectively kill or neutralize when they are administered to an ailing animal. The antibodies are administered alone or coupled to some toxic compound such as arsenic. The result of such a passive therapy is that the antibodies specifically seek out and destroy the tumor or virus anywhere in the body that that particular antigen is found.

This process makes tumor or viral therapy economically feasible in the animal world. This approach has the added advantage of producing only local reaction to the therapy, rather than throughout the system as may be caused by alternative therapies such as surgery, chemotherapy, or irradiation.

Anti-idiotypic Vaccine. Another application for monoclonal antibodies in veterinary medicine involves the use of an "anti-idiotypic vaccine." In this complex but exciting scenario, a monoclonal antibody prepared against the antigen-binding cleft (idiotype) of another monoclonal antibody actually becomes the vaccine.

For example, a monoclonal antibody is prepared against the neutralization site of the pseudo-rabies virus—an economically important disease-producing agent of swine. Next, another monoclonal antibody is prepared against the first monoclonal antibody's antigen-binding cleft (anti-idiotype antibody). The anti-idiotypic antibody can then be passively administered to a pig, where it seeks out and binds to B-lymphocytes that carry as an antigen receptor an antibody that is specific for the neutralization site of the pseudo-rabies virus. This event then causes that B-lymphocyte to divide and give rise to a large population of B-cells secreting antibody that can neutralize pseudorabies virus. The main advantage of an anti-idiotypic vaccine is that most animal vaccines are live, and they themselves have the potential of mutating and causing disease. Through the uses of anti-idiotypic vaccines, losses due to vaccination will be decreased.

Disease Diagnosis. Yet another use of monoclonal antibodies is in the quick and definitive diagnosis of ani-

Fred Witte, ARS

Creating monoclonal antibodies from cloned cells in cuture media requires time, patience, and many microplate test wells. ARS scientists are finding highly specific antibodies that could lead to improved diagnostic methods for livestock and crop diseases—and to vaccines against these diseases.

mal diseases. Often, when animals become ill, especially with viral or parasitic diseases, the farmer or veterinarian must simply treat the symptoms and wait and hope for the best because there is no way to quickly and inexpensively identify the cause of the disease.

For example, a poultry producer's flocks develop a respiratory disease. Many agents produce respiratory disease in poultry and there are about as many tests to diagnose them. Some tests take days or weeks to complete.

Now, with the advent of monoclonal antibodies, a series of quick and sensitive enzyme-immuno assays allow the farmer, during a short period, to identify not only what agent, but exactly what subspecies of agent, is involved in the infection.

With this information, the producer or veterinarian can administer a more selective therapy or vaccination program more quickly.

Monoclonal antibodies will be used

in "dipstick" diagnoses. These antibodies can be used early in the infection, well before more conventional tests. Using dipstick technology, where plastic sticks are coated with monoclonal antibodies, it will eventually be possible to dip the sticks in body fluids and actually fish the disease agent out. After immersion, the dipstick is rinsed in a series of short baths; a color change is produced if the agent is present.

Eventually, this type of monoclonal-antibody-based dipstick technology will provide additional information to producers. It will provide information about the level of contamination of feed with mycotoxins or pesticides. It also will be of benefit in defining whether potentially harmful drug residues, antibiotics, or carcinogens have contaminated milk, meat, or poultry products. In the future essentially anywhere a substance, organism, or compound needs to be detected, measured, or monitored, monoclonal antibodies will play a role.

Research

In the animal world, especially in research, monoclonal antibodies are being used in purifying compounds, tracing milk synthesis during lactation and in understanding the origin and development of various disease-producing agents, including the role of certain proteins and enzymes in cancer. Rapid and accurate monoclonal-antibody-based pregnancy tests for cows and horses are on the way. Even the possibility of presexing embryos fertilized in test tubes looms in the future.

Indeed the potential use of monoclonal antibodies to assure unequaled animal health, to promote agriculture in general, and to provide more wholesome products for the consumer is only limited by our imagination and the speed with which these reagents may be created.

Genetic Engineering Can Help Control Disease

James L. Bittle, *adjunct member, Department of Molecular Biology, Scripps Clinic and Research Foundation, La Jolla, CA*

Infectious diseases are still the main cause of illness and death in domestic livestock. The estimated annual loss incurred from infectious disease in cattle and swine exceeds 1 billion dollars and for all livestock species exceeds 2 billion dollars.

The widescale use of therapeutic drugs and biologics, such as antibiotics and vaccines, also has added to the cost of raising livestock. Yet they have reduced the losses only marginally because of the changes in agricultural production methods which often promote the occurrence of infectious disease. The concentration of animals in feed lots, dry lot dairies, integrated swine operations, and broiler production units are examples of husbandry that increase the spread of infectious agents as compared with less confined types of animal raising.

Methods of Control

Three major methods are used to reduce losses from infectious disease. One is to eliminate the infectious agent from the environment so that animals will not be exposed. This requires destroying any animal infected with the organism, whether it be the host animal or an intermediate host, such as an insect that carries the organism. This has been effective in controlling infectious agents that are in "dipstick" diagnoses. These antibodies can be used early in the infection, well before more conventional tests. Using dipstick technology, where plastic sticks are coated with monoclonal antibodies, it will eventually be possible to dip the sticks in body fluids and actually fish the disease agent out. After immersion, the dipstick is rinsed in a series of short baths; a color change is produced if the agent is present.

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The low-level feeding of antimicrobial drugs is another way to control infectious agents, especially in newborn animals. The development of resistant strains of many micro-organisms to a number of antimicrobials has caused concern although this method is still widely used.

A third method of control is to immunize animals with a form of the organism that will induce an immune response. This requires the use of vaccines containing an immunogen that induces persisting protection against the invading organism.

Actually, all three methods may be used in some form, but the third method, immunization, offers the greatest promise. It is simple, inexpensive, requires few administrations, and, most importantly, prevents infection and, therefore, minimizes damage that often accompanies infection. Greater safety and effectiveness in newer biological products will enhance their use.

Immune System

To understand how vaccines protect, it is important to understand how the immune system defends an animal against an infectious agent. (Editor's note: To conserve space, the author's explanation of the body's immune system was eliminated, and the reader's attention is directed to an explanation of that system in Gary A. Splitter's article.)

Vaccines in Current Use

Instead of allowing infections to occur naturally, it has long been the practice to expose animals to infectious agents artificially so that they will develop antibodies and be protected against the common disease-causing organisms. Thus, many vaccines have been developed and used in animals to control the more serious infectious diseases. The vaccines in use now are made from either attenuated living organisms or inactivated organisms.

The attenuated living organisms have reduced virulence, are required only in small amounts, and, in general, induce long-lasting immunity. They elicit a controlled subclinical infection and, in general, are very effective. Occasionally, however, they produce side effects that may be as severe as the natural infection.

Inactivated vaccines are safe in that they do not contain any infectious material, but they are weak in terms of stimulating an immune response. They usually require multiple injections over several weeks to induce an immune response comparable to that induced by living organisms. They also may cause undesirable side effects evident both at the site of inoculation and sometimes as a general side reaction as the animal responds adversely to the many antigenic components in the vaccine.

In other words, the use of whole organisms in either the living or inactivated form may cause adverse reactions. These reactions are due to certain components of the whole organism, that is, proteins, lipids or carbohydrates that may not be necessary for immunization.

Synthetic Vaccines

Biosynthetic Process. The objective of vaccine development over the years has been to identify the important antigens responsible for protection and to produce them in the purest form. But only recently has recombinant DNA technology, (rDNA, genetic engineering) become available to help produce defined antigens, or antigenic determinants, on a large scale and in a cost-effective manner. The isolation of these antigenic determinants on the surface of infectious agents represents the first step in trying to produce a more specific antigen. Since these determinants occur in repeating subunits and their production is controlled by specific genes in the nucleus of the organism, these genes may be used to produce antigenic determinants.

By isolating the specific gene (DNA) that encodes for the surface antigenic determinant, and by using a plasmid (a piece of DNA that occurs naturally in bacteria and yeast) to insert this gene as a bacteria, yeast, or mammalian cell, the gene recombines with the cell's own genes to produce the antigenic determinant along with other cellular products. The antigenic determinant may be isolated and used as an immunogen. This immunogen will be recognized by the immune system as being foreign and will stimulate the production of antibodies or a cellular response that will protect the animal or prepare the animal's immune system for future infection with the infectious agent.

Antigenic determinants can be produced by growing the cells on a large scale and collecting and purifying the antigen as it is expressed. The antigen may have improved characteristics compared to the antigen derived from the whole organism. These characteristics are purity, safety, and stability. Also, the risk of having the vaccine contaminated with infectious material used in production of the whole organism is reduced. All of these characteristics help in developing improved vaccines.

Chemical Synthesis. Another method of producing antigenic determinants is chemical synthesis. Most antigenic determinants are proteins composed of chains of amino acids. Individual amino acids may be linked together in a linear form to mimic antigenic determinants. So, if the amino acid sequence of the native antigenic determinant is known, it can be made synthetically.

One way to determine the amino acid sequence of an antigenic site is to isolate the gene that encodes for it. The gene is composed of DNA that contains the genetic code in its nucleotide sequence. This nucleotide sequence can be determined, and it will translate into an amino acid sequence (the bases, adenine, thymine, guanine and cytosine code in triplet combination for each amino acid). Thus, an amino acid sequence for a surface protein may be derived from the nucleotide sequence of its gene. Only a small part of this surface protein may be required to produce an immunogen.

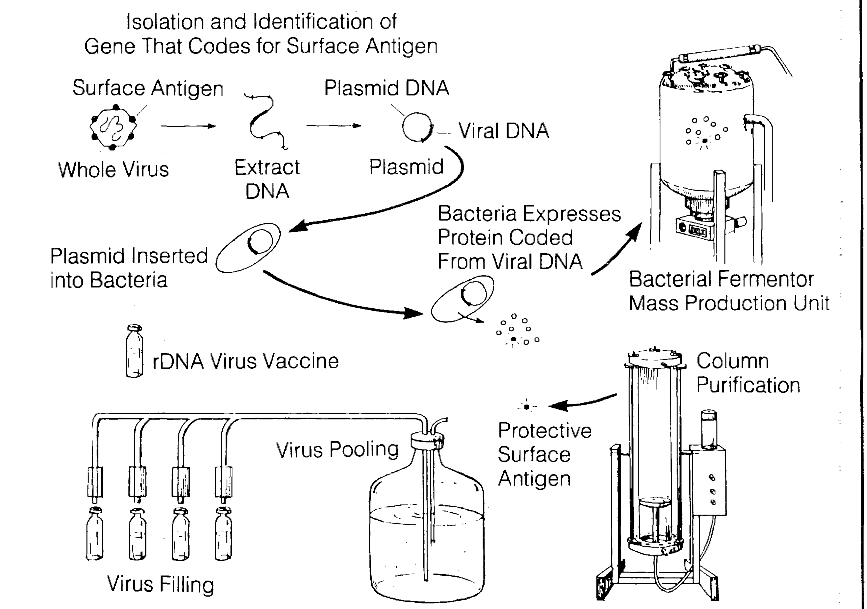
The peptide can be made by sequentially adding amino acids. Forty or 50 amino acids may be joined together in a linear sequence forming a peptide by using an amino acid synthesizer controlled by a computer program. The peptide is removed from the resin and may be coupled to a carrier protein or polymerized to increase its size. These forms of the antigenic determinant have been found to be active in inducing humoral and cellular immune responses.

The advantage of chemically synthesized peptides over biosynthesized peptides is that the chemical process is more precise and reduces the variability found in a biological process. This precision leads to further improvement in purity. There also is no chance that an infectious agent or foreign nucleic acid will find its way into a chemically synthesized product.

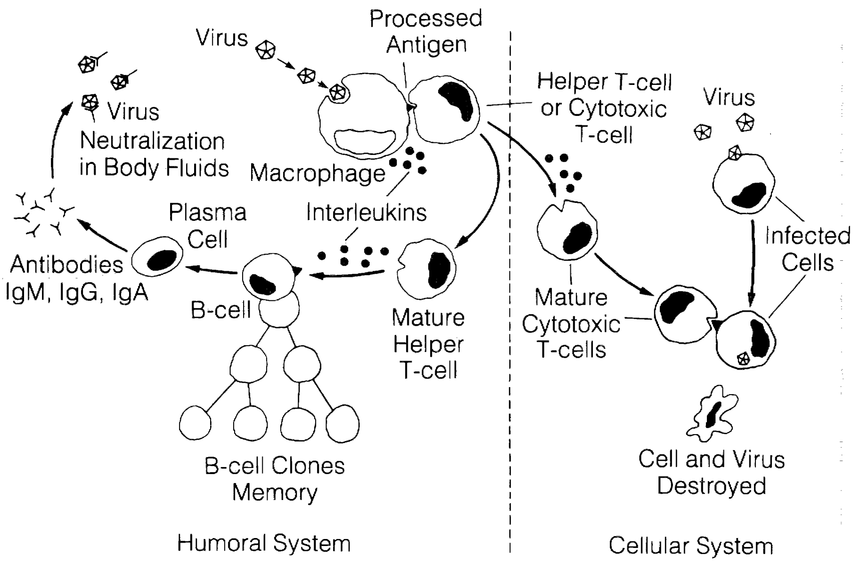
Other Approaches to Improve Vaccines

The use of live attenuated organisms as vaccines to produce a controlled infection has been the major method

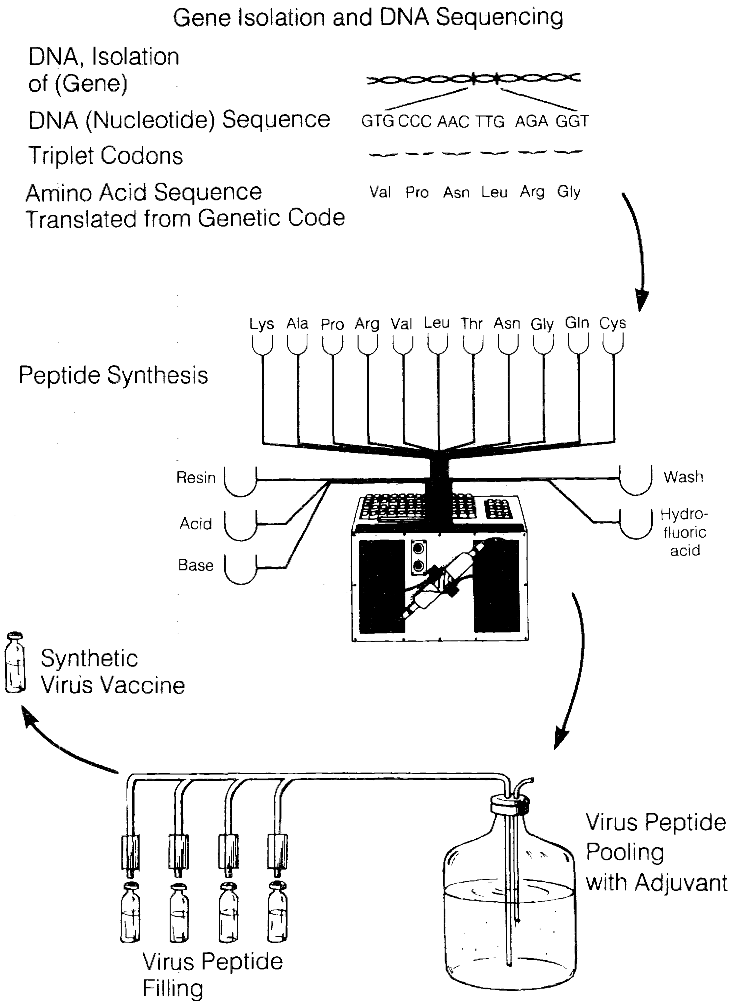
rDNA Virus Production



Immune Response to Viral Infection



Synthetic Virus Production



of protecting animals and humans. This type of vaccine usually yields a long-lasting immune response with one inoculation. Although there is some risk that the organism used in this type of vaccine may revert to a more virulent form or that the individual animal may respond adversely to the organism, the benefit usually outweighs the risk incurred.

Recombinant technology offers a method of improving this type of vaccine by recombining genes for immunodominant antigens from other infectious agents with the genes normally found in the organism used in the vaccine. Vaccinia (cowpox virus) has been the most widely studied virus used for this purpose because of its large set of genes and wide host range. It will infect many animal species by replicating, causing antibodies to be produced against both the vaccinia virus and also against other proteins encoded by the inserted DNA.

A number of bacterial organisms also have been used for this purpose. These include *Salmonella typhi* and *Vibrio cholera*. Using genetic engineering techniques, the genes causing the virulence of these organisms may be deleted while still allowing the organism to propagate in the host animal. Genes that encode for a surface antigenic determinant may be inserted into the bacterial genome (set of chromosomes, with genes), thereby allowing the organism to express an immunodominant antigen. This type of bacterium has the advantage that its cellular material often attracts leukocytes, allowing more rapid processing of the antigens bringing an improved immune response.

The advantage of attenuated living organisms in vaccines is that they reproduce—allowing a small number of organisms to be used. These may mimic the natural organism, producing a large amount of antigen that results in a longer lasting immunity.

Use of Vaccines

Although vaccines are effective in controlling many animal diseases, many debilitating, life-threatening diseases are still endemic. Present vaccines are not always safe, are not stable (require refrigeration), and have not been developed for many infectious diseases. The new technology called genetic engineering will help solve many of these problems and make more vaccines available that are safer, more stable and more effective. Their wide-scale use as multivalent products will further reduce infectious diseases.

Immunopharmaceuticals

Relatively few pharmaceutical products are used today to regulate the immune system of animals. These products are being used as aids in vaccines to stimulate the immune response to prevent disease or to treat disease conditions such as in immunodeficiency or in chronic infection. Crude bacterial extracts from Mycobacteria, Corynebacteria, Pseudomonas and Salmonella organisms have been used. They have proved to have an immuno-stimulating effect, although their mode of action is not entirely clear. Separated fractions of these bacterial products have been shown to be more active and much safer to administer than the crude products.

Recent developments in the field of immunology have furthered our understanding of how to regulate the immune system and will lead to the development of many new pharmaceutical products. Some of these are natural products from the immune system, such as thymic hormones, monokins (interleukin 1), lymphokines (interleukin 2), and interferons. These substances modulate the immune system by causing either stimulation or suppression.

There also are chemical substances that exert a similar influence such as levamasol, isoprimosine, corticosteroids, and cyclosporin A. These are available as products but are not widely used.

It is now clear that the immune system is the master control system that has great influence over most body functions. Products that affect this system will be important in the future of animal health.

New Vaccines for Old Diseases

Kenneth J. Cremer, *associate program manager, Biotechnology Competitive Research Grants Office, Office of Grants and Program Systems*

Opportunities for advances that will improve livestock productivity are greater today than ever before through the powerful new products of the biotechnological process. Each year, because of disease, the productivity of livestock and poultry in the United States is reduced by an estimated 15 to 20 percent. Investigations show that many animal diseases can be controlled by combinations of procedures, such as improved diagnosis, control of the insect carriers of disease, vaccination of susceptible animals, enhancement of the immune system, and improved therapy.

Most vaccines against pathogenic (disease-producing) organisms of viral, bacterial, fungal, or parasitic origin consist of the organism being either killed or chemically weakened or genetically modified to reduce its virulence. The animal's immune system responds to vaccines by producing antibodies that bind to antigens or surface structures of the infecting organism, labeling it for attack and destruction by the immune system. Antibodies produced in response to the modified or killed pathogen circulate throughout the animal's body and render the animal resistant to later infections by the live pathogenic organism.

Vaccinia Virus Vectors

During the last few years, several groups of U.S. scientists have designed vaccine vectors (carriers) that may someday be universally used to safely vaccinate a variety of animal species against a number of infectious agents. Vaccinia virus vaccines were used extensively worldwide during the smallpox eradication campaign 10 to 20 years ago. These same smallpox vaccines have recently been genetically engineered to express foreign proteins from different disease-causing organisms, allowing their potential use as vaccine vectors for domestic animals as well as humans. The genetically modified vaccinia virus grows in most animal species and can be engineered to express one or more foreign protein antigens, thus increasing their general utility and potential effectiveness.

The use of modified, weakened live viruses to stimulate immune responses exemplifies the exciting and powerful recent advances in applying genetic engineering and recombinant DNA technologies to the problems of control and eradication of infectious diseases in domestic animals, both in the West and Third World countries.

Vesicular Stomatitis Virus

Vesicular stomatitis virus (VSV) is a highly contageous disease of cattle, horses, and pigs, characterized by vesicular lesions on the tongue and other areas inside the mouth. The lesions are similar to those seen in animals infected with foot-and-mouth disease, another highly contageous and fatal cattle disease. Humans also are susceptible to VSV, and exhibit influenza-like symptoms. Outbreaks of VSV have been devastating to the livestock industry, as exemplified by a recent epizootic outbreak in 13 Western States.

VSV has five distinct proteins, only one of which, the G-glycoprotein, has been shown to promote protective immunity. Vaccinia virus has recently been genetically engineered to express the VSV G-glycoprotein. Experiments recently completed with this vaccine indicated that immunity to the G protein was induced in vaccinated cattle. It effectively protected animals from a controlled infection by VSV under laboratory conditions, whereas unvaccinated animals were susceptible to mouth infection of VSV. Field trials are planned to determine this vaccine's effectiveness in a natural setting.

Bluetongue Virus

Bluetongue (BTV) is an arthropod-transmitted viral disease of both domestic and wild ruminants in the United States, Asia, Australia, Europe, and Africa. The virus can be transmitted between cattle and sheep by gnats.

The disease is characterized by fever, erosion, and ulceration inside the nose, lameness, weight loss, and eventual death of some infected animals. Direct losses from subclinical disease, fetal death or abortion, and the hazards of animals introducing the infection to a susceptible flock or herd are well appreciated by ranchers and veterinarians. A segment of the bluetongue virus genome (set of chromosomes with genes) has been cloned recently. Construction of a recombinant vaccinia virus expressing one of the BTV capsid structural proteins is under way. Limited experimental trials of the recombinant virus under controlled conditions are contemplated for the near future.

Anaplasmosis

Anaplasmosis is a parasitic blood disease of cattle and other ruminants caused by the micro-organism rickettsia *Anaplasma marginale*. Anaplasmosis occurs worldwide in tropical and subtropical areas, including several regions of the United States, where

Courtesy of Dr. T. Yilma, Washington State University

Lesions on a cow's tongue show the presence of vesicular stomatitis virus.

annual losses amount to 50,000 cattle deaths with an estimated value of $100 million.

The rickettsia is transmitted by ticks and biting flies to susceptible cattle where it infects the red blood cells. During the acute infection the parasite increases geometrically in number, causing extreme anemia. The next step is a marked weight loss, abortion in pregnant cows, and even death. Cattle that recover suffer persistently from low-level infection and serve as a reservoir for transmitting the organism to other susceptible cattle.

Recently, one of the major surface antigens of the anaplasma parasite was identified. Current research focuses on more fully characterizing the genetic material (DNA) coding for

Lowell Georgia, ARS

A sheep receives an injection of a killed-virus bluetongue vaccine.

this gene. It is envisioned that this gene could be genetically engineered into vaccinina virus vectors.

To be completely effective, a parasite vaccine must provide sufficient immunity to eliminate 100 percent of the infecting organisms, since at each stage of the parasite's life cycle, different surface proteins may be present. Because a vaccine against one stage may not be effective against a later stage of the same parasitic disease, it may be necessary to construct vaccines expressing surface antigens from each stage of the parasite's life cycle for complete protection.

Immunoadjuvants

The antiviral and immunoregulatory effects of bovine interferons and interleukin-2 are being assessed in cattle for their potential to increase the cattle's immune response to specific viral antigens. Interferon is one of several lymphokines (proteins) that act directly on B-cells and stimulate immunoglobulin secretion by twofold to fivefold in experimental animals. Interleukin-2 (IL-2), an immunomodulator, is released from antigen-stimulated lymphocytes and functions to switch T lymphocytes into a proliferative phase, thus allowing for clonal expansion of the stimulated population of cells.

The bovine genes for these biologically important immunomodulators will soon be inserted into vaccinia virus vectors so that their potential to enhance the immune response can be assessed in a domestic animal. If these immunomodulators can increase the immune response, the concept of vaccination may be revolutionized.

Advantages of Live Vaccines

Live vaccines, such as vaccinia virus vectors, have distinct advantages over inactivated, subunit, or synthetic vaccines because they multiply in the vaccinated host and produce more antigen, and potentially a higher level of and more durable immunity. In addition, several related or unrelated foreign protein antigens can be simultaneously expressed from a single vaccine preparation, allowing the vaccination of a herd of animals against several diseases simultaneously.

Recombinant vaccines expressing varied combinations of foreign proteins can be constructed, allowing vaccines to be targeted specifically for diseases of extreme veterinary concern in different regions of the world. The eventual exportation of these vaccines and their technologies to Third World countries is an endeavor toward which everyone associated with basic research in disease prevention is striving.

V
Biotechnology: Its Application to Plants

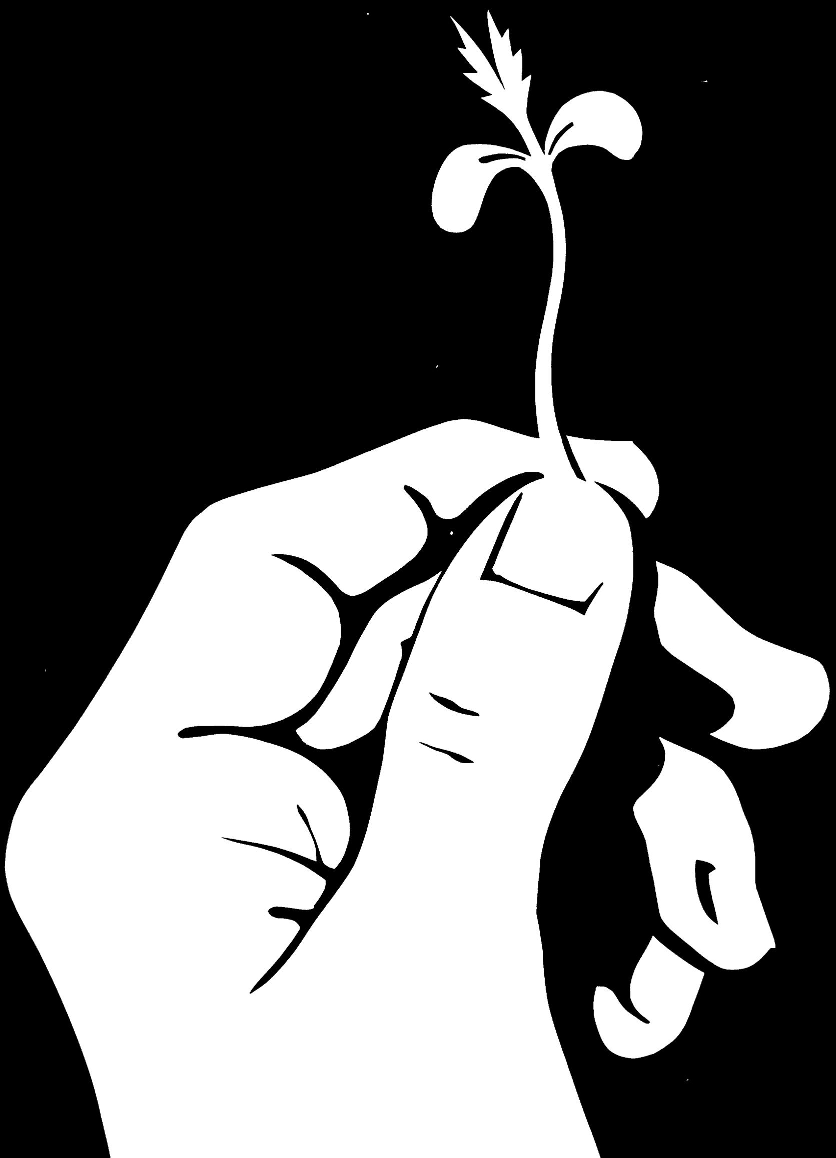


Photo-synthesis: Improving Conversion of Sun Energy

David W. Krogmann, *professor, Department of Biochemistry, Purdue University, West Lafayette, IN*

The process of photosynthesis is of supreme importance to all of us in that it is the basis for agriculture and the source of biological fuel and building blocks for virtually all living creatures. In addition to providing the food and fiber of this year's crops for this year's needs, photosynthesis has provided, in ancient times, the vast amounts of green plant material that became trapped in the earth and were converted into coal and oil—the fossil fuels which provide so much of our energy supply today. Furthermore, photosynthesis has, over the long history of our planet, supplied the oxygen in the atmosphere which makes life possible for us.

Characteristics of Photosynthesis

Several characteristics of the process of photosynthesis should be emphasized. The first is that photosynthesis is a process of enormous magnitude on the global scale. About one hundred billion tons of carbon from the carbon dioxide gas in the atmosphere are converted each year by green plants into the organic molecules which become the substance of newly grown plants.

In addition to uniqueness in magnitude, photosynthesis is unique in the efficiency with which it converts light energy into useful chemical products. Green plants are far more efficient than the photocells which power pocket computers and power some of the devices in satellites and space probes.

Finally, there is a uniqueness in the uniformity of photosynthesis in that the chemical machinery in the leaves of grass and the leaves of oaks is nearly identical. This is of great practical importance since if we learn to regulate the process in some very simple plant like a microscopic alga, we will be able to regulate the process in complex crop plants like corn.

Photosynthetic Energy Conversion

Light energy is collected by an array of pigment molecules which act like a radio or a TV antenna in collecting radiant energy which falls on its surface. The energy is transferred at enormous speed to a processing center.

In your house, antenna collection and energy processing result in sound or a picture. In the plant, the collected energy is used to do chemical work that ultimately results in more plant material. The energy processing occurs in what is called a "reaction center," a complex of proteins and pigments. Light energy collected in the antenna and delivered to the "reaction center" is used to make a chemical change—to push an electron away from one molecule into a neighboring molecule. This happens with dazzling speed—in less than a pico second (10^{-12}) which is one millionth of one millionth of a second. A quick reaction occurs when light strikes many molecules, but the usual result is for the electron to bounce back to its point of origin and no chemical change is accomplished.

Photosynthesis is unique in that the energized electron is captured and stabilized with high efficiency. Part of the efficiency may come from the series of slightly slower steps that move the electron on to other neighboring molecules. Only recently, with the development of laser technology, could we measure changes that occur so rapidly. Now the pico second measurements are allowing new understanding of the result of light absorption by a molecule. Part of the efficiency may depend on the way in which the complex molecules of the "reaction center" are fitted together.

In 1985, it became clear that we could know the precise architecture of the "reaction center" from breakthroughs in x-ray crystal structure analysis. This analysis will pinpoint the locations of the many thousands of individual atoms in the complex molecules that make up the "reaction center." Like a child looking inside a watch, we can now see all the pieces and how they fit together. When we understand how each piece works, we will not only know why photosynthesis is unique in photoconversion of energy, but we also may hope to improve on the efficiency of human devices like photocells.

In recent years, herbicide-resistant varieties of weeds have appeared. With knowledge of which polypeptide interacts with the herbicide, we have begun, with the new techniques of molecular biology and genetic engineering, to study this polypeptide in more detail. By learning more about how the herbicide poisons this protein, we can design new herbicides to poison the new resistant varieties of weeds. Resistance can be genetically engineered into crop plants to more easily rid them of susceptible weeds.

This is but a single example of the frequent experience of the last few decades. Precise knowledge of the structure and function of individual molecules gives us great power to manipulate nature to the best advantage.

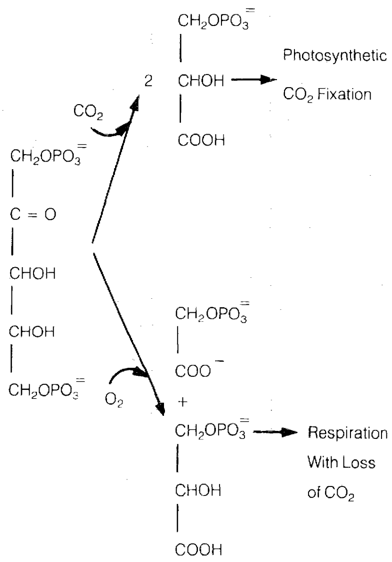
Gene Alexander, SCS

Recent research into the process of photosynthesis is helping scientists genetically engineer superior crops and improve crop productivity.

The diagram outlines a pathway to stable products of photosynthetic energy conversion which are used in yet another complex process of conversion of carbon dioxide from the atmosphere into sugar molecules. These molecules can then be converted into all the other kinds of molecules—proteins, nucleic acids, fats, and so forth—that are the substance of the new plant.

The first step in this CO_2 fixation process is made possible by the enzyme ribulose bis phosphate carboxylase. It is the limiting reagent of photosynthetic CO_2 fixation. If there is more enzyme or if the enzyme works more efficiently, there is more CO_2 fixation and more plant production. It catalyzes the series of reactions indicated in the upper pathway which also use compounds produced by light and which ultimately fix the CO_2 into the stable products of a growing plant. The alternative is for the enzyme to react with O_2 instead

Pathway to Stable Products of Photosynthetic Energy Conversion.



of CO_2 as shown in the lower pathway, and the result is a lowering of CO_2 fixation and a decrease in productivity. This undesirable alternative often occurs in crop plants.

Presently we are learning the precise structure and the chemical details of functioning of this enzyme. There is a good possibility that the powerful tools of biotechnology—molecular biology and genetic engineering—will allow us to regulate the choice between these two alternative reactions and so improve crop productivity at its most fundamental level.

Nitrogen Fixation in Non-leguminous Plants

Iris F. Martin, *associate program manager, Competitive Research Grants Office, Office of Grants and Programs*

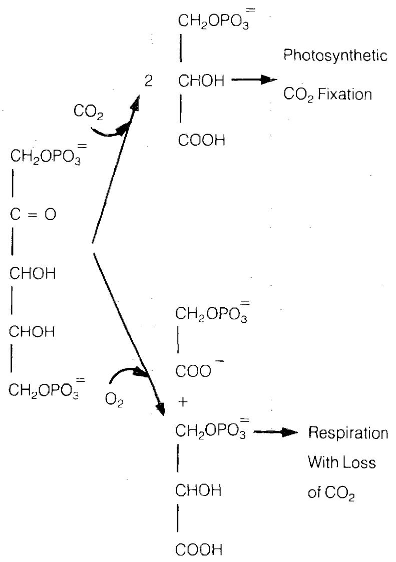
Tremendous advances have been made in the last 10 years toward understanding nitrogen fixation at the molecular level. The transfer to plants of nitrogen-fixation genes is an intriguing consideration. Let us first look at the process of biological nitrogen fixation and then at the more recent developments in molecular genetics that are providing information that may make such transfer of genes possible in future years.

Process of Biological Nitrogen Fixation

Nitrogen gas (N_2) makes up 79 percent of the earth's atmosphere. But before plants can use this molecular nitrogen for the synthesis of amino acids and proteins, it must be converted to combined or "fixed" nitrogen compounds. Plants do not have this ability. Making atmospheric nitrogen available to the food chain is restricted to certain prokaryotes (cellular organisms without a distinct nucleus), such as bacteria and cyanobacteria (blue-green algae), which contain an enzyme called nitrogenase. Nitrogenase is composed of two proteins—iron and molybdenum-iron—and catalyzes the reduction of gaseous nitrogen (N_2) to ammonia (NH_3).

This process requires large

Pathway to Stable Products of Photosynthetic Energy Conversion.



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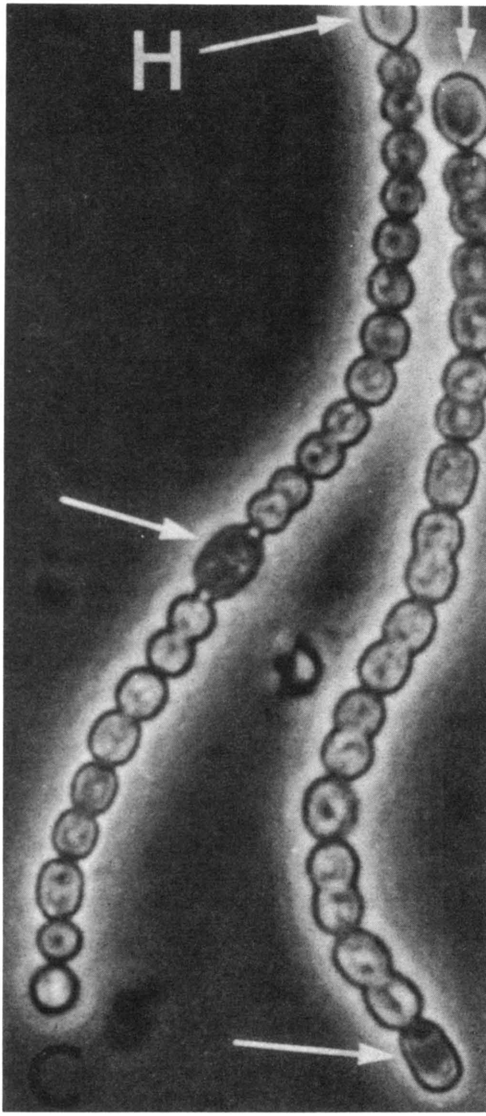
amounts of energy (ATP) and reducing equivalents (electrons). The sun is the ultimate source of the energy for nitrogen fixation with the ATP being derived from carbon compounds such as sugars manufactured by the plants through photosynthesis.

The reducing equivalents pass from an electron donor, a protein such as ferredoxin or flavodoxin, to the iron protein and then on to the molybdenum-iron protein where the conversion of N_2 to NH_3 occurs. Since both proteins of the enzyme are inactivated by oxygen, some bacteria fix nitrogen only when they are growing in the absence of oxygen. Others have evolved mechanisms and anatomical structures which protect the enzyme from oxygen.

Nitrogen-Fixing Symbioses

Some bacteria fix nitrogen in the free-living state and others only when living in a symbiotic relationship with a plant. Dissimilar organisms which live together in a mutually beneficial relationship are said to be in symbiosis. The smaller member is the symbiont. Legumes such as soybeans, peas, and alfalfa are well-known plants which enter into nitrogen-fixing symbioses when their roots are infected by specific bacteria called *Rhizobia*. The plant forms nodules in which the bacterium reduces N_2 to ammonia. More complex compounds of nitrogen are synthesized from the ammonia and transported to other parts of the plant. The plant provides the bacterium with carbon compounds that are metabolized to obtain the energy for the reduction of the nitrogen.

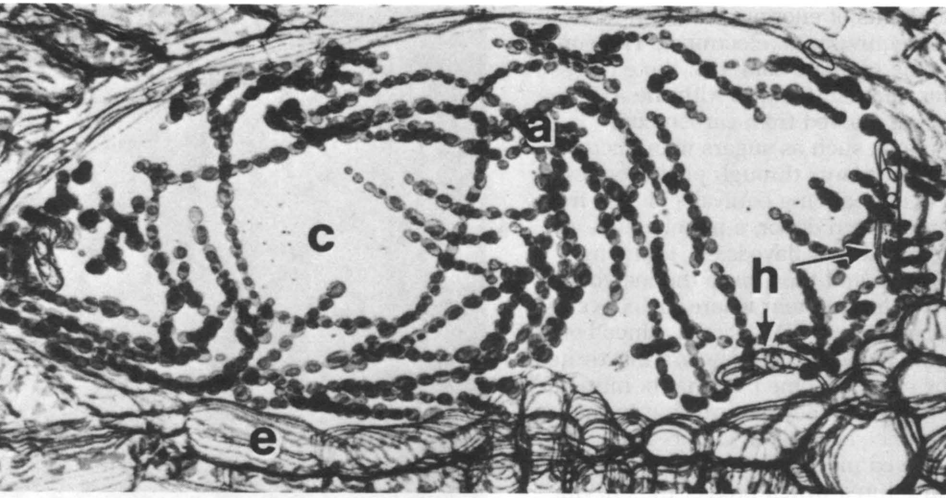
Some plants that are not legumes also enter into nitrogen-fixing relationships and contribute significant quantities of fixed nitrogen to their environments. One example is a small water-fern, *Azolla*, which harbors a



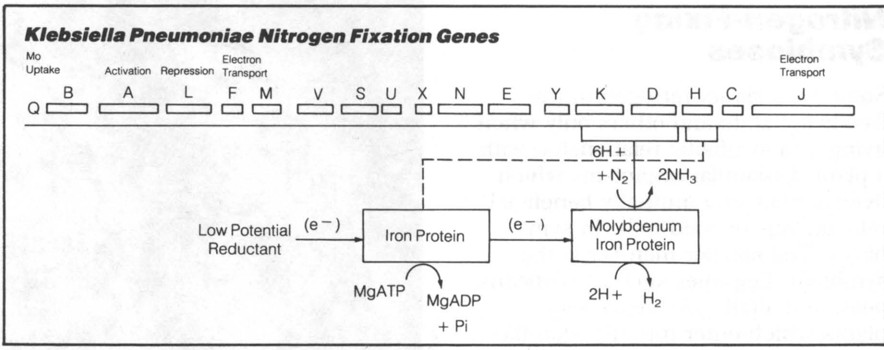
Courtesy of Dr. Robert Haselkorn

When Anabaena *filaments grow in the absence of fixed nitrogen, some cells may differentiate into heterocysts (indicated by arrows).*

cyanobacterium *Anabaena azollae*, as a symbiont. It is used as a source of nitrogen in the cultivation of rice. Another group includes certain trees and



As an Azolla leaf develops at the apex of the stem, a cavity forms and becomes inoculated with Anabaena *filaments.*



shrubs, whose roots become infected with the bacterium *Frankia*, for example, the alder tree. Study of the partners of these symbioses and their interactions are likely to provide new insights and unique opportunities to obtain genetic information that will have parallels in the legumes.

Azolla-Anabaena Symbiosis.

Nitrogen is frequently a limiting element in rice paddies, and the cost of nitrogen fertilizer is often prohibitive especially in the poorer countries. The water-fern, *Azolla*, can serve as a source of biologically fixed nitrogen for rice. The *Anabaena* symbiont can meet the complete nitrogen requirement of the fern, and decomposition of the fern supplies nitrogen to the rice plant. *Azolla* can be used as a green manure or grown as a companion crop with rice plants increasing rice yields by as much as 100 percent over unfertilized controls.

Cyanobacteria such as *Anabaena* are not only among the few organisms which can fix nitrogen while growing under aerobic conditions (that is, with oxygen present) but are the only oxygen-evolving organisms with this capability. Free-living *Anabaena* grows in the presence of combined nitrogen as a filament of vegetative cells. In the absence of a combined nitrogen source, some cells along the filament differentiate into specialized cells called heterocysts. They develop an outer envelope, lose their oxygen-evolving capacity, and provide an environment in which nitrogenase can function. When certain strains of *Anabaena* live in symbiosis with *Azolla*, they become less dependent on their own photosynthetic capacity as an energy supply. More vegetative cells differentiate into heterocysts, more nitrogen can therefore be fixed, and the nitrogen requirements of the host can be met. In *Azolla* the *Anabaena* reside in a cavity of the leaf. This symbiosis exhibits synchronous development. As a leaf develops at the apex of the stem, the forming leaf cavity becomes inoculated with *Anabaena*. As leaves age, an increasing percentage, up to 40 percent, of the *Anabaena* cells become differentiated into heterocysts, and parallel adaptations occur in the fern tissues.

Actinorhizal Symbioses. Strains of the bacterium, *Frankia*, infect a large array of nonleguminous trees and shrubs. These plants (actinorhizal) fix significant nitrogen in forests, especially in poor soils, and a number of them can grow under dry or acid conditions. These attributes make them excellent primary colonizers of post-glacial and post-mining soils.

Although nodules have been observed on actinorhizal plants for over 150 years, *Frankia* was not isolated in pure culture until 1978. Many different strains of the bacterium have since been isolated. Some have recently been grown on a scale adequate for inoculant production.

Frankia behave very much like the bacteria that infect legumes but considerably less is known about the actinorhizal symbioses. The bacterium multiplies rapidly in the area of the root and there is evidence of recognition between the *Frankia* and the plant. The bacterium invades the root, and the plant responds to this invasion by the formation of a nodule. Unlike a soybean nodule, in which the concentration of oxygen is quite low, actinorhizal nodules contain oxygen at approximately atmospheric levels. Within the nodule of most host plants, *Frankia* develop vesicles, or pouches, which apparently protect nitrogenase from oxygen and in which nitrogen fixation occurs.

A compound resembling hemoglobin, capable of readily binding and releasing oxygen, has recently been identified in nodules of some actinorhizal plants. It may prove to have a function comparable to that of leghemoglobin in legumes—maintenance of oxygen flux at low concentration.

Molecular Genetics

Actinorhizal symbioses, cyanobacterial symbioses, and free-living cyanobacteria can be of agronomic benefit through their capacity to use the sun's energy for photosynthesis and through the conversion of nitrogen from the air to more usable forms. Recently developed probes of molecular genetics are providing significant new insights about nitrogen-fixing organisms, but they are dependent upon physiological and biochemical advances for an understanding of which genes should be modified and the function of the gene products. The following nitrogen-fixing bacteria have been studied at some length.

Klebsiella Pneumoniae. The nitrogen fixation (*nif*) genes have been most fully characterized in the free-living bacterium, *Klebsiella pneumoniae*. The genes were first cloned, mapped, and subjected to nucleotide sequencing in the late 1970's. At least 17 adjacent genes code for the structure and regulation of the enzymes required for nitrogen fixation. The structural genes, *nif* H and D, and K that code for the protein precursors of the two nitrogenase components, the iron protein and the molybdenum-iron protein respectively, have been most thoroughly studied. Their nucleotide sequences have been determined and the amino acid sequences of the proteins deduced from these. *Nif* A controls the activation of the other *nif* genes, and *nif* L codes for a protein that acts to repress nitrogen fixation. The expression of *nif* A and L is in turn regulated by a central nitrogen assimilatory system.

Rhizobia. Significant information has been gained in the last few years on the nitrogen fixation genes in *Rhizobia*, which primarily infect legumes. Genes required for nodulation have been located in some strains and evidence for signaling between the plant and the bacterium is just emerging.

Anabaena. Gene structure and regulation have been studied extensively in one strain of free-living *Anabaena*. Only four *nif* genes have so far been identified, among them the three structural genes for nitrogenase. In the vegetative cells where one does not observe any nitrogen fixation, one of these genes is separated from the other two. A significant recent development is the discovery of gene rearrangement that occurs when the vegetative cell differentiates to a heterocyst. A section of DNA that separated the genes in the vegetative cell is excised such that, under nitrogen-fixing conditions, the structural genes are present and are transcribed as a single unit.

When growing in symbiosis with *Azolla*, *Anabaena* exports a large portion of the ammonia produced to the host. Biochemical and genetic studies have revealed significant modifications in the nitrogen assimilatory system of the *Anabaena*. A thorough understanding of the regulatory system could allow genetic manipulation of *Anabaena* in the free-living state for large-scale ammonia production.

Frankia. Among the least studied of the symbiotic nitrogen-fixing bacteria are *Frankia*. Initially, their slow growth rate in culture made molecular genetic studies difficult. However, culture methods have been improved, and genetic studies are now possible. Work is actively being pursued on the molecular biology of both the nitrogen-fixation genes and the interaction of the symbionts. *Frankia* are unusual in that they are capable of infecting a wider range of host plants than other known nitrogen-fixing bacteria. Biotechnology may be able to further extend that range.

Future of Transfer of Nitrogen Fixation Genes

It has been suggested that nitrogen-fixation genes might be transferred to plants that do not now have this nitrogen-fixation capacity. These genes would have to be in a form that could be incorporated into the plant genome, replicated, and expressed. The genes would have to be expressed in an environment amenable to nitrogen fixation where the enzyme, nitrogenase, could be protected from oxygen and where the enzyme system could tap into the sources of reductant and energy from the plant.

The full complement of nitrogen fixation genes has been cloned from *Klebsiella pneumoniae* and transferred to and expressed in another bacterium, *Escherichia coli*. These genes also have been transferred to yeast, but they could not be expressed. Transfer to a plant is a much more complicated process involving many more genes and still remains highly speculative.

Plant Growth Regulators

Machi F. Dilworth, *associate program manager, Competitive Research Grants Office, Office of Grants and Program Systems*

Plant growth regulators are hormone-like chemicals that occur naturally in plants, and play a central role in their growth and development. Five major classes of plant growth regulators have been identified as plant hormones, but scientists believe that there are more waiting to be discovered.

The five growth hormones include auxins, gibberellins, cytokinins, abscisic acid, and ethylene. Collectively, they regulate many facets of plant growth and development including seed germination, root growth, stem elongation, leaf expansion, flowering, seed development, fruit ripening, and dropping of leaves and fruits.

Each of these processes is directly relevant to agriculture; what is harvested for food, feed, or fibers is the result of one of these developmental events. For example, cereal grains are the seed, potatoes are the highly specialized stem, spinach is the leaf, and cotton comes from the highly developed cell walls of the ovule, a part of the maternal reproductive structure. The more we understand these processes, the better chance we will have of developing a strategy for crop improvement. With the advent of biotechnological techniques, it is now distinctly possible to manipulate the natural regulatory mechanisms to produce improved crop varieties with desirable genetic traits.

Physiological and Biochemical Regulation

Earlier research has identified a general role for each of the five classes of plant hormones as follows; auxin, a cell elongation hormone; gibberellin, a regulator of tissue and plant parts; cytokinin, a cell differentiation hormone; abscisic acid, a senescence regulator; and ethylene, a fruit-ripening hormone. Further research has uncovered more detailed information about their physiology and biochemistry. How these hormones regulate plant growth and development is extremely complex, yet the genetic makeup of each plant determines its precise developmental program. Moreover, the environmental factors interact with plant hormones in the regulatory process.

Interaction of Growth Hormones

The five classes of growth hormones can act independently in regulating many developmental events, but evidence is accumulating that they interact with each other as well. One of the clearest examples of this interaction is the auxin control of the biosynthesis of ethylene. Indole acetic acid, an auxin, has been demonstrated to stimulate the enzyme that catalyzes the last step of the ethylene biosynthesis. The interaction of auxin and cytokinin in determining shoot and root formation from callus tissue (a mass of undifferentiated plant cells) has been a well-known phenomenon since the 1960's. Abscisic acid has inhibited the induction of a starch-hydrolizing enzyme by gibberellin in the seed of barley. The gibberellin-to-auxin ratio has been shown to determine the number and length of cotton fibers.

Interaction Between Growth Regulators and Environmental Factors

Examples of the interaction between the plant growth regulators and envi-

Seed development is one of the facets of plant growth affected by natural plant hormones. These soybeans are ready for harvest.

ronmental factors are equally abundant, suggesting even more complicated mechanisms of hormonal regulation. Environmental factors such as light, moisture, and temperature are important signals to which the plants react in executing their developmental programs. Light, for example, plays a crucial role in plant morphogenesis including seed germination, shoot growth, and flowering.

Some of the effects of environmental signals seem to work through the same processes as do plant hormones while others do not. The effect of light on seed germination can be replaced by gibberellin, for example, but the effect of light on the initiation of flowering cannot be replaced by a known plant growth regulator.

These observations are based on biochemical and physiological studies that have been carried out by many investigators. The diversity of the phenomena involving plant growth regulators has puzzled many researchers as to the fundamental mechanism of hormone action in regulating plant growth and development. It has led to a hypothesis that the plant hormones do not act directly in the cell, but through some secondary messengers such as a calcium ion or a small carbohydrate molecule. So far, the hypothesis has not been proved or disproved. It also should be recognized that not all plant growth regulators need to work through the same mechanism.

Plant Growth Regulators and Gene Expression

Most of the recent advances in plant growth hormone research are being made in the studies on the effect of plant hormones on gene expression. The new molecular biology and various immunological techniques have allowed new approaches to the old problem of how the plant growth regulators regulate developmental processes.

It appears that all five plant growth regulators influence the expression of genes at the transcriptional (DNA to messenger RNA) level, the translational (messenger RNA to protein) level, and the posttranslational modification of the proteins.

Auxin. The first suggestion was made in the 1950's that auxin-regulated cell elongation may be mediated by auxin-controlled gene expression. It is only in the past few years, however, that conclusive evidence shows that auxin induces specific gene products, both messenger RNA's and proteins, in elongating shoots. The manner by which an auxin interacts with the gene and the nature of the gene products are being investigated by several laboratories.

Gibberellin. In the 1960's, it was shown that gibberellin induces the synthesis of a group of enzymes in the barley seed. These enzymes hydrolyze the material stored in the seed, converting them to usable nutrients for growing seedlings. Twenty years later, evidence is available to show that gibberellin increases the enzyme synthesis through stimulating the production of messenger RNA's specific for the hydrolytic enzymes. One of the best studied enzymes is alpha-amylase, an enzyme that converts starch to sugar molecules. The genes for alpha-amylase have been isolated and characterized by several groups of scientists. How gibberellin interacts with the alpha-amylase gene in increasing its messenger RNA's is under intensive investigation.

Cytokinin. The molecular biology research on cytokinin has led to the identification and isolation of a gene that encodes for the enzyme for the production of plant growth substances in bacteria. With a variety of genetic engineering techniques, the bacterial gene can be used as a probe to identify cytokinin biosynthesis (chemical production) genes in higher plants, or alternatively, the bacterial gene can be inserted into higher plants and expressed.

Both approaches would not have been possible a few years ago, but are now being tried by several laboratories. The latter approach is likely to produce valuable information about the mechanisms of cytokinin regulation of cell differentiation.

Abscisic Acid. High levels of abscisic acid are found in the developing seeds of many plants. It is thought that the function of abscisic acid in the developing seed is to prevent premature germination by the embryo before the seed maturation process is completed. Studies being carried out on the developing seeds of wheat, cotton, and other plants indicate that abscisic acid exerts its regulatory influence by increasing the level of specific messenger RNA's and possibly stabilizing the messenger RNA's that are important in maintaining the embryonic state of the seed. Abscisic acid also induces a set of messenger RNA's and proteins in germinating cereal seeds where abscisic acid has been known to act as an antagonist to gibberellin. This observation suggests that abscisic acid does not simply reverse the effect of gibberellin, but rather has a distinct function, possibly being to protect young seedlings from unexpected dehydration.

Ethylene. In agreement with the general notion of ethylene as a ripening hormone, it has been shown that ethylene induces the synthesis of a series of enzymes that contribute to the softening of plant fruit tissue. The genes that are activated by ethylene have been isolated and identified as the genes encoding for cellulase and galacturonase, both enzymes involved in cell wall degradation. How ethylene regulates the expression of these genes is being investigated.

New Technological Developments

In addition to the molecular biology studies, new developments in immunological techniques such as monoclonal antibodies are being used to identify the cellular targets of the plant growth regulator, and to isolate and assay the quantity of plant hormones from plant cells. These new biotechnology techniques are proving useful in increasing the basic understanding of the processes involving the plant growth regulators.

At the same time, genetic engineering technologies have opened up the possibilities of directly manipulating plants for agronomic traits associated with the growth and development.

It should be emphasized that recent advances in the plant growth regulator research using biotechnology are made possible because of the enormous amount of basic background information accumulated over the years about the physiology and biochemistry of plant growth regulators. Much is still to be learned about the plant growth hormones. Continued efforts in the area of physiology and biochemistry will be needed to take full advantage of the emerging biotechnological techniques in understanding plant growth and development and in applying the knowledge to crop improvement.

Producing Disease-Resistant Plants

Roger N. Beachy, *professor of biology, Washington University, St. Louis, MO*

Diseases caused by a variety of pathogens inflict enormous losses to crops each year. Control of diseases has historically relied on several approaches, including application of chemicals to control the spread of disease-inciting agents (bacteria or fungi) or their insect vectors, removing diseased material from the field to reduce the source of inoculum, maintaining good cultural practices, and incorporating genes for disease resistance. The latter is, by far, the most environmentally and, generally, economically sound way to control the spread of disease. It is also the most limiting approach, however, since disease organisms far outnumber the genes for resistance so far identified.

The search for resistant genes involves screening cultivars or species of plants to identify individuals that exhibit resistance to infection, replication, or spread of a pathogen. If the resistance trait is the result of expression of a single gene or genetic locus, plant breeders begin the task of introducing the resistance trait into a cultivar having desirable agronomic traits that will ultimately be released to the farmer. The plant-breeding process usually requires more than 5 years and considerable evaluation of progeny to eliminate plants that contain undesirable traits in addition to the disease resistance trait.

Search for Disease Resistance Genes

Isolating a Gene Based on Its Function. With the advent of the techniques of recombinant DNA and the transformation of plants, research scientists began to explore alternate approaches for producing disease-resistant plants. In the first and most favored approach, fundamental research is carried out on host pathogen interactions to determine the molecular basis that enables one plant to be resistant to a pathogen, while another is susceptible. In this approach, which is more or less standard, although difficult, researchers attempt to identify and isolate a specific gene or genes expressed in the resistant plant but absent or not expressed in a susceptible plant.

Scientists in a number of laboratories, primarily in the United States and in Europe, have taken this approach to study resistance to viral, bacterial, and fungal diseases. This work has led to the identification of genes in the production of phytoalexins, a class of chemicals that can act as part of a plant's defense reaction. It remains to be demonstrated that phytoalexins alone are capable of stopping pathogen invasion. More likely, resistance to disease is the result of a number of different processes of which a physical barrier or a chemical reaction may be only a part.

In some disease interactions, the resistant but not the susceptible plant produces one or more gene products *of unknown function* that may play a role in the resistance reaction. In one example, that of resistance of a single variety of cowpea to cowpea mosaic virus, resistant cells apparently block a specific step in virus replication according to G. Bruening, University of California, Davis. Isolating and characterizing this and other gene products that block steps in disease development may ultimately lead to their isolation and transfer to a susceptible plant, in this way conferring resistance.

Isolating a Gene of Unknown Function. The second method to isolate a gene for disease resistance in the absence of knowing the function of the gene involves an approach known as gene tagging. Gene tagging can theoretically be carried out in any plant species that contains a well-characterized system of transposable elements.

Also known as jumping genes, transposable elements have the capacity to move from one position on a chromosome to another. Such elements have been isolated and characterized from several plant species, including maize. A scenario for tagging a gene for resistance to stalk rot disease of maize is to start with a maize line resistant to the disease and to sexually cross this plant with a maize line containing a transposable element such as AC or Mu.

Seeds are collected from this cross, planted, and taken to flowering. After self-pollinating these plants, progeny contain both the gene for resistance and the transposable element. When each seedling is inoculated with the pathogen, all will be resistant unless the transposable element has inactivated the resistance gene, in which case the plant will be susceptible. The resistance gene can then be isolated by virtue of its being "tagged" with the well-characterized transposable element. Transferring the resistance gene to a susceptible plant may confer disease resistance to the recipient.

Although gene tagging has been proposed, it has not yet yielded a disease resistance gene. A primary reason for the lack of success to date may reflect the large size of the maize genome, and the unlikelihood that the element will insert into a resistance gene. It is also possible that the element will not insert into the target gene because it lacks the DNA sequences needed for such insertion.

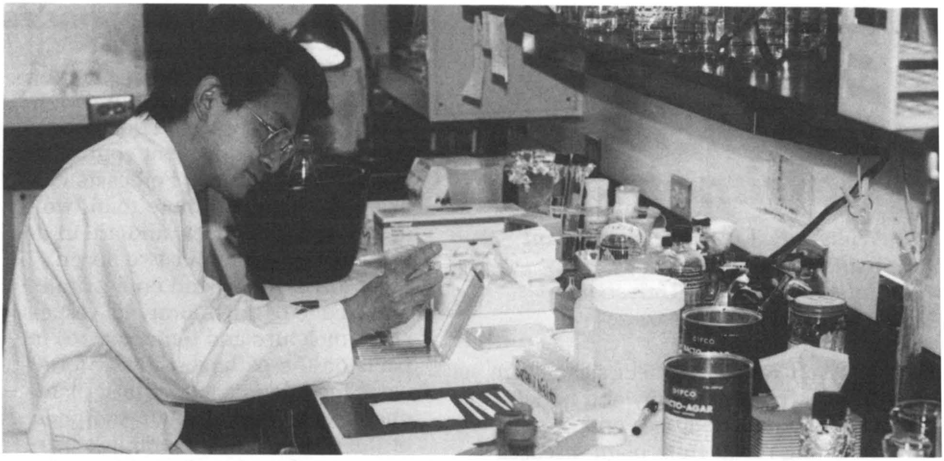
Disease Resistance by Transferring a Specific Gene

A third approach to produce disease-resistant plants is to generate plants that are cross-protected against virus infection. In the classical sense, cross-protection refers to the condition in which a plant infected by a mild strain of a virus is somewhat resistant to infection by a severe strain of the virus. The result of cross-protection is that, while the infection by mild strain of virus may depress the yield potential of the crop, it is substantially better than if a severe virus infection had spread through the crop.

A number of hypotheses have been proposed to explain cross-protection, but the molecular mechanism remains unknown. R. I. Hamilton suggested, in a 1980 article, that expression of viral genes in transformed cells might induce a protective response by the plants. In other words, expression of a single virus gene in cells might trigger the cross-protection mechanism, engendering disease resistance to transformed cells and plants.

Recent research results from my laboratory in collaboration with scientists at Monsanto Company, St. Louis, MO have shown this to be correct. We produced transformed tobacco and tomato plants that express the coat protein gene of tobacco mosaic virus (TMV). Transformed plants and their progeny are resistant to infection by TMV.

This result, reported in *Science* , May 9, 1986, is the first example of producing plants that exhibit resistance to virus infection as the result of a transfer of a single gene. It can be



Roger N. Beachy

Modern approaches to producing disease-resistant plants require the use of a variety of techniques. At Washington University in St. Louis, Missouri, a visiting scholar carries out an antibody reaction to determine if a transformed plant is expressing a "foreign gene."

anticipated that this approach will be applied to a variety of plant viruses that invade a number of different types of plants.

The mechanisms that cause the tobacco and tomato plants to be resistant to TMV infection have not been identified, and may involve the direct interaction of the product of the introduced gene with the infecting virus, or a defense response of the host triggered by expressioin of the introduced gene, or both. Substantial research effort will be needed to identify the mechanism and the degree of efficacy of this resistance in agriculture.

The success of these gene transfer experiments in producing virus-resistant plants lends hope that a similar approach might be used to induce resistance reactions against bacterial and fungal pathogens.

For many years plant pathologists, such as Prof. J. Kuc, University of Kentucky, have shown that when the lower leaf of some plants is treated with an extract of a pathogen, a disease resistance reaction is induced in upper leaves of the plant. If the inducing molecule is identified, it may be possible to genetically engineer plants to be permanently induced to resistance.

Although this approach currently is only an hypothesis, it should be tested. But a great deal of work must precede such an experiment, since, to date, the identity of the inducing molecule remains to be elucidated.

Long-Term Basic Research Commitment Needed

There is a high potential payoff for plant agriculture in the 21st century if disease-resistant plants can be generated either by classical approaches or by the new gene transfer technologies. Application of the new techniques to plant disease resistance, however, requires indepth understanding of how and why plants are susceptible or resistant. This can only be accomplished by a strong, broadly based and long-term commitment to a program of basic research in government, industry, and public and private university research laboratories.

Plant Microbes: Beneficial and Detrimental

William E. Fry, *professor of plant pathology, Department of Plant Pathology, Cornell University, Ithaca, NY*

Plant microbes affect agriculture both detrimentally and beneficially. Economic losses and human suffering result from plant diseases caused by microbes, so much ecological research deals with plant pathogens (disease-producing agents). Unfortunately, there are so many important crops, diseases, and agroecosystems that only a small proportion can be investigated intensively.

Recently, however, scientists have begun to focus on microbial influences which maintain plant health. (Beneficial microbes also are discussed in the chapter dealing with biotechnology and soil microbes.)

Motivations for Investigating the Ecology of Microbes in Agroecosystems

Much research is aimed at cutting economic losses and human suffering. Recent ecological research has supported the development of disease predictions (specific forecasts and general models to estimate disease loss probabilities) and is providing the knowledge for predicting the impacts of altered agricultural practices on microbes. Biotechnology and genetically engineered microbes are likely to contribute significantly to biological control, but research to assess the ecological impact of engineered organisms is needed.

Some Current Emphases

Disease Predictions. Accurate forecasting techniques will result in better disease control, reduced use of pesticide with equivalent control, and avoidance of disease. Forecasts have been developed for more than two dozen major diseases, and are in development for another two dozen. Most forecasts depend on accurate knowledge of environmental (especially moisture and temperature) impacts on the pathogen. A few forecasts include impacts of host plants, chemicals, or other biotic components of the ecosystem. General loss estimates are based on knowledge of: a) the most important environmental effects on pathogen and disease development; b) pathogen population size; c) probabilities of future weather; and d) their important interactions. Although application of computer simulation models is still in its infancy, these models have an increasingly important role in loss predictions. Our goal is to create estimates with sufficient lead time so that growers can adjust cropping plans.

Impacts of Altered Agricultural Practices. Changes in agricultural practice can lead to disastrous losses, such as the devastation caused by a leaf blighting fungus on rubber trees when rubber was shifted from forest to plantation agriculture. This shift to monoculture caused a minor problem to become a major one. Knowledge of the ecology of the microbe causing leaf blight of rubber would have enabled scientists to predict the problems associated with the move to monoculture.

In the United States, scientists knew enough about the ecology of major corn pathogens to predict that adoption of conservation tillage would not create an overall serious increase in disease. That prediction appears accurate.

Gene Alexander, SCS

Properly managed conservation tillage cropping systems provide many benefits and do not create an overall serious increase in disease.

Impact of Biotechnology

Benefits. The development of new diagnostic techniques via biotechnology creates new possibilities for research, identification, and the application of disease forecasts. A major limitation to ecological research in agroecosystems is that microbes are difficult to recover and identify. Now genetic engineering is making it easier to discover and monitor microbial populations through the use of tools with such sophisticated names as: cDNA probes, monoclonal antibodies, and restriction fragment length polymorphisms. Consequently, the influence of various factors on such populations will be much more readily identified.

The new diagnostic technology should enable more reliable application of disease forecasts, and integrated pest management systems. Consequently, pesticides (fungicides, insecticides and nematicides) are more likely to be used only when needed, rather than in unvarying schedules regardless of need. Disease diagnoses will also become more rapid and more accurate.

Biotechnology will enhance our ability to develop biological controls of diseases and of weeds. In general, biocontrol of plant diseases has been difficult.

One of the few successful applications involves cross protection, in which the infection of plant tissues by one virus suppresses the disease caused by another closely related strain of the virus. The protecting strain must have negligible impact on the host. Such strains have been found naturally, but also can be created in the laboratory via biotechnology. Cross protection has been used successfully in protecting citrus trees from severe strains of Citrus tristeza virus.

Another successful example involves the bacterium which causes crown gall of stone fruits and other plants: a nonpathogenic (or "friendly") strain produces an antibiotic which inhibits the pathogenic strain. Because the two strains are closely related, the nonpathogen survives in the same niches as the pathogen, and responds similarly to environmental fluctuations. Consequently, upon deliberate release of the biocontrol agent, close association of the two bacteria is assured.

For crown gall, the biocontrol agent was naturally occurring, but with biotechnology it will be possible to engineer normal resident nonpathogenic microbes into biocontrol agents.

Some microbes can be used as biocontrol agents for weeds. For example, a fungus is used to control Northern jointvetch in rice and soybean fields. Knowledge of the ecology and epidemiology of this fungus contributed to the development of a rational, effective biological control approach. Even though the genetic and biochemical bases of pathogenicity are unknown for this pathogen, it is so specific in its actions and is relatively unable to be dispersed widely that it makes a desirable biocontrol agent. With biotechnology, other pathogens of weeds can be altered for use in biocontrol. The ecology of specific candidates will have to be well described to assure selection of those with the greatest potential for safe, effective use.

Risks. Concern is widespread about the deliberate release of genetically altered organisms into the environment. This concern apparently comes from opinions that biotechnology speeds the natural rate of genetic change, and that genetically engineered microbes may be designed specifically to have modified ecological roles.

The first of the proposed releases of an engineered microbe, a genetically altered leaf-inhabiting bacterium, has generated significant publicity. Concern about the potential hazard to the environment delayed the release of that bacterium for some years. The wild form causes ice nucleation and hence frost damage on plants, while the altered form is non-ice nucleating and suppresses frost injury. Non-ice nucleating forms also occur naturally.

Unfortunately, inaccurate analogies have been drawn between genetically engineered microbes proposed for release and exotic microbes known to be dangerous. Certainly, some exotic microbes pose serious threats. Some of these have been accidentally introduced into the United States in spite of quarantine efforts (i.e. the microbes which cause Dutch Elm disease and Chestnut blight). The microbes proposed for release, however, are not of this known dangerous type. Instead, they are more like nitrogen-fixing bacteria introduced routinely to legume crops.

Assessment of Biotechnology Impact

Clearly the environmental impact of genetically-engineered organisms must be assessed before their release. Suggestions for attendant regulations include: an environmental impact assessment, subsequent monitoring of organism and system effects, identification of containment procedures, and contingency plans for mitigation. The competitive survival abilities, and relative fitnesses of natural and engineered forms and their effects on ecosystem processes need to be assessed.

Such assessments are not easy because relationships among organisms are altered in complex ways by different environments. Experiments must be conducted in contained facilities under controlled environmental conditions. The development of methods for such assessments must accompany biotechnological advances if we are to reap the full benefits of our technology. At present, it appears unlikely that specific regulations can apply to all releases. Instead, a case-by-case assessment of releases is likely to occur.

Jumping Genes That Control Plant Traits

Lila O. Vodkin, *research geneticist, Plant Molecular Genetics Laboratory, Beltsville Agricultural Research Center, Agricultural Research Service*

Recent advances in molecular genetics have generated excitement in agriculture and the plant sciences. One reason for this is the potential for commercial application, and another is the expanded opportunity to find out at the molecular level how genes function to control plant growth and development. These aims are not mutually exclusive but are likely to be closely interdependent. Advances in one area will stimulate progress in the other.

Mobile or transposable elements (sometimes popularly referred to as jumping genes) provide an opportunity to isolate and identify genes that would enhance crop quality and productivity. These mobile elements provide a direct link between plant characteristics (for example, disease resistance, plant height, organ shapes) and the DNA molecules that control the particular traits.

Gene Research

For thousands of years, genes have been manipulated empirically by plant and animal breeders who monitor their effects on specific characteristics or traits of the organism to improve productivity, quality, or performance. A basic understanding of how traits are transmitted from one generation to the next was formed by Gregor Mendel in the 19th century. His experiments and concepts showed that traits were controlled by units of heredity called genes. Extensions of this work led to formation of applied genetics and breeding programs.

The physical and chemical nature of genes remained unknown until the 1950's when James Watson and Francis Crick discovered that genes consist of a chemical known as DNA (deoxyribonucleic acid). DNA contains the information to control the synthesis of enzymes and other proteins that perform the basic metabolic processes of all cells. Each gene is a specific DNA sequence, and more than 100,000 different genes are found in a higher plant or animal species. This total set of genes for an organism (referred to as the nuclear genome) is organized into chromosomes within the cell nucleus. The process by which a multicellular organism develops from a single cell through an embryo stage and into an adult is ultimately controlled by a program contained in the genetic information of the cell and by an interaction of genes and gene products with environmental factors.

Flow of Genetic Information

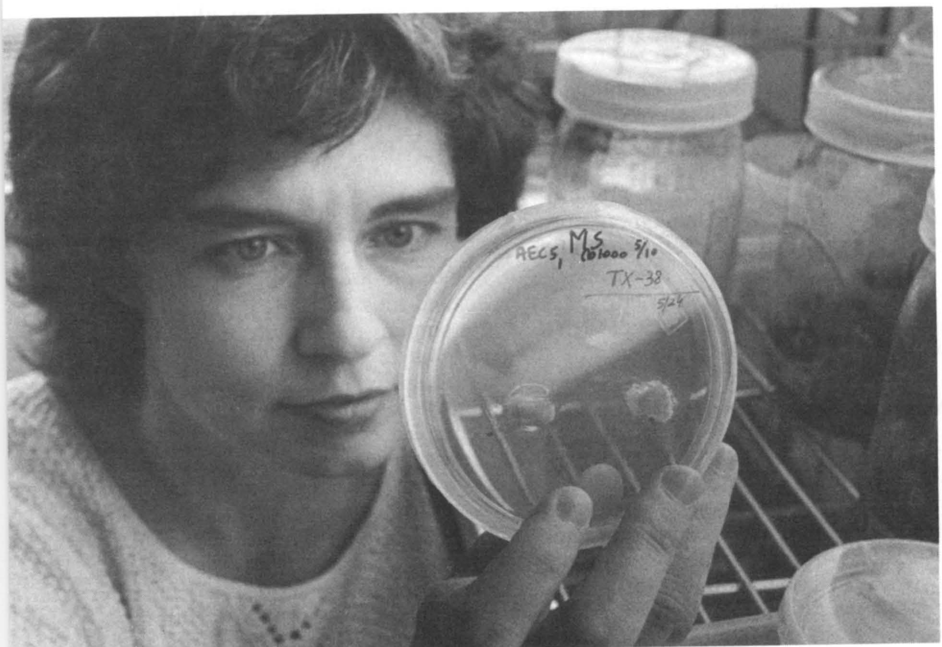
DNA produces a short-lived molecule called messenger RNA (mRNA) that is similar in structure to DNA. It serves as a temporary message carrier through which information encoded in the DNA is transmitted. Using complex cell machinery, the RNA messages are translated into specific sequences of amino acids that produce the structure of enzymes and other proteins. These protein molecules do the actual work in forming cells and organs and in carrying out metabolic processes within them. They interact in complex sets of pathways to produce particular characteristic features, or traits, of the individual. An observable or measurable trait of an organism is referred to as its phenotype, while the physical makeup of its genetic material is known as its genotype.

To physically isolate a gene that codes for a particular protein, the researcher generally works backward along this path of genetic information from proteins to DNA. Knowledge at the protein level is central to the process. At best, enough of the protein of interest must be produced to allow its isolation and characterization. Using knowledge of the properties of the protein, the researcher can identify the mRNA and eventually isolate the gene that encodes the protein. Since the discovery of recombinant DNA technology in 1975, isolating and identifying genes has become technically much easier. Because few proteins are abundant enough for this process to work easily, a large gap still exists, however, in our ability to identify and physically isolate genes that control most plant traits.

Transposable elements provide one way of physically isolating genes that control complex plant traits because they provide a direct connection between the observable trait and the DNA molecule that controls it. Despite the fact that all the intermediate steps in the process (the messenger RNA, the proteins produced by the genes, and the pathways) may be unknown, the gene responsible for the trait can be identified and physically isolated using a procedure known as transposon tagging.

Transposon Tagging

While most genes occupy a fixed position in the chromosomes, transposable elements can change their locations. When an element moves, it



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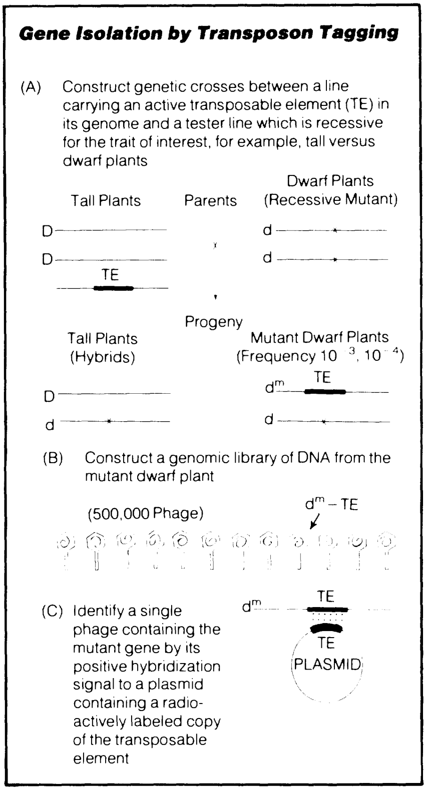
After identifying and isolating useful genes, researcher develops cell tissue cultures to modify plant germplasm and, ultimately, help plant breeders design better crops.

inserts into or near other genes and often affects how the invaded gene expresses itself, leading to a mutant trait.

The classic work of Barbara McClintock and other maize geneticists during the 1940's documented the existence of transposable elements in corn. In recent years, several different types of mobile elements in corn have been isolated and cloned by recombinant DNA techniques. These elements can now be used to "tag" other genes. For example, assume the need to isolate a gene involved in controlling plant height. The dominant form of the gene is designated *D*, and a mutant form that produces dwarf plants is designated with a lower case *d*. The process begins with a genetic cross between these two parental lines, one of which harbors an active transposable element (designated TE) somewhere in its chromosomes.

Each parent carries two copies of this particular plant height gene, and each offspring will inherit one copy from each parent. So all the progeny are expected to produce tall plants because they inherited one copy of the dominant gene that will mask or compensate for the defective mutant gene. A few dwarf progeny, however, may be found at a frequency of about 1 per 1,000 to 1 per 10,000 plants. These would likely result from movement of the transposable element into or near the normal gene *D*, leading to its inactivation, in effect creating a new mutation, designated d^m.

The next step is to extract DNA from the mutant plant (d^m) and to use standard recombinant DNA techniques to clone the plant's DNA. In this process, the DNA is cut into random fragments and cloned into a bacteriophage (a natural bacterial virus) vector. Each recombinant phage will contain a small piece of DNA about the size of one or a few genes. To have every gene of the plant represented in this library of genomic DNA, about 500,000 recombinant phage must be generated.



The third step is to identify which one of the half million phage contains the gene that controls plant height. The transposable element in the d^m gene serves as a molecular tag enabling this identification. Since the transposable element has previously been identified and cloned into a plasmid (a piece of DNA in the cell that is separate from the chromosome), it can be radioactively labeled and used to probe the entire genomic library for its complementary sequence. This process is known as DNA hybridization. It is an intrinsic property of all double-stranded DNA molecules. The radioactive transposable element DNA from the plasmid will attach to the DNA of the single phage that contains a copy of the element, and it will not attach to the other phage DNA's. In this manner, the d^m gene controlling plant height has been tagged with a radioactive signal and can be separated from all the other plant genes.

Once the gene that controls plant height has been isolated, it can be characterized to decipher the particular protein information it encodes and how this protein works in the plant.

Applications of Transposon Tagging

The basic approach of transposon tagging previously described is highly simplified. Although it has been used extensively in bacteria and in *Drosophila melanogaster* (fruit fly), the only plant in which the method has been used to date is *Zea mays* (corn). Some elements that inactivate genes have been identified by variegation effects or DNA sequence features that indicate transposable element action in several higher plant species.

In contrast to the wealth of knowledge about transposable elements in corn, genetic and molecular descriptions of mobile elements in other plants are much more limited. Future research will attempt to determine whether transposable elements from corn or other species will move within the chromosomes of new host plants into which they are transferred by genetic engineering rather than sexual crossing.

Plant biotechnology in the future will benefit by modification and transfer of genes for disease resistance and other valuable agronomic traits in higher plants. Mobile elements and other recently emerging approaches, such as mapping DNA by restriction fragment length polymorphisms (RFLPs) provide a way by which to identify and physically isolate these genes.

Genes for Pathogenicity

George H. Lacy, *associate professor, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg*

Molecular techniques for studying genes for pathogenicity have provided powerful insights for understanding the complex interactions among pathogens and their plant hosts. Further, these insights have provided ideas that may be exploited for controlling plant disease.

Pathogenicity is defined here as the ability of a disease-causing organism to establish a symbiotic relationship with a host plant that includes infecting, colonizing, and damaging the host plant. Genes for pathogenicity are sequences of DNA-mediating rearrangement of pathogenic genomes and regulation or synthesis of proteins or other compounds involved in the phenotype for pathogenicity.

Infection

The infection process consists of penetration of the host by the pathogen and establishment of a nutritional relationship with the host. For penetration to occur, the bacterium must come into contact with and, in many cases, attach to the host. For example, agrobacteria attach to plant cell walls through interactions of bacterial lipopolysaccharides with plant cell wall carbohydrates. More secure attachment is provided by cellulose fibrils produced by the bacterium which lace bacterial cells to the plant cell surface. Genetic elements related will attach to the DNA of the single phage that contains a copy of the element, and it will not attach to the other phage DNA's. In this manner, the d^m gene controlling plant height has been tagged with a radioactive signal and can be separated from all the other plant genes.

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Penetration. Penetration of bacteria into their hosts occurs by several methods: they may be forced into plant tissue by water congestion, they may be introduced into wounds, they may penetrate directly, or they may be injected into their hosts by sucking insects. Molecular studies of the soil bacterium *Streptomyces scabies*, causal agent of potato scab, have led to the cloning and characterization of DNA sequences mediating an extracellular cutinase that may be involved in direct penetration of the mycelium of the pathogen through the cuticle into its host.

Agrobacteria, which cause crown gall (*Agrobacterium tumefaciens*) and hairy root (*A. rhizogenes*), are especially interesting since the oncogenicity-inducing plasmids, pTi from *A. tumefaciens* which controls tumor formation and pRi from *A. rhizogenes* which controls root formation, contain within their genomes portions of DNA that are inserted directly into the host plant's genome. The major portion of the pTi or pRi plasmids does not become incorporated and is probably degraded by host endonucleases.

Since only these oncogenicity-mediating gene sequences (TDNA's) are required for pathogenicity, they are pathogens while both the bacterium and the pTi or pRi plasmids are merely biological and molecular vectors, respectively. The processes by which the plasmids and the TDNA's penetrate through plant cell walls, cross the plasmalemma, and arrive in the nucleus have not been described; however, proteins produced from genes located on pTi are known to be involved in DNA transfer to plant cells.

Nutritional Relationship. For infection to succeed, a nutritional relationship must be established between the pathogen and its host. Detecting this relationship is understandably difficult; however, for bacteria a nutritional relationship has occurred and infection has taken place at the point when the lag phase following penetration ends and the exponential growth phase begins.

Pathogenic TDNA's pose a special problem. Like viruses, they do not have nutritional processes of their own, but depend instead upon the host's synthetic pathways to increase their numbers. In this case, a nutritional relationship has been established at the point following its recombination into the host genome and at the initiation of host directed-DNA synthesis of the TDNA. For pathogenic TDNA's, establishment of a nutritional relationship depends upon insertion of the pathogenic TDNA into the host genome by an unknown process. DNA border sequences, however, have been identified at the left and right ends of the inserted TDNA that are involved in successful recombination. Further, the sequences from the right border are absolutely required and may replace entirely the sequences for the left border for successful insertion. These border sequences fit the definition for genes for pathogenicity although no protein products have been associated with them.

Host Range

The host range of plant pathogenicity usually refers to the range of different genera and species on which a particular pathogen may cause disease. In this usage, host range represents the basic compatibility between a pathogen and its host that allows disease development. The best molecular studies of host range have been performed with agrobacteria and have revealed that the plasmids related to oncogenicity-mediated differences in host range.

Molecular studies revealed that a portion of the pTi plasmid outside of the TDNA region is responsible for the differences in host ranges. This region of pTi has been named the virulence region, and several *vir* genes have been described within that region. It is unfortunate that the term *vir* was used to indicate genes controlling host range since it compounds the confusion created by an alternate use of the term virulence.

It has been learned, however, that exposure to plants of different species induces the formation of different proteins. This suggests strongly that host range differences require production of gene products by the pathogen. In the future, these studies will lead to a molecular knowledge of basic compatibility between pathogens and their hosts.

Overcoming Host Resistance

The term virulence also is used to mean the ability of pathogens to overcome host resistance. This usage differs from the usage concerned with host range since it refers to host-specificity among cultivars of plants within a species rather than the ability to cause disease among a group of species or genera.

It follows that pathogens are organisms capable of causing disease on some host plant. Nonpathogens, then, do not cause disease on any host plant. Virulent pathogens, however, can cause disease on a particular cultivar of a plant species, avirulent pathogens do not cause disease on a resistant cultivar, but can cause disease on some susceptible cultivar of the same species.

A virulent pathogen on its susceptible host cultivar comprises a compatible interaction. Conversely, an avirulent pathogen on a resistant host cultivar yields an incompatible interaction. Virulence is superimposed over basic host range compatibility and comprises a fertile area for molecular research into the interactions of pathogens and their hosts.

For some time it has been recognized that specific genes in the host mediate specific resistance to specific races of pathogens. Further, it has been found that the incompatible or race-specific resistance is mediated by the presence of a specific gene in the pathogen. In other words, specific incompatibility implies that a gene-for-gene relationship exists between the pathogen and its incompatible host. Avirulence genes, then, differ from host range genes in that they block pathogenesis rather than enable pathogenesis. It is possible, therefore, that virulence genes exist as separate entities from host range genes and modify the expression of host range genes in response to the presence of resistance genes in the host.

Support for this model is found in the discovery that avirulence genes may be moved from an avirulent strain of *Xanthomonas campestris* pv. *vesicatoria,* causal agent of bacteria spot of peppers and tomatoes, to a virulent strain and cause an incompatible interaction in the presence, but not the absence, of a single host resistance gene.

Other studies have indicated that transfer of an avirulence gene from one species of a pathogen to a second results in the second species developing incompatible reactions to the resistance gene specific for the first pathogen. In this case, an avirulence gene from *Pseudomonas syringae* pv. *glycinea* was transferred to *Xanthomonas campestris* pv. *glycines,* and both soybean pathogens responded in an incompatible manner to the pseudomonad resistance gene in soybean lines.

Host Damage

For pathogens, damage caused to the host is related to the production of toxins, enzymes, or plant growth regulating compounds that result in cellular disruption and release substances useful for pathogen nutrition. In soft rot pathogenesis, degradative enzymes such as pectate lyases, polygalacturonases, cellulases, proteases, and phosphokinases or phospholipases destroy elements of plant cells and release cell wall sugars, amino acids, or components of cell membranes for the use of the pathogen.

Chief among the aims of molecular studies will be the discovery of the coordination of the various enzymes required to cause soft rot and elucidation of the regulation of the enzymes. These studies will indicate how soft rot pathogens differ from several nonpathogenic organisms that have many if not all of the enzymes system apparently required for pathogenesis, yet remain saprophytes unable to colonize living plant tissue.

The production of low molecular weight toxins is an important mechanism for plant damage for several plant pathogens. In the case of phaseolotoxin produced by *Pseudomonas syringae* pv. *phaseolicola,* causal agent of halo blight of bean, molecular studies have located several genes probably in the biosynthetic pathway for toxin production. Further, molecular mechanisms for resistance to their own toxins have been discovered in *P. syringae* pv. *phaseolicola* as well as in *Pseudomonas syringae* pv. *tabaci* which produces tabtoxinine beta-lactam.

One possible outcome of this research will be the transfer of genes for these resistance factors from the pathogen for orntihine carbamoyltransferase (resistant to phaseolotoxin) or glutamate synthetase (resistant to tabtoxinin beta-lactam) into plant genomes to create crops resistant to toxin damage.

Tumor-causing bacteria such as *Agrobacterium tumefaciens* and *Pseudomonas syringae* pv. *savastanoi,* cause plant damage through alteration in levels of plant growth regulating compounds such as auxins or cytokinins. For the olive knot organism (*P. syringae* pv. *savastanoi*), two genes for auxin production are located either on a plasmid or in the chromosome of the pathogen. This pathogen modifies its host by secreting auxins into the plant tissue.

For the pathogenic TDNA of the crown gall organism, the picture is different. In this case, genes for both cytokinin and auxin production are carried on the TDNA, inserted into the host plant's genome, and expressed using eukaryotic rather than prokaryotic transcription and translation machinery. In this second model, the pathogen has changed the genetic machinery of the host to produce the plant growth regulating compounds.

Researchers have already taken advantage of the ability of the TDNA to insert into host DNA to engineer plants for resistance to antibiotics, herbicides, and disease resistance by deleting the information for the genes mediating plant growth regulating compounds and replacing them with the desired genes.

Techniques to Improve Plant Characteristics

Karen Woodbury Hughes, *professor and head, Department of Botany, University of Tennessee, Knoxville*

Plant cell and tissue culture techniques hold considerable promise for inducing new genetic variability within a species, and at least a portion of the variability so induced may have commercial potential. These techniques are a valuable addition to the battery of procedures available for crop improvement today.

The development of plants with improved vigor, yield, disease resistance, and other desirable traits by either conventional or nonconventional techniques is a common goal of researchers in the plant sciences.

To improve a given crop, however, genetic variability for a desired trait must be available. When a desired trait is not available within a given crop species, the appropriate gene or genes may sometimes be introduced from a related wild species. But in many cases, the wild species and domestic crop cannot be intercrossed. So techniques for creating novel variability within the crop species are needed.

One approach involves the use of plant cell and tissue culture techniques to induce new variability.

Novel Variation Recognized

The phenomenon of novel variation appearing in tissue culture-derived plants was recognized as long as 20 years ago but considered to be undesirable by scientists who were trying to obtain identical clones. Such variants "got in their way." Recently, however, variability from culture has been recognized as having potential value.

The general term somaclonal variation is used to describe new genotypes, (genotypes are classes of organisms sharing a specified genetic makeup) different from the source genotype, which appear in plants regenerated from culture. Technically, however, the term should be reserved for cultures derived from somatic (body) cells. The term "gametoclone" has been suggested for plants derived from cultures of gametic tissues.

Somaclonal variability probably arises from two sources, the somatic tissues of the parent plant and the tissue culture process itself. Somehow, genetic changes occur with higher frequency in somatic tissues than they do in meristematic tissues which give rise to the germ line and which are capable of dividing indefinitely. How this happens is not well understood. But tissue culture techniques can be used to induce plant formation from somatic tissues, and this previously untapped source of variability is available to the breeder.

It may be that mobilization of transposable genetic elements causes chromosome breakage and mutations. This could explain, at least in part, the appearance of chromosomal aberrations and point mutations in cultured cells. McClintock has suggested that transposable elements are released under conditions of stress and that placing tissues in culture creates a form of stress.

A second possibility is that the rapid cell division which occurs in culture systems may overwhelm the cells' normal repair mechanisms. Rapid cell divisions also may lead to instability in the mitotic (cell division) apparatus bringing increases in a set of chromosomes (polyploidy) or increase or decrease in a single chromosome (aneuploidy).

Many studies using somaclonal var-

Geneticist emasculates cuphea flowers before crossing with other cuphea species as part of a hybridization program.

iation to produce new phenotypes involve simply growing plants obtained from tissue culture and examining them for potentially useful changes. In some cases, however, it may be desirable to eliminate the majority of random changes occurring in culture by incorporating a selective agent in the culture medium, thus leaving only the desired mutant for further study.

Examples include selection for herbicide resistance, salt tolerance, toxin resistance, and biochemical pathway mutants.

If the frequency of a desired mutation arising through somaclonal variation is not high enough, the natural variability induced by the culture system can be supplemented with a mutagen, a substance that increases the frequency or extent of mutations. Somaclonal variation includes single gene mutations, chromosomal aberrations, and variation in multigene quantitative traits.

Chromosomal Aberrations

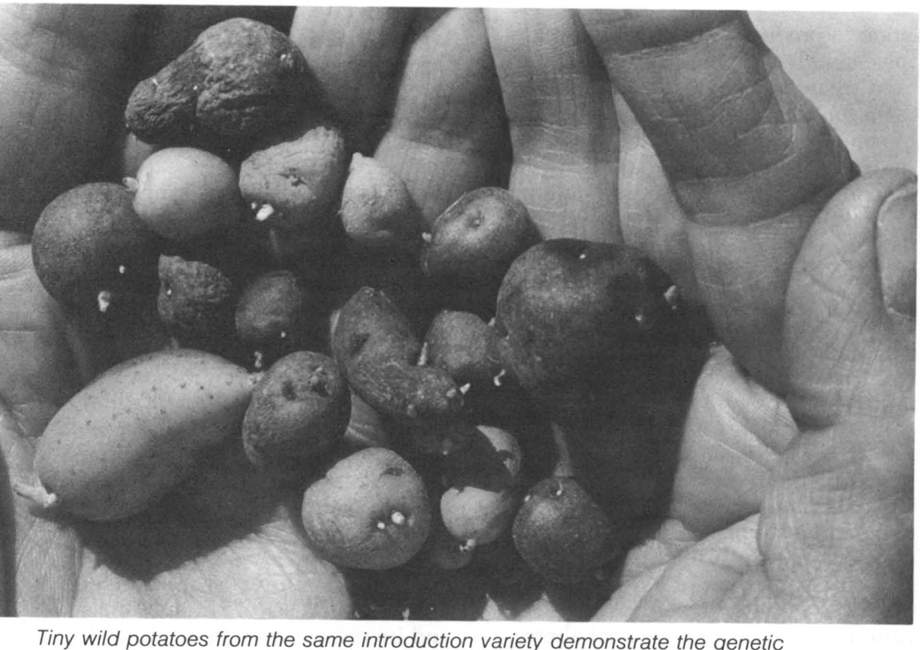
Chromosome aberrations occur in culture systems and in plants regenerated from culture. The extent of chromosomal instability ranges from slight to substantial. Numerous factors contribute to chromosome instability. Yet no characteristic instability for a particular species can be cited.

In some studies, the proportion of chromosomal aberrations is low, in other studies quite high. For example, between 55 and 70 percent of plants regenerated from alfalfa protoclones showed some type of chromosomal aberration, but in other studies few or no chromosomal changes were observed.

Changes in chromosome number observed in culture systems include increases in a set of chromosomes and increases or decreases in a single chromosome. Intrachromosomal changes such as duplications, deletions, and translocations also have occurred.

Explant Process. One source of chromosomal aberrations observed in culture is the explant source itself—removing living tissue and placing it in a medium for tissue culture. Chromosome numbers in species are generally constant in tissues such as root tips and reproductive cells. However, differentiated somatic tissues of a plant may have cells that vary in chromosome number. Processes leading to chromosomal duplication include endoreduplication (chromosomes duplicate several times before mitosis) and failure of cytokinesis and endomitosis (repeated nuclear divisions without cytoplasmic division). When these tissues are placed in culture, the various levels of repetition of the basic number of chromosomes become represented in the culture system; however, as the culture ages, this distribution can change significantly.

Media Factors. Media components also can affect the frequency of chromosomal aberrations in a culture system. Media factors such as the plant hormone (auxin) 2,4-D have been implicated in the induction of chromosome aberrations including polyploidy and aneuploidy in some species; however, in studies with alfalfa, there was no correlation between levels of 2,4-D in the culture medium and the frequency of aberrations. Auxin and cytokinin (another growth substance) ratios can affect the proportion of cells with polyploidy but again, different species tend to respond differently. Species and hormone interactions apparently play a role. Coconut milk and yeast extract when added to the medium may in-



Bob Biork, ARS

Tiny wild potatoes from the same introduction variety demonstrate the genetic diversity that provides potato breeders with large gene pools. Somaclonal variation provides another source of exposing genetic diversity.

crease the frequency of polyploidy. Relatively simple factors such as frequency of subculture, light duration and intensity, and cell density could affect the frequency of chromosomal aberrations, but there is little data in this area.

Age of Culture. Several studies have indicated that the proportion of cells with chromosome aberrations increases with the increasing age of the culture. Often changes accumulate to a level which inhibits regeneration of plants from the culture. Where regeneration does occur, cells with gross chromosomal aberrations are apparently selected against in the differentiating tissues.

There are exceptions. Extended time in culture (up to 9 months) did not significantly increase the proportion of chromosomal aberrations in a study with alfalfa. So there are species differences in response to culture factors. The induction of chromosomal aberrations depends on a number of different and poorly defined factors and may vary from species to species.

Tissue culture systems offer a mechanism for altering the chromosomal makeup of a species. Much of the somaclonal variation appearing from culture is because of changes in the number or organization of the chromosomes. In rice somaclones, potentially useful traits such as thicker stems, larger leaves, and increased grain size were associated with a spontaneous doubling of the chromosomes in culture.

Point Mutations

Point mutations are changes in a specific gene or segment of DNA as opposed to the larger chromosomal changes mentioned. There is good evidence that point mutations do occur in culture systems. One hundred forty-two plants were regenerated from tissue cultures of the wheat variety Yaqui 50E. Extensive biochemical and morphological variation was observed in the regenerated plants and their progeny. Four hundred plants from seeds did not exhibit the variability seen in tissue culture-derived plants, indicating the potential of tissue culture for novel variation.

Mutants included dominant mutations, recessive mutations and mutations that were apparently polygenic, that is, involving more than one allele. Surprisingly, in some cases, the regenerated plants were homozygous. Homozygosity could occur by gene conversion or by chromosome substitution through aneuploidy followed by a return to the diploid state, where the basic chromosome number doubled. Plants regenerated from culture can exhibit variability for more than one trait, and the traits segregate independently and are found on all seven of the wheat chromosomes.

The detailed genetic analysis needed to confirm single gene mutations also has been completed for tomato by researchers at DNA Plant Technologies including a color mutant (tangerine-virescent), and jointless pedicel. Some of the tissue culture-derived mutants segregated independently of previously known mutants with similar phenotypes so the mutations are indeed new to the breeding population. Single gene mutants also have been reported in tissue culture-derived plants of corn and rice.

Other Mutations

Mutations in culture also occur in the genes which control the plant's photosynthetic and energy-production processes. Sexually propagated plants of Corn with T (Texas) cytoplasm are male sterile (in the absence of fertility-restoring genes) and are susceptible to toxins produced by *Helminthosporium maydis* Race T. Yet some

Somaclonal Variation From Culture

Species	Types of Variability
Tomato	Increased solids, jointless pedicel, fruit color
Wheat	Height, awn size, spike fertility, tiller number, awnless
Lettuce	Increased seedling vigor
Celery	Pathogen resistance
Rice	Dwarf, panicle shape, heading date, fertility
Triticale	Spike length, fertility, height, kernel protein

plants regenerated from Corn with T cytoplasm were shown to be resistant to the toxin produced by *helminthosporium maydis*. In some of the experiments, no selection pressure was applied during the culture period. In other experiments selective pressures were applied, that is, corn cultures were grown in the presence of the toxin to select for the mutation. Agarose gel electrophoresis of the mitochondrial DNA indicated changes associated with the change to resistance and inheritance of the trait was shown to be extranuclear.

Commercial Applications

Variation from tissue culture is being tested in a number of species for potential value. While the majority of observed variability is not useful and actually decreases the viability of regenerated plants, some potentially valuable variants have been obtained.

Protoclones (plants derived from protoplasts) of the Russet Burbank potato exhibited a surprisingly high frequency of variation. The range of variation included resistance to *Alternaria solani* and *Phytophthora infestans*. The latter is a late blight pathogen and Russet Burbank is very susceptible to the disease. Approximately 2 percent of the protoclones exhibited significant resistance to the disease. Other traits such as white tubers and altered growth habit also were observed.

The majority of the traits were preserved through four cycles of vegetative propagation and field testing. However, sexual propagation is not possible in this variety, and the genetic basis for many of the changes could not be established.

Pathogen resistance also was observed in plants regenerated from celery cultivars. The plants were examined for resistance to the pathogenic organisms *Cercospora apii* and *Septoria appicola, Pseudomonas cichorii* and *Fusarium oxysporum*. Variable disease resistance was observed in the regenerated plants, ranging from highly susceptible to highly resistant.

A number of agronomic characters of potential value to agriculture were observed in plants regenerated from wheat tissue culture including height and tiller number which can affect yield, awnless cultivars which may be valuable during drought, and mutations of the seed gliadin proteins which can affect flour quality. In "Carmen" triticale, two second generation plants were found to have a significant increase in percent kernel protein relative to the controls. This type of variant should have immediate use in breeding programs for yield improvement.

Grasses, including tall fescue and turf grasses, are potential candidates for improvement through somaclonal variation. Researchers at O.M. Scott and Sons have regenerated turf grasses and tall fescue from tissue culture and are presently testing the regenerated progeny for potentially useful new variants.

Plants Defend Themselves Chemically

Udo Blum, *professor of botany, Department of Botany, North Carolina State University, Raleigh*

Plants contain and may subsequently release into the environment molecules that provide them with defenses against disease, nematodes, herbivores, and other plants. Because of genetic differences and continuous selection pressures from the natural environment, the distribution of such molecules is irregular. In addition, the concentrations of such plant molecules are determined by the environment in which they grow. Thus potential levels of chemical defenses are determined by the genetic makeup as well as the growth environment of the plant. In cases where molecules must first enter the soil before acting on an associated species, the role of soil factors such as microorganisms, amount of organic matter, and soil pH also are important in determining the active concentrations.

Little information is available on the mode of action of most of these molecules. Such information can be useful in manipulating interactions to the benefit of agriculture. For example, toxicity of simple phenolic acids in soil solutions can be minimized or enhanced by manipulating soil pH and soil nutrition.

The plant kingdom is a vast storehouse of chemical molecules waiting to be identified, isolated, manipulated, and used. With the advent of molecular biology and biotechnology, new opportunities for effectively using such molecules in agriculture are now at hand.

Before discussing specific plant chemical defenses, let us look at the kinds of molecules found in plants.

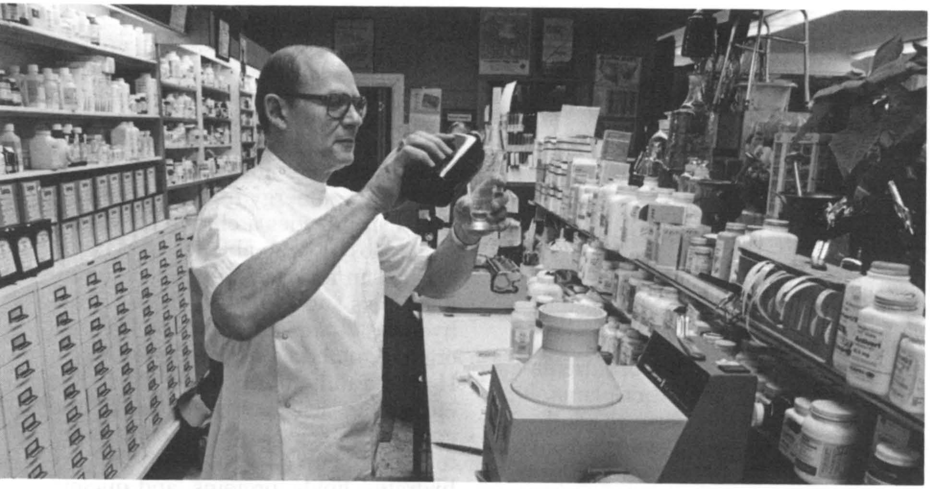
Plant Molecules

Apart from the short period during seed germination when plants are heterotrophic (dependent on their seed stores for energy), all higher green plants are autotrophic (capable of obtaining energy from the sun). This fact provides a clue to the enormous biosynthetic abilities of plants. Plants can make universally required molecules such as DNA, RNA, carbohydrates, lipids, and proteins from inorganic materials that include CO_2, H_2O and mineral nutrients (N, P, K, etc.). They also can synthesize all the complex molecules which contribute to the makeup of their tissues. Carbohydrates, lipids, proteins, and nucleic acids are important for growth and development in both plants and animals.

However, among the compounds synthesized by plants are a series of complex materials that appear to have no immediately obvious metabolic function in plants (called secondary metabolites). These include alkaloids (complex and bitter-tasting substances such as quinine, morphine, and nicotine), phenolics (such as tannins), and terpenes (compounds found in odor-giving oils such as peppermint).

Over the last 100 years 5 percent of the world's plant species have been examined for alkaloids resulting in the isolation and identification of 5,600 alkaloids. All alkaloids contain nitrogen, frequently as part of a heterocyclic carbon ring system. They are classified either according to their ring system or according to the amino acid from which they are derived.

Plants also produce thousands of compounds that contain one or more phenolic residues. These compounds can be divided into major groups according to the number of carbon atoms in their skeleton. Most phenolics arise from a common biosynthetic intermediate, phenylalanine or its close



Barry L. Runk, Grant Heilman Photography

Plants provide substances found in about a fourth of all prescription drugs.

precursor, shikimic acid.

Finally, there are probably more terpenes than any other group of plant products. The term "terpene" is used to denote branching compounds containing five carbon units. Terpenes are essential to plant growth since chlorophyll and carotenoids, which are essential for photosynthesis, also are derivatives of terpenes. The roles of alkaloids and phenolics in plant metabolism have not been clearly identified. (For more information, you may wish to read J. B. Harborne's book, *Introduction to Ecological Biochemistry*, Academic Press, 1983.)

Plant Chemical Defenses

Have you ever wondered why some plants are resistant to fungi, bacteria, nematodes, or herbivores while others are clearly susceptible to such organisms? Or wondered why some plants are more effective in reducing the growth of associated plants than others? There is ample evidence to show that at least some of these differences in behavior are associated with the presence and absence of chemical defenses produced by plants.

Defense Against Disease.

Plants are resistant to the majority of micro-organisms, including pathogens, that come in contact with them. Much of this resistance is associated with plant-produced molecules. Each plant species or even variety has its own unique set of molecules. Tomatoes make a number of cyclic and acyclic mono- and sesqui-terpenes, for example, α-pinene and α-humulene respectively, which fight fungi. This was discovered when it was observed that plants with many glandular hairs, sources of these compounds, were infected less by fungi than were plants with fewer glandular hairs.

Plants also produce a variety of substances called phytoalexins. These substances are produced by a plant only after it comes in contact with the pathogen. Each species produces only one or a few phytoalexins that usually are unique to closely related species. Most phytoalexins within a plant tribe or family are similar in structure. For example, cotton sesquiterpenes isolated from *Xanthomonas*-inoculated leaves (bacterial pathogen) have been shown to exhibit antibacterial activity. Much smaller amounts of these compounds were isolated from both inoculated susceptible as well as uninoculated resistant leaves. Chemically characterized phytoalexins have been isolated from at least 15 plant families.

(For the source of the examples cited here and additional information, you may wish to read A. Stoessl's "Secondary plant metabolites in preinfectional and postinfectional resistance," *The Dynamics of Host Defence*. J. A. Baily and B. J. Deverall (eds.), Academic Press, 1983.)

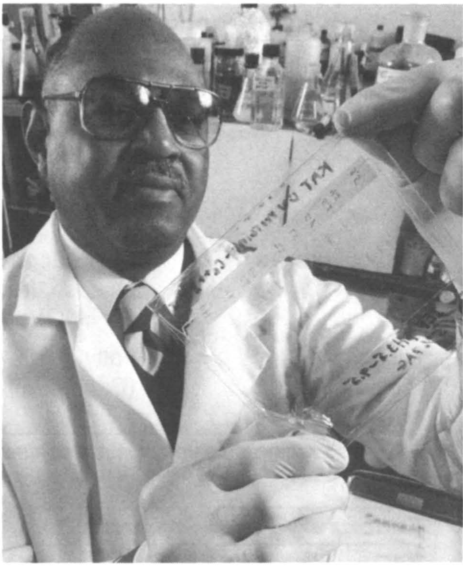
Defenses Against Nematodes. In a number of instances plant root exudates and decomposing plant debris have been observed to be antagonistic toward nematodes. For example, the presence of asparagus roots in soil leads to a decline in the number of stubby-root nematodes. In addition, the number of nematodes do not increase even in the presence of a suitable host if its roots are intermingled with those of asparagus.

(For additional information you may wish to read N. A. Minton's "Plant-nematode relationships of an allelopathic nature," *Report of the Research Planning Conference on the Role of Secondary Compounds in Plant Interactions*. USDA, 1977.)

Defenses Against Herbivores. Many bitter or astringent substances such as certain lactones, alkaloids, cyanogenic glucosides, and tannins are important in deterring mammalian herbivores from consuming plants. Plants also contain a variety of molecules that a) prevent insects from feeding, b) disrupt normal growth and development, and c) kill insects outright. (The chapter, *Natural pesticides,* deals with this subject.)

The presence of such substances in plants can be beneficial to agriculture (e.g., crop production), but they can also be detrimental (e.g., livestock poisoning). The economic impact of livestock poisoning by plants in the United States is enormous. According to USDA's Agricultural Research Service, 3 to 5 percent of cattle, sheep, and horses on western ranges are lost because of poisonous plants. For example, Johnson grass, a species of wide distribution, furnishes good forage under normal conditions, but can become toxic to livestock during dry weather or after frost, drought, or high temperatures. Johnson grass contains dhurrin, a cyanogenic glucoside. When plants are under stress, plant enzymes release hydrocyanic acid or prussic acid from dhurrin.

(For additional information you may wish to read R. F. Keeler, K. R. Van Kampen, L. F. James, *Effects of Poisonous Plants on Livestock*, Academic Press, 1978.)



Tim McCabe, ARS

ARS chemist conducts basic and applied research on fruits and vegetables and their products, including investigations of the properties of plant enzymes.

Primary Plant Products

Name	Major elements	Polymers
Proteins	Amino acids (C, H, O, N, several contain S)	Enzymes, etc.
Nucleic acids	Nucleotides (C, H, O, N, P)	Deoxyribonucleic acid (DNA), Ribonucleic acid (RNA)
Carbohydrates	Monosaccharides, e.g., glucose, fructose, etc. (C, H, O)	Polysaccharides, Starch, Cellulose, etc.
Lipids (neutral fat, phospholipids, etc.)	Fatty acids, glycerol (C, H, O, P)	

Polymers are large macromolecules composed of repeating units of smaller molecules.

Secondary Plant Products

Name	Example
Alkaloids	Quinine
Phenolics	p-coumaric acid
Terpenes	α-pinene
Cyanogenic glucoside	dhurrin

Plant-Plant Interaction. Not only do plants have chemical defenses against micro-organisms, nematodes and herbivores, but they also have chemical defenses against crowding by other plants. A large number of plant products have been identified (phenolics, alkaloids, terpenes, and so forth) which, when released into the environment in sufficient quantities, will inhibit the growth of neighboring plants. These materials are released by rainwash or by fog drip from leaf surfaces and glands, by volatilization from leaves and roots, by secretion and exudation of roots, and by decay of plant parts.

There is considerable evidence that several of our more aggressive perennial weeds including quackgrass, Canada thistle, Johnson grass, and yellow nutsedge can inhibit the growth of certain crops by release of such toxins. Some crop accessions may also inhibit weeds. Effective weed suppressors have been found in collections of sunflower, oats, wheat, and soybeans. Toxins which can suppress crops and weeds have been identified from several cover crop residues associated with minimal- or no-tillage crop production.

A. R. Putman and W. B. Duke, of Michigan State University, East Lansing, hypothesized that many presently cultivated species may have possessed chemical molecules capable of inhibiting weeds when growing in their wild habitat. Such traits could have been lost through domestication with intense breeding and selection for specific desirable traits. It may be possible to reintroduce such chemical traits into at least some of our present crop species.

(For additional information on chemical plant-plant interactions you may wish to read E. L. Rice's book, *Allelopathy,* Academic Press, 1984.)

VI
Insects and Weeds

Natural Pesticides

Martin Jacobson, *research chemist, Insect Chemical Ecology Laboratory, Agricultural Environmental Quality Institute, Beltsville Agricultural Research Center, Agricultural Research Service*

From the time of the early Romans until 1900, only three plant-derived insecticides—pyrethrum, hellebore, and nicotine—have had widespread use. The discovery of rotenone and several plant-derived insecticides followed in rapid succession. Advances in chemistry and improved screening techniques have led to the discovery of many plant-derived insect toxicants, repellants, attractants, feeding deterrents, growth inhibitors, and sterilants.

Some of these compounds, produced by the plants as defenses against pests and pathogens, may be developed commercially from arid or semiarid plants established as new crops. They would expand the range of available products for insect pest control as safe substitutes for some synthetic insecticides that are ecologically disruptive and for others to which insects have developed resistance.

Six Promising Plants

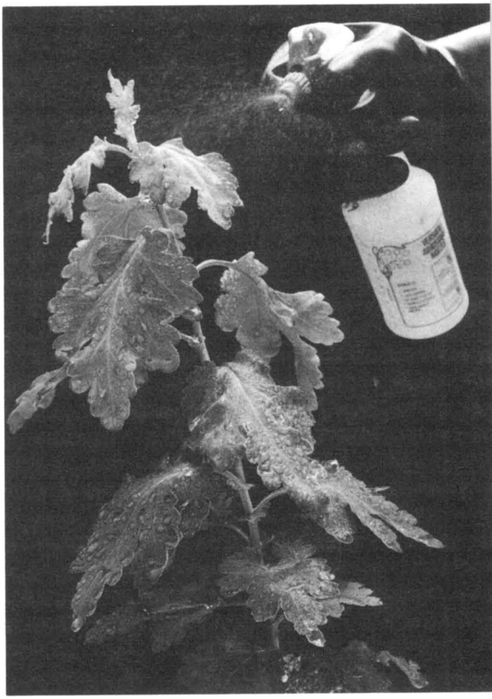
Six plants appear to be particularly promising. Not only are they good sources of insecticides and related chemicals, but they are adapted to areas that are marginal for production of traditional food and fiber crops and represent potential multiproduct crops for the United States. They are calamus (*Acorus calamus* L.), basil (*Ocimum basilicum* L.), big sagebrush (*Artemisia tridentata* Nutt.), chilcuan [*Heliopsis longipes* (A. Gray) Blake], mamey (*Mammea americana* L.), and neem (*Azadirachta indica* A. Juss.). Although all six could be commercially viable, the neem tree is by far the most useful and likely to succeed. Much applied research on agronomy, commercial processing, and marketing is needed before commercial production of these species as sources of insecticides would be possible in the United States.

Calamus. This plant (also known as sweetflag) is a member of the family Araceae. It is a semiaquatic robust perennial that can also grow on dry land. Calamus is 5 to 6 feet tall, has a horizontal rootstock, and grows at altitudes from 3,000 to 6,000 feet. The plant grows wild in the United States from Florida to Texas and in Idaho, and in the various provinces of Ontario and Nova Scotia in Canada. It is propagated by division in the spring or autumn.

The large rhizomes are repellent or toxic to clothes moths, house flies, fleas, lice, mosquitoes, and many stored-grain insects. Beta-asarone, the component primarily responsible for these pesticidal effects, is highly effective against the rice weevil, which is probably the most damaging insect pest of stored grains in grain elevators. Beta-asarone would probably be very useful as a fumigant for protecting grain-filled storage areas without leaving residues on the grain after the areas are ventilated. Other potential uses of calamus compounds are for the treatment of tuberculosis, as a germicide, and in perfumery.

Basil. Sweet basil is a smooth or slightly pubescent aromatic herb with white or slightly purplish flowers. It was experimentally cultivated from seed by USDA in Virginia for several years in the 1930's. The seed was imported from France, and the whole fresh flowering herb was used for distilling the oil. The plants grow rapidly on clay soil improved by mulching with manure and reach a height of 13 to 16 feet. Good yields of the oil may be produced in many parts of the United States and sold at reasonable prices.

In addition to its widespread use as a spice, sweet basil, which is a member of the family Lamiaceae, is recommended for use against gastric disorders, malarial fevers, and skin diseases, and for insect control. The oil distilled from the fresh flowers or the entire plant is used extensively as a flavor in confectionery, baked goods, condiments, and spiced meats, and as an aroma in certain perfume compounds. It is also an effective repellant and larvicide for mites, aphids, and mosquitoes; a growth inhibitor for milkweed bugs; and a fungicide. Although not all the repellent compounds have been identified, cineole, linalool, and methyl chavicol are implicated. Two compounds, designated as "juvocimene I" and "juvocimene II," are responsible for the growth inhibition of milkweed bugs.

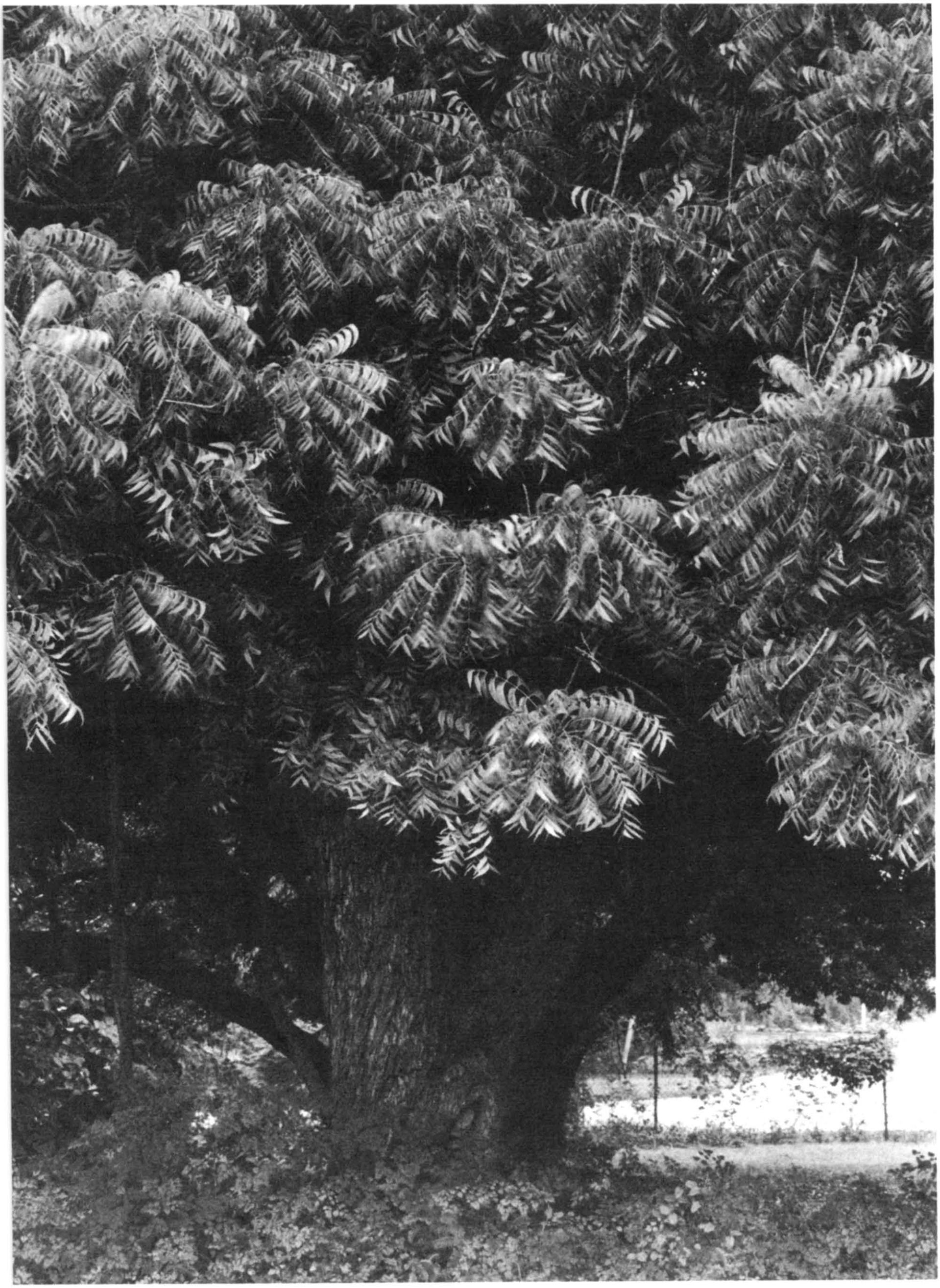

Tim McCabe, ARS

Neem-based insecticide is sprayed on a chrysanthemum to test its efficiency against leafminers.

Big Sagebrush. A member of the family Asteraceae, big sagebrush is a rapidly growing multibranched aromatic perennial that is the dominant plant of the Great American Desert. It has been in the West since 1881 as a fodder plant for range cattle and occurs wild in parts of Utah, Colorado, northern Nevada, and northern Arizona, where it reaches a height of 10 feet. The plant thrives in light, well-drained, dry, stony soils.

The leaves and shoots are placed in granaries to protect stored cereals from weevils and other pests, and the water in which they are steeped is used to kill or repel insect larvae, fleas, and locusts. Several species of ticks are killed rapidly by exposure to the vapors of the plant. An extract of the branch ends is exceptionally effective in preventing the Colorado potato beetle from feeding. (The beetle's resistance to insecticides in potato-growing areas is an increasingly serious problem, and this resistance probably will become widespread.) Various parts of the plant are used to destroy or expel parasitic worms. One compound responsible for preventing feeding has been identified as deacetoxymatricarin. Like many other species of *Artemisia*, big sagebrush contains absinthin, which is avoided by insects.

Chilcuan. Chilcuan is a perennial herb, 4 to 11 feet tall, in the family Asteraceae, native to Mexico but eminently suited for cultivation in the mountainous regions of the United States. Its roots are used locally in



Tropical neem trees thrive throughout the Caribbean and could do well in Southern Florida and Hawaii, according to ARS scientists.

Mexico as a spice, medicine, anesthetic, and an insecticide; root extracts are effective against house flies, mosquitoes, body lice, cockroaches, clothes moths, bean weevils, and other household and agricultural pests. The compound responsible for the insecticidal properties has been identified as an amide that has been given the names "affinin" and "spilanthol."

Wild plants have been transplanted successfully, in rows and beds at elevations of 5,900 to 7,900 feet. The plant also can be propagated commercially by seeds. Roots of suitable size and quantity for harvest should be ready within 2 or 3 years after planting.

Mamey. This tree (family Clusiaceae), 39 to 59 feet tall bearing edible fruits, is found in Latin America and the West Indies and is suitable for growth as a commercial crop in southern Florida, Puerto Rico, and the U.S. Virgin Islands. Mamey can be grown in Florida as far north as Palm Beach. The flowers, fruits, seeds, and leaves are effective against a wide variety of insect pests including melonworms, fleas, ticks, lice, armyworms, mosquitoes, and cockroaches. The leaves have been used in the West Indies for many years as a wrapping around the stem of newly set garden plants to prevent garden insects from attacking them. The durable wood from the tree is used for building furniture and houses; the sweet flesh of the fruit (known as "mamey apple") is eaten raw or cooked; and the fruit juice makes a refreshing drink.

A mixture of coumarins in the plant is responsible for the pesticidal effect, with the major component named "mammein" or "mameyin."

Neem. This hardy tree, also called "nim" or "margosa," (family Meliaceae) may reach a height of 60 feet when fully grown. It is common in dry scrub forests of India (at least 14 million are known to occur there) and other countries of Asia and Africa, and is being cultivated in several countries of the West Indies and Central and South America. Experimental plantings of neem are thriving in southern Florida, Puerto Rico, and the U.S. Virgin Islands. Young trees grown from seed seem able to survive the climate of southern California and Arizona.

Although all parts of the tree are repellent to insects, extracts of the seeds are outstanding as repellants and feeding deterrents for a broad spectrum of economic agricultural and household insects. Seed extracts deter at least 45 species of crop pests in the United States from feeding, inhibit growth and development of others, and render still others sterile. Several species of nematodes and fungi are also affected. Examples of the most destructive insects affected are Japanese beetles, cucumber beetles, Mexican bean beetles, aphids, tobacco budworms, rice weevils, confused flour beetles, and leafminers. The oil, obtained by pressing or extracting the seeds, can be used for the manufacture of wax and lubricants, and the seedcake left after oil extraction makes an excellent fertilizer and cattlefeed.

Unlike most of the present insecticides available on the market, the seed extracts appear to be nontoxic to humans and animals and are essentially not poisonous to plants. Because these extracts are absorbed by the tissues of the treated plant and translocated through the roots into the foliage (systemic activity), they offer relatively long-lasting protection to crops even after rain showers of high intensity.

Although several chemical compounds present in the seeds are responsible for the pesticidal effects of neem, the major active component is a limonoid named "azadirachtin"; it can be used effectively as an insect-feeding deterrent at concentrations as low as 1/10th of a part in 1 million parts of water.

Neem is envisioned to grow effectively in hot, dry climates with little rainfall where other agricultural crops are unproductive (shallow, stony, or sandy soils) or present a severe erosion hazard. The tree has a wide range of possibilities for economic development.

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Biological Control

Lloyd A. Andres, *research entomologist, Plant Protection Research Unit, Western Regional Research Center, Agricultural Research Service, Albany, CA*

Looking over the large grassy meadow in northern California's Humboldt County, it is hard to imagine that in 1945, the colorful but poisonous weed St. Johnswort literally held this prime grazing land in its grasp. Property values had dropped to the point that ranchers could not afford the recommended, albeit marginally useful, control treatments.

That year, in an effort to break the weed's hold on the land, University of California and U.S. Department of Agriculture entomologists introduced a shiny blue-green beetle, *Chrysolina quadrigemina*, into the area. The scientists knew from studies in Europe, the native home of St. Johnswort, and in Australia, where the weed also had become a problem, that the beetle fed exclusively on St. Johnswort, or closely related plants, and would not become a pest on agricultural crops. Once released, the beetle adapted quickly to California conditions and by 1950, St. Johnswort was well on the way to being controlled.

Tried and True Method

Deliberate introduction of natural enemies to control pests goes back to the first U.S. project in 1888. Since then, it has been proved time and time again that introduced parasites and predators can control their pest hosts and, in fact, have saved farmers a limonoid named "azadirachtin"; it can be used effectively as an insect-feeding deterrent at concentrations as low as 1/10th of a part in 1 million parts of water.

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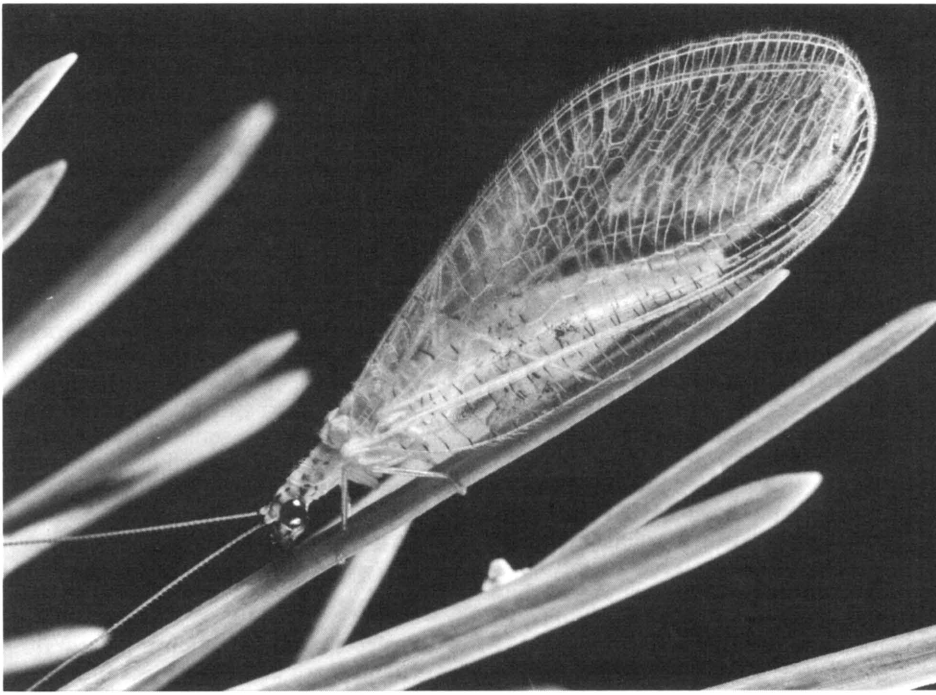

Runk/Schoenberger, Grant Heilman Photography

The delicate and beautiful green lacewing adult, along with its voracious larvae, feeds on a variety of soft-bodied insect pests, including the pink bollworm.

and ranchers millions of dollars in control costs and losses.

Although U.S. researchers will soon celebrate the 100th anniversary of that initial biological control project, the method has not lost its relevancy, even in today's high-technology agriculture. In fact, a recently completed census of insect pest species introduced to North America notes that the reservoir of foreign pests in the United States is increasing. Each year, an estimated 11 new immigrant species take up residence in the United States, 7 of which will become pests of some importance. New weed arrivals further compound the pest problem. Biological control research will play a vital role in the future to meet the new threats to our agriculture and environment.

Biological Control Concept

The introduction of natural enemies into the United States from a pest's native area is a deceptively simple concept. It is based on the fact that each weed or insect pest has a complement of parasites, predators, and diseases that are part of that pest's coevolved natural checks and balances. When a plant or insect is freed from these checks by being moved to new areas without its natural enemies, the new arrival enjoys a competitive advantage over already existing plant and insect species. This advantage often allows the newcomer to increase to pest population levels. Biological control workers seek to reduce this advantage by traveling to the pest's place of origin, collecting its former parasites and predators, and then introducing them into the pest's new home.

Research Needs

The process of locating the origin of the pest and then finding and introducing new natural enemies, although simple in concept, poses logistical and ecological challenges. For example, to locate the origin of leafy spurge, a weed of importance in the northern Great Plains, early plant collection records were reviewed to determine when and where this spurge first appeared in the United States. The localities noted indicated that spurge could have arrived with early immigrants. A further check of immigration and church records revealed that a number of the settlers to these sites came from farms in Eastern Europe and the Ukraine.

Another scenario indicates that spurge may have arrived as a contaminant with shipments of new plant germplasm from Eastern Europe and Asia. About the time that spurge first appeared, two USDA plant explorers were collecting crop and ornamental plants, one working in China and one in Russia, that would be well adapted to our northern Great Plains. While on vacation, a USDA entomologist who was intrigued as to the origin of our weed checked botanical collections in Japan and Korea for records of leafy spurge in Asia. His search turned up plants resembling the North American pest species, substantiating the possibility that our weed could have originated in Asia or was a multiple introduction from both Asia and Europe. The process of obtaining and matching plants from Eastern Europe, Asia, and the United States to verify this hypothesis is still under way.

Traveling to the pest's point of origin to survey for parasites and predators is the next step. Success in searching out and obtaining natural enemies hinges on the support and close cooperation of like-minded scientists and foreign governments around the world.

Once the natural enemies have been found, studied, and cleared for release, the final challenge is to establish them in the highly automated and artificial setting of today's agricultural world. Pesticides, ongoing disturbances of the habitat by agricultural operations, and the removal of noncrop vegetation that might otherwise offer food and shelter to the natural enemies are some of the obstacles that have hindered establishment and control.

Matching Pests, Climates, and Natural Enemies

Projects often fail when the natural enemies are poorly adapted to the U.S. pest or climate. For example, early shipments of the mite *Aceria chondrillae* to the Western United States to control rush skeletonweed, *Chondrilla juncea*, failed to establish. Incompatability between the mites, which originated in Greece, and the U.S. plants was suspected. A second mite shipment from Italy readily established on American plants.

In another case, a small parasite *Trioxys pallidus* introduced to California from France to control the walnut aphid *Chromaphis juglandicola* established well in coastal areas but failed in the warmer interior valleys. Introductions of the same parasite succeeded when it was obtained from an area of Iran where the climate more closely approximated the interior areas.

To improve the matchup between populations of weed-feeding insects and their weed hosts, chemists are "fingerprinting" the invading weeds by isolating and identifying key chemical components and comparing these with similar isolates from foreign populations. Entomologists on the other hand are identifying differences between insect populations by comparing enzyme systems. Some researchers have suggested that a reevaluation of early biological control attempts with these new techniques would help to explain some of the early failures.

Increasing the Numbers of Natural Enemies

Natural enemies sometimes fail when their numbers remain at levels too low to properly control their host. Artificial diets are being formulated and methods developed to produce and disseminate parasites and predators to increase low field populations. For example, the indigenous fungal pathogen *Colletotrichum gloeosporioides* f. sp. *aeschynomene* is now being cultured inexpensively and sold to control northern jointvetch, a weed native to southern rice fields. The fungus can be applied to the weed with conventional pesticide application equipment.

Similarly, forms of *Bacillus thuringiensis*, a bacterium that has proved valuable in the control of important chewing insects and mosquitoes, are being produced and marketed to farmers. New microbes and improved implementation strategies are being sought.

Genetic Improvement

Although the idea to improve performance of natural enemies by introducing or developing new genetic strains has been around for several years it wasn't until the recent development and field colonization of a new strain of the predatory mite *Metaseiulus occidentalis*, which is resistant to several insecticides, that this has proved practical. The mite is used to control spider mites feeding on crops.

Genetic modification of beneficial micro-organisms could facilitate artificial production as well as increase virulence and environmental tolerances. Fortunately, many species of natural enemies already have a high degree of genetic variability. Successful control is often a matter of finding these variants and introducing them to the problem areas.

Habitat and Behavioral Modification

Planting of cover crops, providing nectariferous plants and sources of alternate hosts in and around fields, and interplanting different crops to provide habitat diversity are all ways of encouraging natural enemies into fields and enhancing biological control.

Much of an insect's behavior is mediated by chemicals emanating from the environment. Entomologists, now aware of this, apply extracts from tomato to corn plants to increase the parasitization of corn earworm eggs. Food supplements applied to alfalfa and cotton can increase the number of green lacewing predators in the crops. Other environmental modifications are being studied to improve biological control.

Although the views on biological control and the perception of its potential to regulate insect and weed pests have changed over the past 100 years, the idea of somehow bringing together a pest and its parasites remains. It is to every society's advantage to use the pest controls that nature has provided. Biological control, a method that derives its energy directly from the pests themselves, is the best.

Altering Insect Brain Chemistry

Michael E. Adams, *assistant professor of entomology, Division of Toxicology and Physiology, Department of Entomology, University of California, Riverside, CA*

Changing the brain chemistry of insects so they become disoriented and unable to function or reproduce, is an area of insect control that shows considerable promise today.

Insects continue to be a major problem in agriculture. Diverse control tactics are now being devised in the basic and applied sciences to manage pest populations. With the development of emerging biotechnologies, both chemical and biological elements could well be incorporated into the design of safer and more selective control agents.

Chemical Control Can Be Dangerous

Enthusiasm for synthetic organic insecticides in insect control has yielded to realization that they are strong, yet often dangerous medicine in the long term. Heavy insecticide pressure on genetically rich insect populations has led to resistant strains which are more difficult and expensive to control. Undesirable environmental and health trade-offs associated with chemical intensive agriculture also are becoming apparent. As a result, the number of safe, yet effective insecticides available to growers is decreasing rapidly in spite of the fact that chemicals often serve as the only reasonable way of dealing with unpredictable pest outbreaks. Insecticides will continue to be an essential option in integrated control strategies, and the development of newer, safer insecticides remains an important goal in agricultural research.

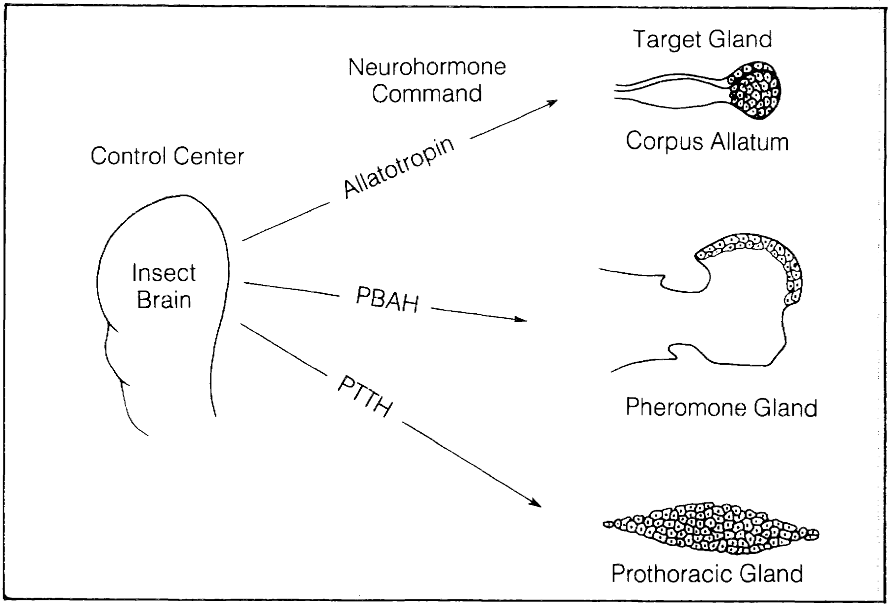
At the same time, there is an increased recognition that more traditional methods for insecticide discovery are too costly and time-consuming to be successful in the future. More sophisticated searching strategies are needed.

How Are Insecticides Discovered?

The evolution of today's major agricultural insecticides can be traced from two main origins. Some have their genesis in the botanical folklore of earlier cultures; for example, pyrethrum from chrysanthemum flowers, nicotine from tobacco, rotenone from *Derris*, and physostigmine from the calabar bean. These naturally occurring substances provided model structures for many of the synthetic organic insecticides introduced since World War II, including the pyrethroids and the carbamates.

Other classes of insecticides were discovered purely by accident in exploratory synthesis programs geared initially for purposes other than insect control. These valuable discoveries gave rise to DDT, the organophosphates, and more recently, the formamidines and the avermectins.

Most modern day insecticides, therefore, have been modeled after existing botanicals or from lead structures discovered by chance. Efforts in agricultural chemistry have been primarily devoted to improving these structures, rather than being directed by any real knowledge of the innerworkings of insect pests. The obvious challenge becomes that of understanding and exploiting the unique features of insect life processes for



the development of more selective control strategies.

Current research is demonstrating that many aspects of insect brain chemistry may provide clues for achieving selectivity at the physiological level.

The Insect Brain

The nervous system of insects, like that of all other animals, integrates and coordinates the functions of many organ systems in the body. Its component nerve cells relay information through the transmission of chemical signals called neurotransmitters. These endogenous brain chemicals are released in minute amounts between cells to regulate nervous activity and to store information.

The most effective of today's crop protection insecticides are nerve poisons acting to upset the delicate regulation of neurotransmitters within the brain. Unfortunately they are general toxins affecting brain chemicals common also to nontarget organisms, hence the high risk associated with their use. The goal of future insecticide development is to focus on the unique aspects of insect-specific physiological processes, thereby increasing the margin of safety for nontarget animals. Because the insect brain is involved in critical, high-level coordination functions, it is a promising target for future insecticides.

In insects, the brain is a central command post which programs developmental, reproductive, metabolic and behavioral states at the appropriate times throughout the body. The brain does this by issuing chemical messages called neurohormones from specific nerve cells, which, in turn, orchestrate the precisely timed liberation of blood-borne hormones from glands. Their structural and physiological properties set them apart from the neurotransmitters, making them unique targets for future insecticides.

Can the brain as a control center

be "short-circuited" through the disruption of neurohormone messages? The discovery and structure elucidation of insect neurohormones are proceeding now at a rapid rate and set the stage for answering such a question.

Critical Insect Brain Chemicals

Insects are highly specialized animals, and many aspects of insect physiology are by nature unique in the animal kingdom. A few examples illustrate the types of unique processes which may be vulnerable to future insecticides.

An obvious distinguishing feature of insects is their hard outer shell or exoskeleton. To grow and change form from larva to adult, a multi-step developmental process known as molting occurs in which the insect emerges from its outer shell several times on its way to becoming a reproductive adult. The timing and form of each new growth stage is programmed by two brain neurohormones which trigger the release of developmental hormones from specialized glands. The neurohormone, "PTTH," released from the brain causes the secretion of the molting hormone from the prothoracic gland. A second neurohormone, "allatotropin," activates the secretion of juvenile hormone from the corpus allatum, a pituitary-like gland directly behind the brain. By regulating the relative levels of juvenile hormone and molting hormone in the blood, the brain determines whether the insect continues its development as a larva or if it is to undergo metamorphosis to the adult form. It is likely that any disruption of the PTTH or allatotropin commands from the brain would prove lethal to the developing insect.

Another vital function associated with the molting process is the hardening and darkening of the exoskeleton. For a time immediately following the shedding of the old cuticle, the insect is soft and vulnerable. To speed the hardening of the new cuticle, the brain sends a neurohormone signal called bursicon to the integument where it catalyzes the appropriate biochemical reactions. Inhibition of bursicon release from the brain would effectively prolong the helpless, vulnerable state the insect finds itself in just after the molting process.

Reproductive processes also are driven by brain neurohormone commands. For example, reproductive females attract males through the release of volatile pheromones into the air from specialized abdominal glands. The brain initiates pheromone release by issuing a recently discovered neurohormone to activate the glands. Egg maturation also depends on a newly discovered neurohormone command from the brain.

Such examples show the importance of critical brain neurohormones that serve as high level command signals to the glandular system. These result in hormonally induced physiological states in the insect. It is the goal of researchers today to devise methods of altering these brain chemicals for the purpose of controlling pest insects.

Altering Insect Brain Chemistry

The basic idea involves changing the level of a particular brain chemical, either to cause overabundance or depletion and to thereby disrupt coordination systems vital to insect survival. The most direct method would be to flood insect systems with chemical analogs that mimic the actions of particular brain chemicals. The conventional insecticide nicotine acts this way on neurotransmitter receptors in the nervous system. An alternative method involves inhibition of enzymes regulating the levels of neurotransmitters in the nervous system, exemplified by the anticholinesterase insecticides.

These conventional insecticides operate in precisely the way we have envisioned for those of the future, namely to upset delicate levels of brain chemicals. But the conventional insecticides have the disadvantage of being very toxic to humans and nontarget organisms as well as to insects. Efforts are now under way to direct future control agents toward brain chemicals, neurohormones, which serve as command signals for hormonal triggers in the insect endocrine system. By focusing on insect-specific neurohormones, it is hoped that problems of general toxicity to nontarget organisms will be avoided.

An important consideration for any chemical control strategy is delivery of the material to the inside of the insect. Practically speaking, this means penetration either directly through the insect's cuticular exoskeleton or by ingestion. This poses special problems when dealing with peptide neurohormones. Although the neurohormones occupy vital, high-level command positions in the coordination of bodily functions, they are complex, unstable molecules lacking the necessary chemical features to be considered as models for insecticides. They cannot penetrate the insect cuticle nor can they survive the physical stresses of field conditions. It is, therefore, impractical to synthesize peptide analogs as candidate insecticides.

Instead, two alternative approaches for altering neurohormone levels in the insect brain are envisioned. One possible strategy would be to inhibit neurohormone-regulating enzymes with chemical analogs. Such analogs could be specifically designed for cuticle penetration and environmental stability. The second approach would be to incorporate genetically engineered insect neurohormone genes into specific pathogens (disease-causing agents) using genetic engineering technology. The pathogens would then infect pest insects and introduce neurohormones at inappropriate times during the life cycle.

Inhibition of Neurohormone Regulatory Enzymes. To recognize the vulnerable aspects of neurohormone dynamics, it is helpful to review the biochemical processes leading to the activation of the hormone message and its eventual termination. The production of a peptide neurohormone begins at the level of the gene. The DNA coding for the neurohormone is read onto a messenger strand, which serves as a template to assemble a precise sequence of amino acids forming a neurohormone precursor protein. From this point on, regulatory enzymes are used to process the active neurohormone from the precursor as well as to destroy the neurohormone after its signaling function has been fulfilled. These processing enzymes are vitally important for appearance of the neurohormone. A chemical analog that blocked the action of these enzymes would function as an antineurohormone, preventing the brain from initiating vital physiological processes.

A second point of attack with chemical analogs are degradative enzymes involved in the termination of neurohormone signals. This type of action would have the opposite result, namely to increase the neurohormone's effect. Such activation of the neurohormone signal would be analagous to the inhibition of the cholinesterase enzyme by conventional insecticides, but ideally would effect an insect-specific neurohormone signal.

These conceptual approaches have already led to the invention of potential pharmaceutical drugs which affect neuropeptide levels in the brain and other tissues of mammals through inhibition of their regulatory enzymes. In the kidney, for example, a substance called captopril inhibits the processing enzyme responsible for activation of Angiotensin I, a peptide implicated in hypertension conditions. Another drug known as thiorphan inhibits the degradative enzyme for the brain peptide enkephalin, leading to activating its effects in the brain.

The development of such drugs suggests the potential for treating neural disorders by affecting the dynamics of peptide messages in the brain. It is hoped that analagous types of enzyme inhibitors can be created to alter the levels of insect neurohormones for control purposes.

Genetically Engineered Pathogens. The development of gene-engineering technologies makes it possible for the first time to envision the use of insect-specific pathogens to transport neurohormones into pests. This approach would obviate the direct use of chemicals and circumvent the problems associated with the instability and complexity of peptide chemistry. Instead, the pathogen would function as a biological packaging and delivery system for the neurohormones into pest insects to cause disruption of normal hormonal states.

Both bacterial and viral pathogens already are used with some success in insect control. Bacteria kill insects by secreting large amounts of a toxic, crystalline protein into the gut. In contrast, viruses infiltrate and commandeer the genetic systems of their hosts in order to propagate themselves. Can the genetic code of either of these pathogen types be used to introduce insect-specific neurohormones into host pests?

In theory, the technology already exists. In fact, recent experiments have demonstrated the incorporation and efficient expression of foreign genes into insect bacterial and viral pathogens. But devising genetically engineered pathogens for crop protection is an exciting and challenging idea that will require much time and experimental work.

First, the genes for insect neurohormones must be identified and details related to their regulation and expression described. Further studies will be needed to work out the details of efficient incorporation of neurohormone genes into appropriate pathogens and finally to produce pathogens in sufficient volume to apply under field conditions. Nevertheless, it appears to be only a matter of time before such new "high-tech" control strategies are ready to be considered as new and safer alternatives to conventional insecticides.

Newer Insecticides Acting on Hormonal Systems

The recent introduction of two new chemical insecticides which act on insect hormonal systems provides examples of what the future could bring in terms of safer and more specific insect control methods. The first example is the insecticide, chlordimeform, which interferes with the insect neurohormone octopamine. The second example, methoprene, disrupts the juvenile hormone system. These materials have as a common feature the ability to control insect populations without causing acute symptoms of poisoning or toxicity. Their mechanisms of action cause the disruption of key insect hormonal systems.

Chlordimeform. The discovery of chlordimeform, as in the case of many other insecticides, was accidental. But it was nonetheless tremendously interesting because of the mechanism by which it controls insect populations. The key to the field efficacy of chloridimeform was not its acute toxicity, but behavioral disruption which resulted in reduction or inhibition of insect feeding. When chlordimeform was tested in conventional insecticide screens, the subtle behavioral actions of this substance were completely missed and the material was not considered to be insecticidal. Field tests, however, showed remarkable suppression of insect populations. When researchers began to scrutinize the effects of this remarkable new chemical on insect behavior, they found that just a few bites of a leaf sprayed with the material caused caterpillars to become disoriented to the extent that they ultimately left the plant.

With time, it was also noticed that ovicidal effects of chlordimeform were also attributable to a behavioral action. Emerging larvae normally chew an exit hole through the eggshell. But in the case of treated eggs, the oral dose obtained by the larva resulted in a cessation of feeding behavior and unsuccessful hatching. Further studies on chlordimeform have revealed disruption in pheromone communication between adult males and females and altered egg-laying patterns.

All these observations point to an exciting new mode of action for chlordimeform involving its ability to mimic octopamine, an aminergic neurohormone in the insect brain. Octopamine is important in controlling behavioral expression as well as the release of hormones from glandular sources. The action of chlordimeform on the octopamine system in pest insects represents the first known case in which disruption of a neurohormonal system has led to effective control through sublethal actions on neurohormonal mechanisms.

Methoprene. Another key precedent demonstrating insect control through disruption of hormonal function was the invention of methoprene, a mimic of the juvenile hormone. As discussed earlier, levels of juvenile hormone in the blood determine whether a larval insect becomes an adult or whether it continues on as another larva. Shortly after elucidating the structure of juvenile hormone, scientists created methoprene by incorporating new features into the molecule, permitting it to penetrate the cuticle while retaining its biological activity. Exposure of insects to methoprene at inappropriate times in their life history caused the development process to go awry in such a way that pseudo-adults resulted, possessing incompletely developed reproductive organs. In other words, the insects were sterile and unable to propagate a further generation.

The success of methoprene, like that of chlordimeform, illustrates how insects can be controlled through the disruption of their own specific hormonal systems. The modes of action of these compounds are fundamentally different from the conventional insecticides in that death results from subtle actions on behavior or development, not from acute neurophysiological poisoning.

The exciting aspect of the methoprene story is its mode of development. It represents the first example of a commercial insecticide being developed from an insect hormone. Although methoprene is suitable only for the control of certain pests of the adult stage (mosquitoes, fleas, cockroaches), other types of directed chemical synthesis may result from basic knowledge of insect neuroendocrinology.

Tinkering With Insects' Bioclocks

Dora K. Hayes, *research leader, Livestock Insects Laboratory, Beltsville Agricultural Research Center, Agricultural Research Service*

Travelers who cross time zones usually experience jet lag. Jet lag is a dramatic illustration of the effects of desynchronization of rhythms in these travelers. Insects are small, complex animals. Their biological systems are similar to those of humans, although these systems are considerably smaller and may appear in somewhat different form anatomically. Some of the rhythms in many insect species, including important agricultural pests, include those of oxygen utilization, susceptibility to insecticides, activity, mating, and egg laying.[1]

Insect Rhythms

In humans, regularly recurring cues provided by daylight and darkness, schedules of social activities, mealtiming, and so on serve as synchronizing mechanisms. Humans don't generally realize that rhythms exist in insects or that understanding insect rhythms will help in learning how to manage pest insects. Insects must hatch, pass through definite developmental stages, emerge from the pupa, and be ready to mate at appropriate times of the year if they are to have a fair chance of survival and of leaving descendants. The timing of these key events is under the influence of metabolic and neural activities which are believed to exhibit circadian (literally, about a day) and other rhythms.

These rhythms are synchronized by regular regimens of daylight and darkness, by regularly recurring high and low temperatures as can occur out-of-doors during daylight and darkness as night follows day. Other regularly recurring phenomena also may serve as synchronizers, and occasionally a single stimulus such as a light flash can synchronize a hatching or emergence rhythm. Responsiveness to these cues raises the odds that the weather and the availability of food or mates will be appropriate to the life stage of the insect.

Insect rhythms are subject to disruption if the regimen of the synchronizer is altered or disrupted. The usual result is an increased chance of death or a reduced chance of successful reproduction. Thus, rhythm modification might help 1) reduce those pesky face flies that suddenly appear when the days get longer, 2) enable large numbers of sterile lab-reared males to compete for mates in the field with small numbers of fertile wild males, 3) enable us to isolate natural hormones where the concentration is highest, 4) permit us to evaluate sex attractants when the insects will respond, 5) dictate when maximum response to treatments or insecticide application might be expected.

Chemical Desynchronization

We have been able to tinker with insects' bioclocks by altering light and temperature schedules; perhaps we

[1] The field of chronobiology deals with quantitating rhythms with periods varying from minutes to years, and sophisticated analyses have been developed to detect meaningful (statistically significant) rhythms in "noisy" data. For purposes of this publication, we accept the fact that rhythms exist and deal with their manifestations.

can tinker biochemically as well with their time-measuring systems. Some chemicals are known which can shift the timing of the peak of some human rhythms; one of these is ACTH-1-17, a synthetic peptide similar to half the brain hormone molecule which stimulates the adrenal gland to produce steroids similar to cortisone. Such a peptide could be used to adjust the timing of the peak of some physiological function so that maximum effect of a treatment could be optimized for the benefit of the patient. Another use of such a material might be to prevent or minimize jet lag. In the case of pest insects, the rhythms would be desynchronized or the peaks would be shifted so that the insect would not complete its life cycle and so would not reproduce. Clearly, this would be a slower method of destroying the insect pest than exposure to a quick-acting stomach poison, but it might have a far less devastating impact on nontarget inhabitants of the ecosphere.

Diapause

On the other hand, the promotion of development rather than preventing growth may also be unfavorable to insect pests. Many insects have a built in mechanism, the diapause response, to keep them alive over periods of time in which food supplies are low or temperatures are not conducive to survival. Diapause in insects is like hibernation in bears; both insects and bears store fat, stop eating, and then use these fat reserves during hibernation at a much lower rate than if they were in the nondiapausing or hibernating state.

Some strains of a species will diapause and some will not. Genetic differences exist among these strains, but we do not understand the mechanisms fully. If an insect possesses the necessary genes, it will exhibit the diapause response. For diapause to occur, the environment must provide the appropriate signals, and the insect must be competent to respond. Interestingly enough, some strains of insects that have been maintained for a long time in the laboratory no longer diapause.

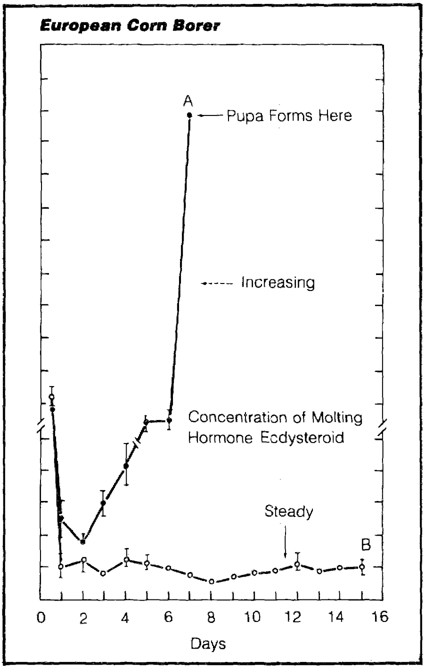
In diapause changes also may occur in the insect body fluids when compared to nondiapausing insects. An example is an increase in glycerol which apparently serves as a biological "antifreeze."

We are familiar with some but not all of the facts concerning how diapause comes about. For instance, we know that if the average temperature is above a threshold level during the time an insect is preparing to diapause, the insects will not diapause even though the photoperiodic regimen is appropriate. This critical temperature differs for each species and sometimes for the same species in each geographic area.

We know, too, that insect hormones which are required for maintaining the immature stage or for promoting development to the adult stage are at least quantitatively different in diapausing and nondiapausing individuals. When days are shortening in the fall, different quantities of hormones are being produced than in the longer summer days. Some scientists have suggested that a special diapause hormone is produced which, when secreted, promotes or maintains diapause.

Preventing Diapause

Diapause can be prevented by extending the natural day or by interjecting light breaks into the dark span in which insects are maintained. This is true whether the insects are under field conditions or are domesticated in laboratory-rearing boxes. However, the biochemistry and physiology which must be investigated are not so clearly known.



In about seven days of 16 hours of light and 8 hours of darkness, larva A develops pupal (worm-like) stage. Larva B, in 12 hours of light/12 hours of darkness sequence, molts several times but fails to develop pupa.
(From the work of D. B. Gelman, ARS, USDA)

The steroid hormone, ecdysone, which induces molting, or ecdysis, has a circadian cycle. Ecdysone levels in insect blood are high in insects synchronized in a day of 16 hours light–8 hours darkness and low in those held in 12 hours light–12 hours darkness. These data show just one measurement every 24 hours and, therefore, will not show the circadian phenomenon.

Precisely how the daylength is measured in insects is unknown. A peptide hormone may be involved. Humans are acquainted with large peptides such as insulin. In insects, molecules with a similar structure are involved. It is also unknown how exposure to appropriate temperature cycles can result in development or diapause if the organisms are maintained in constant darkness or constant dim light.

Manipulation of Light. Even without detailed knowledge of the biochemical steps, the principles of pest control by manipulation of daylight and darkness or photoperiod manipulation have been demonstrated. When we studied populations of European corn borer larvae in a stand of corn and codling moth larvae in apples out-of-doors, we changed the length of the day artificially, and the larval insects either developed into adults in the late, cold fall or the diapause state was disrupted over the winter so that spring emergence of sexually mature adults was prevented.

In this study, a span of 13 hours or less of daylight in the fall was extended to 16 hours with artificial lights. The light sources were either fluorescent lights in screen cages or large mercury arc lamps similar to those used to illuminate shopping center parking lots. This method of extension of the light span (or photophase) for preventing diapause was shown to be technically possible and might be an alternative to adding chemical pesticides to the environment. We and other investigators also have found that short interjections of light pulses prevented hibernation, but, in our hands, photophase extension produced more consistent results than did the light pulses.

At the time these tests were completed, it was evident that for a given application the costs for installing and operating fixed light sources to control insect pests would be at least 100–1,000 times those of commercial pesticides and other control measures for the average farm operator. Since changing daylight time with lights would be too expensive at the present time for farmers, other ways of tinkering with rhythms were studied.

Colored Substances. We began by determining what colors or wavelengths of light were most effective. We found that blue to blue-green light with wavelengths between 440–490 nanometers was most effective in preventing or terminating diapause in three species of moths. This finding suggests that one or more of many colored substances found naturally in insects might be acting as the photoreceptor. Included could be heme pigments similar to human hemoglobin, which is the red pigment-protein in red blood cells, some vitamins or their precursors such as riboflavin (yellow), carotene (yellow or orange) and pyridoxin (sometimes producing a colored product when combined with enzyme protein) and highly fluorescent substances such as the pteridines which give eyes of the fruit fly, *Drosophila melanogaster,* much of their color.

Demonstrating either that one of these colored substances or that a combination of two or more of these substances working together are responsible for the development resulting from the extended day is not an easy task. One approach is to determine the effects of light on various biochemical reactions in the intact insect.

In one such test, we exposed pink bollworm larvae to light during a time when they would normally have been in darkness. This resulted in a decrease in the activity of an enzyme, catalase, below the level found in insects not so exposed. This enzyme, which converts hydrogen peroxide generated by both humans and insects into water and oxygen, is red because it contains the heme nucleus, one of our candidate pigments.

The experiment suggests that light does act on colored molecules in living insects and provides the basis for further study. In this case, the eyes are not responsible for the response.

In other cases, however, insect eyes are the photoreceptors involved in synchronizing daily rhythms. Because many susceptible insects enter diapause in a stage in which they do not have eyes, it is widely believed that the receptor molecules for the diapause response are in the insect brain itself in cells that may be responsible for secretion of neurohormones. An Agricultural Research Service investigator, Robert Bell, found that the level of neurosecretory material in nerve cells from the heads of tobacco hornworms exhibits a circadian rhythm which can be synchronized.

Migration. Some insect species receive their cues to migrate from the changes in daylength and darkness that occur in the late summer and early fall. Migration is an alternative to diapause and a well-known case is that of the monarch butterfly, a colorful species that is not an agricultural pest. This insect flies south and spends the winter in the mountains of Mexico, Guatemala, and Honduras. Probably the photoreception occurs in a similar manner in migrating and in diapausing insects; migration is another expression of environment-gene interaction.

Changing Rhythms of Livestock Insects. Insects that affect livestock diapause, as do insects that affect plants. Of particular concern are the filth flies, the house fly, stable fly, horn fly, and face fly. Maximum diapause in the face fly adult can be obtained when it is exposed to temperature and light-dark cycles similar to those occurring naturally in the fall. Because the face fly adult is attracted to pyramidal traps, it might be possible to treat the surfaces of such traps with material which would alter the hormone balance in the face fly so that diapause would be prevented.

Relatively more face flies are

Researcher counts face flies attracted to pyramidal traps.

caught in these traps in the morning than other parts of the day. This suggests that there is a circadian rhythm in the activity of the flies. Alternatively, because the larval or maggot stage of this insect must develop in freshly deposited manure, a feed-through or feed additive compound which interfered with development might be added to the diet of the cow or formulated as a bolus which could be placed in the rumen. Such a preparation would not be taken up by the tissues of the cow or found in the milk, but it would desynchronize development of the larvae in the manure pat and cause death. It also is possible that desynchronizing the developmental process would reduce fertility of adults. Hormone activity rhythms could be altered as well in the stable fly and the house fly by introducing compounds, which affect rhythms required for normal development, into the water or food of young calves. Calf-pen bedding is an excellent breeding site for filth flies; such an application of feed-through technology would provide a means to alter expression of developmental processes.

Shifting Affects Rhythms. Insect rhythms can be manipulated to produce effects other than interference with the diapause response. When coding moth larvae and pupae and face fly adults were subjected to shifts simulating repeated movement across 6 or 12 hourly time zones (mimicking repeated trips from the United States to England or to Japan), the life span of the insect was affected.

The differences in survival depend upon the number of days between shifts. This apparent rhythm in survival has a period of about 4 to 8 days, that is, a "circaseptan" or 7-day rhythm. Shifts every 2 or 9 days throughout life resulted in shorter life spans while shifts every 4 or 5 days resulted in survival sometimes greater than that of unshifted controls. We observed in another experiment that in unshifted insects that are diapause-bound, there is a suggestion of a 5-day rhythm, with lower ecdysone levels every 3, 8, and 13 days. Without rigorous mathematical analyses, this possible ecdysone rhythm remains merely a speculation and a lead for future studies.

The work on the circaseptan response of the face fly led other investigators to examine other species of animals and plants. Studies on phase shifting in species as diverse as the rat, a primitive wingless insect (the springtail), and a marine alga known as *Acetabularia,* showed similar increased or decreased life spans depending upon the shift schedule used. Since we cannot turn off the sun, we cannot study insect pest populations in the field exposed to many of the regimens which provide such interesting data in the laboratory. Such laboratory manipulation of photoperiod techniques can be useful in fine-tuning hormonal responses, particularly as our technology for isolating and characterizing biologically active neurohormones improves.

These studies also have provided and will continue to provide exciting leads for scientists studying animals and humans in which the average life span is considerably longer by months or years than the 40–80 days the average face fly or codling moth lives in the laboratory.

Thus, tinkering with bioclocks of insects will provide information that will enable us to improve our management of pest populations and may also point the way to improving quality of life for human beings.

Decoding Insects' Chemical Communications

Wendell L. Roelofs, *professor of insect biochemistry, Department of Entomology, Cornell University, NY*

Insects have survived for millions of years, in part because of their ability to produce and to perceive an amazing variety of volatile chemicals. These chemicals are the basis of extremely efficient communication systems for sexual attraction, alarm behavior, trail-following to food supply, host finding, egg laying, territorial displays, raiding, nest mate recognition, marking, and the mediation of many other social interactions.

In some instances, insects may key on a few specific chemicals emitted by their host plant—such as an apple maggot fly being attracted to certain short-chain esters from among the thousands of odors present in an apple orchard. In other instances, they may produce their own unique chemical signals to provide the specificity needed for efficient communication. In either case, decoding the communication system provides us with a potential means of manipulating the chemical signals for monitoring and controlling insect pest populations.

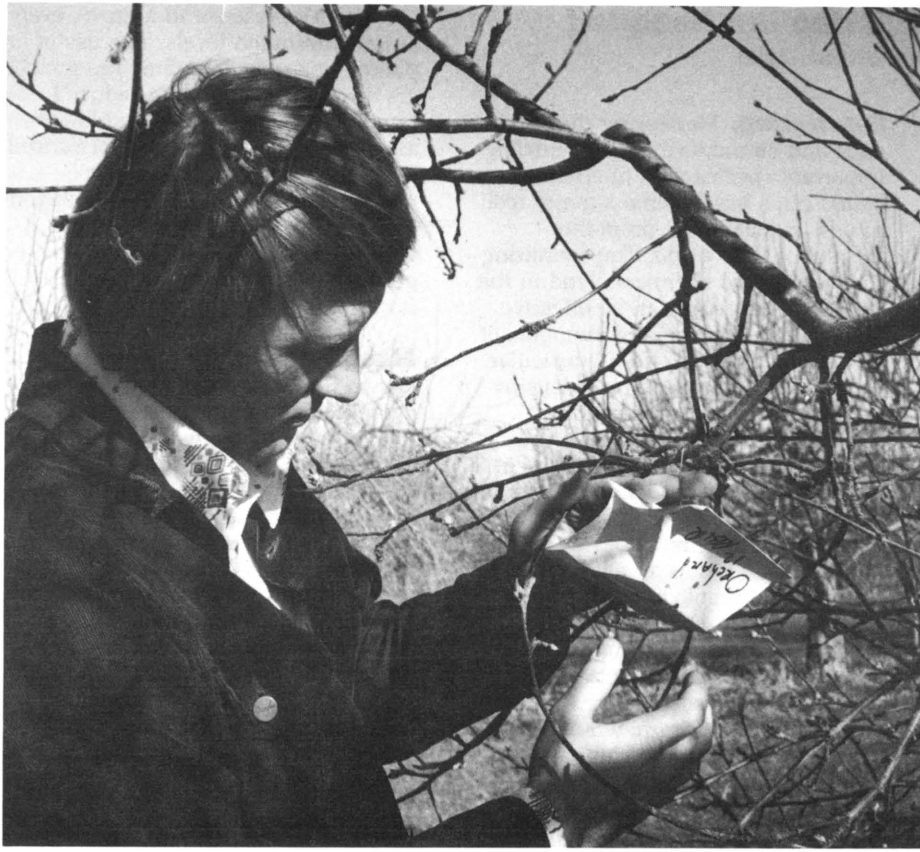
Sex Pheromones

Much of the research on insect chemical signals in the past two decades has been centered on sex pheromones. The term pheromone was coined in 1959 from the Greek *pherein*, to transfer, and *horman*, to excite, to refer to substances emitted by one individual and eliciting a specific reaction in a second individual of the same species. Sex pheromones, then, include the chemicals emitted downwind to attract individuals of the other sex or aggregate both sexes for mating. By 1961 German scientists had shown that it indeed was possible to isolate and identify the sex pheromone used by the commercial silkworm. Decoding this signal took over 30 years and the sacrifice of millions of female moths. It, nevertheless, gave impetus to other scientists to attempt the decoding of sex pheromones used by pest species.

Chemical Identifications

Although sex pheromones have been found to exist in species throughout the animal kingdom, efforts to decode the signals were concentrated in the Lepidoptera (moths) and the Coleoptera (beetles) because they comprise the majority of agricultural pests. Chemists at first extracted thousands of female moths to identify the sex pheromone components because of the extremely small amounts of active material in the oily extracts. The responding male's antennae are so sensitive and sharply attuned to their own signals that the female only needs to produce and emit less than a millionth of a gram of pheromone for long-distance attraction.

The specificity and sensitivity of these antennal olfactory sensilla provided the basis for an excellent technique called the electroantennogram (EAG) for determining the active chemicals of a certain species by using a male's antenna of that species. This technique, coupled with advances in gas chromatography (GC), which is used to separate mixtures such as crude gland extracts into individual components, allowed chemists to identify the pheromone compo-



E. H. Glass, Cornell University

A monitoring trap in a New York apple orchard is checked for redbanded leaf-roller moths.

nents of many of the major pest species. For example, by 1980 sex pheromones were identified for several hundred moth species.

Decoding of the chemical signals went through stages: a) with many species, only the most predominant component was identified; b) better GC technology allowed chemists to find specific ratios of geometrical and positional isomers of the main component; c) sophisticated syntheses and analytical tools provided the means to define (+) and (−) stereoisomers with components possessing chiral centers; and d) great advances in column technology for capillary GC allowed analysis of single pheromone glands to determine the presence of a number of pheromone components present in trace quantities.

Characterization of trace components has been aided greatly by the development of microtechniques and new computerized instruments interfaced to Fourier transform data systems. These advances have been important because it has become imperative to decode the entire chemical signal.

Using the Decoded Message

Monitoring. Monitoring the presence and abundance of economically important species with pheromone-baited traps has become a major tool in pest management programs throughout the world. Traps emitting the appropriate chemical blend in the correct release rate can be effective and specific in attracting members of the responding sex of that particular species. This specificity and sensitivity makes these traps useful in a) timing pesticide applications so that they are used only when the pest is present and in sufficient density to cause economically defined damage, b) detecting the first appearance of adults to be used as a biological fix on the seasonal profile of moth emergence so that, in conjunction with thermal accumulation units, the data can be used to time insecticide applications to the susceptibility window that occurs after egg hatch and before larval entry in the fruit, and c) detecting the presence or the spread of certain quarantined or introduced insect pests. Government agencies use over 600,000 traps a year for this purpose, for example, in detecting new infestations of the gypsy moth as it spreads across the States.

The economic value of pheromone monitoring was calculated recently for a California red-scale research project that ran from 1966 to 1983. This scale is a major pest of citrus, and before 1971 growers relied on repeated labor-intensive and unreliable visual inspections of orchards for determining the need for pesticide applications. Although the scale is commonly found in localized pockets within an orchard, the entire orchard normally was treated. Inexpensive pheromone traps were developed that proved to be accurate in monitoring the insect's presence in a grove, even at low infestation levels. The use of pheromone traps benefited the growers through savings from reduced hours to detect red scale and lower amounts of pesticides used for control since they could localize control measures to "hot spots." A calculation of the savings for growers compared with the research costs for the program showed a savings of up to $16 for each dollar spent on the research.

Mass Trapping. Studies have shown that pest populations can be decreased and maintained at economic levels by using large numbers of pheromone-baited traps. This is a costly technique because of the number of traps and the labor needed to service them. But a huge mass trapping project in Norway and Sweden for the spruce bark beetle appears to have been successful in averting a catastrophic pest outbreak and in reducing the insect numbers. The project used over a million pheromone-baited traps a year for 4 years and resulted in beetle captures of up to 4 billion a year.

Mating Disruptions. This technique is used commercially to control pest populations with sex pheromone. Disruption is achieved by permeating the area under treatment with a small amount of synthetic pheromone to confuse or habituate the responding insects. Commercial formulations for releasing the pheromone compounds slowly over several weeks include hollow plastic fibers, laminated plastic flakes, and microcapsules. These formulations are applied in the field with appropriate stickers so that they adhere to the foliage. With some moth species the responding male moths attempt to mate with the individual fibers or flakes in the field. Because of this behavior, a small amount of insecticide added to the sticker was found to increase the effectiveness of the pheromone treatment.

Direct control with pheromones has been commercially successful where the target pest is the only significant one. Also, since the success of direct control with pheromones depends on reducing mating between the adult insects, an essential part of the control program is to reduce the influx of mated females from outside the control area. This is usually done by treating large areas or isolated fields. All three formulations have been found to be effective in keeping down numbers of larvae and contain infestations to a level similar to, or less than, that achieved with conventional insecticides.

The biggest commercial success for the mating disruption technique has been in the control of the *pink bollworm* on cotton. In practice, less than a handful of pheromone-filled fibers are broadcast over each acre of cotton to disrupt the mating of the pink bollworm. Hundreds of thousands of acres of cotton have been treated with pheromone for pink bollworm control in the United States, Latin America, Brazil, India, China, and Egypt in the past 6 years. The pink bollworm is a key cotton insect pest, and the insecticide treatments for this insect in late June and early July devastate the parasites and predators that are needed to control other pests coming in August, such as the bollworm, budworm, cotton leafperforator, and spider mites. By using pheromone control instead of insecticide in the first 2 months, beneficial insects are preserved and can play a significant role in suppressing the other pests. Commercial success has been extended now to other key pest species, such as the tomato pinworm and the artichoke plume moth.

Novel methods. Further uses of pheromones in insect control are being developed. They are being used in combination with conventional insecticides to attract insects to certain treated areas or to raise the general activity level of the moths to increase the effectiveness of the applied insecticide. In development are methods of encapsulating pheromone into plastic strings as it is sprayed from the planes to avoid problems associated with the use of specialized equipment needed to spray out fibers or flakes.

The Communication System

The decoded signals now play a vital role in pest management systems as described, but research on the mating communication system may lead to new methods of manipulating pest species. The communication system can be visualized as the emitters and receivers.

The *emitter,* such as a female moth that releases a sex pheromone blend to attract male moths, integrates a number of physiological and biochemical processes to perform this function.

Biosynthetic studies have revealed several unique enzymes in the pheromone gland that function specifically to produce the specific pheromone compounds. These enzymes are produced by genes that eventually can be identified and possibly inserted into plant material so that the plant itself can be a slow-release source of pheromone for mating disruption.

Physiological studies have revealed that the biosynthetic processes and the act of releasing pheromone at a particular hour are under neural and hormonal controls. Characterization of these controls could lead to antagonists or neuroactive materials that inhibit females from releasing pheromone.

The *receiver,* such as a male moth that is attracted over long distances to a female moth, also must integrate many processes to perceive a specific blend of chemicals and carry out a complex behavioral sequence that allows it to arrive at the source of the odorous plume. Studies on the effect of various neurotransmitters and neuromodulators have shown that odor perception and response periodicity is greatly influenced by several biogenic amines. Further studies on the effect of agonists (a chemical substance capable of combining with a nervous receptor and initiating a reaction), antagonists (a chemical that acts within the body to block its nervous receptor), and related pharmacological agents on the action of these biogenic amines could lead to a new way of "jamming the receiver" and, thus, a new approach to the mating disruption technique.

The manipulation of a communication system that is as basic to the insect's survival as the sex pheromones requires an indepth knowledge of the whole communication system, from whole-body behavior to the molecular level.

Keeping Ahead of the Wolf: Pest Resistance to Agricultural Pesticides

B. A. Croft, *professor, Department of Entomology, Oregon State University, Corvallis, OR*

The Resistance Problem

Only after decades of pest control remedies and problems has an appreciation grown of the threat posed by pesticide-resistant pests to world and U.S. food production. Since the first case of resistance to lime sulfur in 1908 in San Jose scale (an insect that sucks plant fluids), 428 species of arthropods (insects, mites, and ticks) have become resistant to one or more pesticides worldwide. Of that number, 268 are agricultural pests; the rest are medical or nuisance pests. Resistance has arisen in 150 plant pathogens (fungi, bacteria) and about 50 weeds to herbicides. Only 10 rodents or plant-attacking nematodes have developed resistant populations.

Multiple and Cross-Resistance

Multiple- and cross-resistance to pesticides among pests are becoming more common, too. Cross-resistance is when a pest develops resistance to one compound, but also shows resistance to another, usually related, compound. Multiple-resistant pests tolerate pesticides from many classes of compounds with diverse modes of action.

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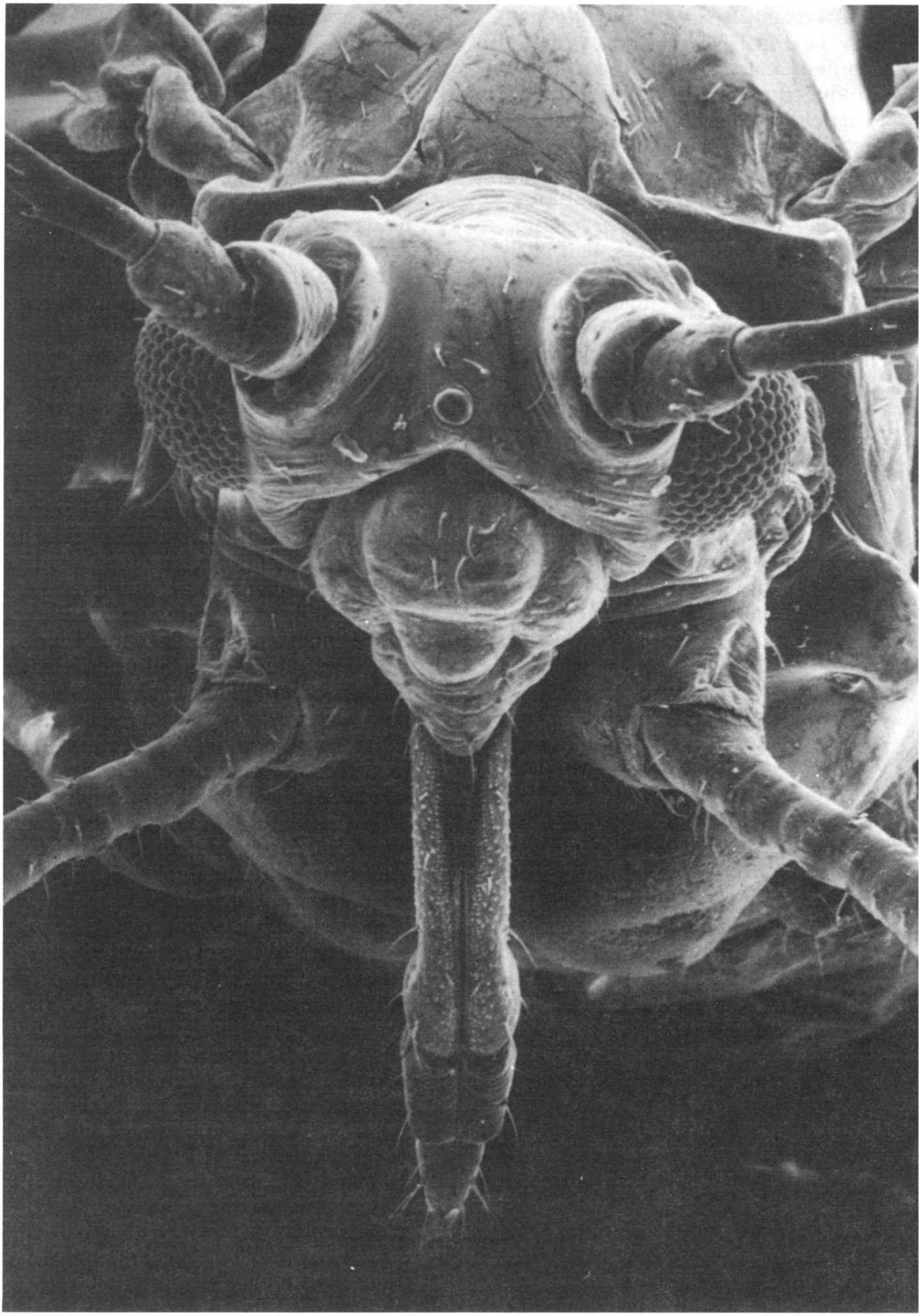


Certain aphids have become resistant to some pesticides (magnified 200 times).

An example is with the *kdr*-factor involved in DDT resistant which also confers resistance to the recently introduced synthetic pyrethroid (SP) insecticides. Resistance of several pests to SP's has been reported even though their use has been limited.

Many pests now have multiple-resistance factors in their genetic makeup. Among insects, half of the 428 species are resistant to 2 or more of the 5 major insecticide groups, and at least 17 have adapted to all 5. The housefly, green peach aphid, beet armyworm, diamondback moth, and twospotted spider mite are examples of these "super" resistant bugs. Most recently, strains of pests resistant to even their own growth hormones and natural pathogens have been found.

One recent, dramatic case of multiple resistance is with the Colorado potato beetle in Long Island, NY where resistances to every compound registered for use on potato has developed. Up to 10 sprays per year of aldicarb and oxamyl were used to control the beetle until recently. Use of these compounds contaminated ground water, and some desperate farmers, unable to use any conventional insecticide, returned to standby pesticides used decades ago. Cases like this raise the question—is the human race winning the battle against these adaptive competitors?

Research on Resistance Management

Back when resistances first became common, researchers sought to understand the genetics and biochemistry of resistance in pests to circumvent or diminish their impact on agricultural crops.

After many failed attempts, a certain inevitability syndrome set in—given time, resistance would eventually develop with intense selection. Many believed that resistance was irreversible and compounds were lost forever.

More recently, and in association with development of the integrated pest management (IPM) approach to pest control which has gained acceptance worldwide, better understanding of resistance and factors influencing its development have been gained. Also, new measures to reduce the occurrence of resistance have been researched and are being implemented.

Basic research to identify the biological, ecological, and operational (those under the control of pest managers) factors influencing resistance development has been done through both experimental and modeling studies. This work has improved understanding of how the complex of variables influencing resistance interact in a resistance episode.

There is now a more wide-ranging perspective from the genetics and biochemistry of resistance at the cellular level to the population genetic or ecological levels. For example, awareness has grown of how the ecological setting of a particular agricultural site (e.g. the type of surrounding habitat and sources of colonization by genetically susceptible organisms) influences the extent or course of resistance development. Improved understanding of resistance has helped identify new methods and better integrated use of old and new methods which conserve pesticides as finite, valuable resources.

Resistance management tactics fall into three categories: new or altered pesticide products, changing pesticide use patterns, and ecological tactics.

New or Altered Pesticide Products. Mixtures or multiple-site compounds attacking several target sites simultaneously are usually more difficult to develop resistance to by pests than are single genetic target-site compounds. In responding to fungicide resistance, chemical companies often use mixtures of chemicals. Synergists applied with pesticides may reduce resistance development by interfering with the detoxifying enzymes that allow the pest to survive pesticides.

Researchers have identified many new chemical agents with novel modes of action and properties that lessen the likelihood of resistance. Pesticides persisting in the environment for short times and tending to act on only limited portions of a pest's generation and specific stages, may slow resistance. By limiting exposure, the pest's full array of potential to develop resistance never comes into play.

Other innovative compounds may be used at low doses that selectively kill plant-feeding pests rather than biological control agents. These place less pressure on pests to develop resistance. Similarly, slow-acting toxicants, which allow host-plant resistance and other factors to take their toll on pests, reduce selection for resistance.

Behavior-modifying chemicals that reduce a pest's ability to locate and attack host plants are additional examples of insecticides that combine selectivity and a broad-spectrum pest activity to aid in resistance management.

Changing Pesticide-Use Patterns. Often, when dosages of pesticides are reduced, fewer pests die, so the pressure to develop resistance is less. Occasionally, increases in dosages also may hinder resistance buildup, but this tactic does not work unless resistance is detected at low levels and knowledge of the immigration of susceptible organisms is available.

Rotation of compounds with different modes of action in sequence may limit resistance to pesticides by permitting pests to revert to susceptibility while alternate chemicals are being used. A variation of this approach involves alternating "negatively correlated cross-resistant pesticides," where resistance to one chemical is associated with decreased resistance to another chemical, and vice versa.

The timing and placement of pesticides also affect resistance. Applying pesticides over limited areas reduces the proportion of the pest population exposed and thus limits resistance by keeping in the population more genes that confer susceptibility. Treating alternating generations of pests allows for more reversion to susceptibility, because of reshuffling of genes and immigration of nonresistant pests between generations.

Ecological Tactics. While these methods of managing resistance have received limited study, ecological factors are major determinants of whether resistance will occur and how severe it will become.

Recent study has centered on the effects of immigration on the evolution of resistance. Under most conditions, high rates of immigration of susceptible individuals from untreated areas (refugia) mean that genes conferring resistance in treated populations are flooded out. Susceptible immigrants can be attracted into an area or released into the environment in nondamaging stages. Also, resident populations in treated areas can be limited by applying pesticides intensively before periods of immigration. If such immigration of pests can be tolerated, these may be effective approaches.

Any resistance-management measure may stem resistance by itself. But multiple, integrated measures as part of IPM are usually needed for best results. Regular and frequent monitoring also is essential to effective management. In the early stages of resistance development, the key is to detect resistance at low levels while the trend can still be reversed. Later, monitoring allows users to switch tactics in response to observed resistance levels, especially where cross-resistance or multiple resistance is a problem.

Cases of Resistance Management

Several recent cases of resistance management show progress in limiting resistance and conserving pesticide resources.

In Australia, resistance to synthetic compounds (pyrethroids) by the cotton pest, *Heliothis armigera* was detected in the early 1980's. By careful monitoring and areawide coordination of limited SP use, resistance has been held in check and effective pest control obtained with chemical products including SP's. Similar programs on cotton in the United States are recommended on a preventative basis to minimize the possibility for resistance in closely related species.

Pear psylla, a serious pest in the United States, has developed resistance to many insecticides of all classes. When the SP, fenvalerate, was proposed for use in the Pacific Northwest throughout the growing seasons, preliminary tests showed that the insect developed resistance in less than 3 years. But where the pyrethroid was used only in early season and an alternative compound (amitraz) was used for summer control, the pest has been effectively controlled for at least 10 years.

In the same region, use of natural enemies to help control spider mites on apples has appreciably slowed resistance buildup to organotin acaricides. Resistance to these chemicals developed in pears and strawberries in the absence of effective biological controls, and additional or substitute compounds were required on these crops for effective mite control. In contrast, in Washington State, integrated control of mites is widely practiced on apples, using predators and limited chemical application (averaging one-half to one annual spray per orchard). There, cyhexatin has remained effective for the 15 years that

Biological and operational factors which influence resistance development to insecticides in arthropod pests.

Biological	Operational
Genetic	
Frequency of R-gene(s)	Avoid cross-resistance
Number of R-gene(s)	Persistence of residues
Dominance of R-gene(s)	Dosage applied-selection level
Fitness of R-gene(s)	Life stage selected
	Treatment threshold
Biotic	Alternation of generations selected
Generation time	Space limited selection
Offspring/generation	Rotation of different compounds
Mode of reproduction	Mixtures of compounds
	IPM
Ecological	
Dispersal capabilities-mobility	
Host specificity	
Refugia within treatment area	

the chemical has been marketed.

In Japan, study of biochemical changes in resistant insects led scientists to develop a method for restoring the effectiveness of carbamate insecticides against green rice hopper. The key was discovering a detoxifying enzyme in the insect, which was overcome by adding a synergist. In addition, by using the organophosphate fungicide Kitazin P to control the disease rice blast, Japanese workers also suppressed organophosphate resistance in the same insect because the fungicide inhibited another enzyme.

Houseflies on Danish farms have become resistant to virtually every new insecticide since the 1950's. Now, through strict regulation and monitoring, prevention of widespread resistance to pyrethroids has occurred. In 1978 and 1979, surveys indicated that resistance was occurring, and would reach high levels since many flies were carrying resistance genes. A decision was made against registering residual pyrethroids for this use.

Continued monitoring indicates that relatively nonpersistent pyrethroids plus a synergist can be used for several seasons if applications are not too frequent.

Need for More Research

While these selected cases of resistance management are encouraging, they are only limited victories in the fight against pesticide resistance. As pointed out in a recent U.S. National Academy of Sciences study on pesticide resistance, additional research on factors influencing resistance, tactics of resistance management, better monitoring methods, improved resistance risk assessment and changes in policy governing pesticide use are needed to stem the tide of pest control failures and keep ahead of the raging wolf of pesticide resistance.

VII
Human Nutrition and Food

Diet and Health in the United States

Daphne A. Roe, *professor of nutrition, Division of Nutritional Sciences, Cornell University, Ithaca, NY*

Many measures of health status have been used to characterize a population. These measures include objective criteria such as growth, life expectancy, death rates, the prevalence and incidence of specific diseases and the prevalence of disability because of these diseases, the ability of people to perform the activities of daily living, and their ability to perform physical exercise.

They also include subjective criteria, of which the most useful is a self-assessment of health status. Our population's health status is related to its self-perceived condition of wellness and to the prevalence of certain chronic diseases which detract from functional capacity, increase health care costs, and reduce life expectancy.

Perhaps the most important advance in our knowledge of human behavior in the last 25 years has been the realization that, insofar as wellness and the risk of chronic disease are concerned, we are capable of shaping our own destiny. Self-determination of health status, which for any individual is incomplete, is achieved by positive health behaviors associated with disease prevention. Such behaviors are largely determined by an individual's perception of the benefits of such action.

Wellness, Exercise, and Nutritional Needs

The positive behaviors significantly related to health promotion include not only avoidance of social poisons such as cigarettes and alcohol in excess, avoidance of injury from our physical and chemical environment, including sunburn and exposure to chemical toxins in the workplace, but also exercise and a prudent diet. Interest in exercise derives from the association of such activity with desirable health including reduced risk of obesity, hypertension, heart disease, and diabetes. The retention of calcium in bones also is favorably affected by exercise, and exercise may delay the onset, or reduce the severity, of age-related bone loss.

National health organizations that have endorsed the public's enthusiasm for exercise include the American Heart Association, the American Medical Association, the American Dietetic Association, and the American Diabetes Association.

Influence of Exercise on Nutritional Needs

While recognizing the advantages of regular aerobic exercise, it also is necessary to understand that exercise performance influences nutritional needs. Adequate intake of water to offset sweat losses is essential. Then, as the amount of daily exercise increases, so food-energy requirements increase. Protein needs are not much increased by athletic training or by regular exercise, but recent evidence from animal studies has indicated that endurance exercise may have a moderate effect on protein requirements.

Needs for certain B vitamins grow with increases in energy expenditure. In the case of riboflavin, studies in young women have shown that the 1980 RDA is inadequate and that exercise increases requirements, whether or not body weight is constant. There is no evidence that the large supplements of B vitamins advocated for athletes improve athletic performance.

Mineral and trace element needs also increase with exercise, especially for minerals such as sodium and trace elements such as copper which are lost in sweat. Men and women engaging in mild to moderate aerobic exercise under temperate conditions, however, do not require salt pills. Sodium depletion is only a significant risk when heavy exercise is undertaken in hot environmental conditions or when the individual exercising either is on a sodium-restricted diet or is taking diuretics.

While many clinical vitamin and mineral deficiencies are associated with decreased physical performance, nutritionists reassure us that the nutritional needs of most athletic men and women can be met by modifications of the usual diet to meet food-energy and nutrient needs. They are currently more concerned about athletes taking excessive amounts of nutrient supplements or other health food products under the mistaken advice of trainers, friends, or sports magazine writers.

Diet in Preventing Cardiovascular Disease

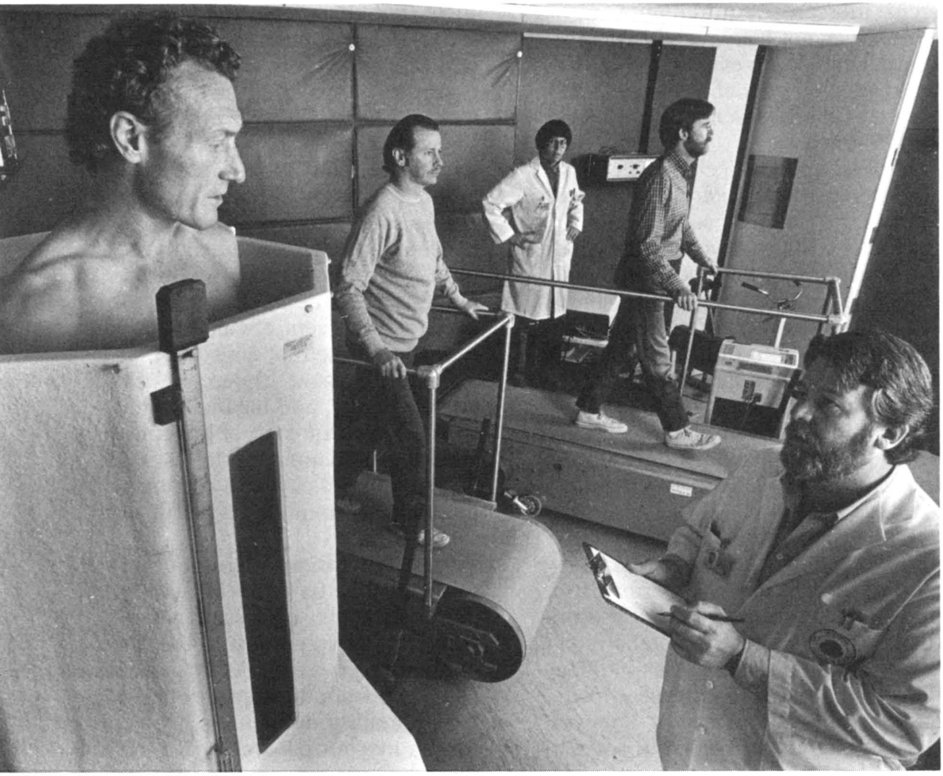
Coronary Heart Disease. Coronary heart disease is associated with increased blood cholesterol values. Evidence is now substantial, however, that coronary heart disease incidence can be decreased by a reduction of blood cholesterol. While this was demonstrated in the Lipid Research Clinics Primary Prevention Trial, the reduction in cholesterol was because of treatment with cholestyramine, which is a cholesterol-lowering drug.

Epidemiological evidence also indicates that changes in the U.S. life style, with reduction in cholesterol and saturated fat intake as well as cessation of smoking, have lowered vascular death rates. Further, we know that countries such as Japan, which have low intakes of cholesterol and fat, have lower coronary heart disease mortality.

Dietary guidelines aimed at reducing the risk of coronary heart disease emphasize reduction in total fat intake to 30 percent of calories, reduction of saturated fat consumption to account for about 10 percent of total energy intake, and balancing that with 10 percent each of polyunsaturated and monounsaturated fats and reduction in cholesterol consumption to about 300 milligrams per day.

Hypertension. A large number of nutritional factors may influence cardiovascular physiology and may, therefore, be important in the development or prevention of hypertension. Evidence from descriptive epidemiological studies, which has been confirmed by controlled clinical trials, indicates that excessive food-energy intake is the most important nutritional determinant of elevated blood pressure. Other dietary factors which are causal determinants of hypertension include dietary sodium and alcohol excess. While it has been suggested that people vary in their response to increases in dietary sodium, such that those with a family history of hypertension are more susceptible, recent studies refute this hypothesis.

In preventing as well as controlling hypertension, it is important to remember that dietary sodium is largely derived from sodium chloride in foods, drinking water, and also in both prescription and over-the-counter drugs. In addition, other sodium salts are used as intentional food additives including sodium bicarbonate, sodium benzoate, sodium ni-



Chris Springman, ARS

Physiologist (background) monitors treadmill exercises while lab technician records body fat content of a volunteer in a water displacement tank.

trate and nitrite, and monosodium glutamate. The Food and Nutrition Board of the National Academy of Sciences has recommended that intake of salt should be in the range of 3–8 grams a day.

Defective calcium metabolism in the smooth muscle cells has been suggested as a mechanism for the development of hypertension. But these changes may be a consequence rather than a cause of hypertension.

Epidemiological Studies of Diet and Cancer

Several lines of scientific evidence indicate that diet plays an important role in human cancer development. The major and potential roles which have been identified are as follows:

- Carcinogens may be present in food, either as natural food toxins, substances formed in food as a result of food processing or food preparation, intentional food additives, or food contaminants.
- Carcinogenesis may be produced in the body, for example, in the stomach or intestine from food constituents.
- Protein-energy malnutrition or specific vitamin or mineral deficiencies may retard or promote tumor formation.
- Dietary excesses of food energy,

fat, or protein may promote tumor formation.
- Specific nutrients or non-nutrient components of food may provide protection against cancer development.

Examples of carcinogens present in food include aflatoxin, polycyclic hydrocarbons, and nitrosamines. Nitrosamines also may be formed in the body from nitrates ingested in vegetables or in meats preserved with nitrate or nitrite. High fat diets have been linked to several common cancers, including breast and colon cancer. Cancer of the mouth, throat, and esophagus have been linked to alcohol abuse.

However, dietary fiber, vegetables like cabbage and broccoli, vitamin A, beta-carotene, vitamin C, and selenium have been shown to exert a protective effect against cancer, at least in experimental animals.

Interest in the relationship between diet and cancer has been stimulated by international studies showing that large differences exist in cancer incidence between and within countries. Strong correlations have been found between dietary factors and cancer incidence, but to support a causal relationship either between specific dietary factors and cancer development or prevention, it has been recommended that double-blind nutritional intervention trials be carried out. In these trials, it will be necessary to obtain an end-point when it is apparent that the imposed dietary change or nutrient supplement has or has not altered the incidence of particular cancers.

Cancers of specific sites have been linked to particular dietary characteristics. For example, there is a high correlation between the level of dietary fat and the incidence of colon and breast cancer, as well as a strong correlation between death from ovarian and prostatic cancer and fat intake. On the other hand, gastric cancer is associated with intake of a low fat diet.

Knowledge of these site-specific differences in dietary factors that affect cancer has provoked skepticism in the United Kingdom about the wisdom of making dietary recommendations. Indeed, one author, M. J. Hill, after discussing this issue, commented ". . . there are at present no grounds for making recommendations, on the basis of a supposed role in carcinogenesis, designed to persuade us to give up or modify the diet we like or have freely chosen."[1]

This viewpoint is in strong contrast to the U.S. recommendations of the Committee on Diet, Nutrition and Cancer who in their 1982 report, proposed that both saturated and unsaturated fat intake should be reduced to approximately 30 percent of total calories to lower the risk of fat-related cancers.

Since there is already good evidence that such diet modification would reduce the risk of heart disease and may decrease the risk of colon and breast cancer, implementation of this guideline on a national scale appears to be justified. Whether or not such intervention has the desired effect on cancer incidence can only be discovered by longitudinal studies of cancer incidence and deaths.

Reexamination of Obesity as Health Problem

In the past 5 years, evidence that obesity is the Number One health problem in the United States has been reexamined. The questions being asked are to what extent obesity confers a health disability and to what extent it contributes to the etiol-

[1]Hill, M.J., *Dietary fat and human cancer*, Proc. Nutr. Soc. 40:15–19, 1981.

ogy of life-threatening chronic disease.

Obesity is a risk factor for coronary heart disease and is causually related to the development of diabetes and hypertension. Further, severe obesity is in itself a threat to life. On the other hand, thinness is associated with a heightened risk of early death in such diseases as tuberculosis and cancer.

Recommended weight ranges have been provided for the United States for over 40 years by the Metropolitan Life Insurance Company's Ideal Weight Tables. These tables, based on actuarial mortality data, give ranges of body weight for men and women of different heights and body frame sizes which, in the company's insured population, were associated with the lowest mortality. In the past, age has not always been considered a variable in making these national weight guidelines. More recent epidemiological studies indicate that, while for younger people, minimal mortality is associated with leanness, for older men and women minimal mortality is associated with somewhat higher weights. For the elderly, it is as yet difficult to make recommendations because of insufficient data.

Therefore, it has been proposed that new recommended weight tables should be made for healthy people and that those who either have a familial predisposition to one of the chronic diseases for which the risk is increased by obesity, or who have one or another of these diseases, should have their weight goals set by established medical guidelines.

Diabetes

Diabetes is classified into several types and subtypes which have different causal factors. The occurrence of the two major types of diabetes are more common in families with a history of these diseases. Type I (insulin-dependent) diabetes is now believed to be the result of virus-induced destruction of the beta cells of the pancreas which produce insulin. On the other hand, in Type II (insulin-independent) diabetes, the tissues have a decreased sensitivity to insulin mainly as a result of obesity.

In diabetes of both types, there is a high risk of vascular disease, and in Type II diabetes, coronary heart disease and other manifestations of arteriosclerosis are common. Because of the fact that obesity is a strong risk factor for Type II diabetes, and because of the heightened risk of heart disease as a complication of Type II diabetes, those with this disease are recommended to keep their weight at or slightly below ideal body weight for their age and sex, and to consume a diet that does not contain more than 30 percent of calories as fat. Other recommendations are to restrict their intake of simple sugars, but to have a liberal intake of complex carbohydrate foods including fruits and vegetables containing fiber sources which decrease the rate of glucose absorption.

Nutritional priorities for diabetics should both reflect those of the population at large and should also incorporate the goals of current diabetes management. These priorities can be summarized as follows:

1. Attainment of desirable body weight;
2. Adequate intake of all essential nutrients;
3. Maintenance of normal blood glucose levels;
4. Reduction in blood lipid levels to normal values; and
5. Consistency in daily food-energy intake.

In addition, Type I diabetics need to space their food-energy and carbohydrate intake during the day and to avoid hypoglycemia after insulin injection or as a consequence of exercise.

Osteoporosis and Calcium Intake

Loss of mass and bone mineral, which occurs with aging, is termed osteoporosis. Osteoporosis is more severe in postmenopausal women than in men of comparable age, more severe in Whites than in Blacks, and more severe in small-boned than in large-boned individuals. It is also exacerbated by lack of exercise. Epidemiological evidence as well as human metabolic studies indicate that the level of calcium intake may influence the extent of osteoporosis.

Osteoporosis is the underlying cause of hip and vertebral fractures of the elderly. Because a high calcium intake may retard osteoporosis' progress and because of the high hospital expenses of people with fractures, it has been recommended that postmenopausal women increase their daily intake of calcium from the level of the 1980 RDA, which is 800 milligrams a day, to 1.5 grams a day. High intakes of calcium also have been justified by the fact that the efficiency of calcium absorption is lessened with age.

While an increase in dietary calcium intake is being advised by many physicians, it is difficult to achieve a daily intake of 1.5 grams a day, unless the calcium is supplied, in part, by intake of a mineral supplement. Calcium carbonate is the preferred form because of its low cost. It has been shown, however, that the absorption of calcium carbonate is impaired in individuals with loss of capacity for gastric acid secretion. Reduced gastric acid secretion occurs in 10 to 30 percent of all elderly people, and therefore it is questionable whether calcium carbonate is an appropriate form of calcium for the management of osteoporosis. Another potential disadvantage of this form of calcium is that it is an antacid and may reduce the absorption of other nutrients such as iron and folic acid.

Lifestyle Modification

Recommendations for health promotion and disease prevention require modification of our lifestyle so that we become less sedentary and modification of our diets so that we avoid caloric and nutrient excess. While we can make no claim at the present time that we can avoid chronic diseases such as heart disease, cancer, diabetes, or osteoporosis by diet alone, the risk and prognosis of these diseases may be ameliorated by following dietary guidelines. But it is important to avoid recommending changes in the U.S. diet or levels of intake of particular nutrients which could have adverse nutritional effects.

Diets of Americans: How Good Are They?

Betty B. Peterkin, *acting administrator, Human Nutrition Information Service*

National surveys track the dietary behavior of Americans, telling us what foods people eat and how well their diets conform to some of the Dietary Guidelines for Americans. (These guidelines are discussed in detail in the next article.) And they tell us how diets change over time between surveys.

From two U.S. Department of Agriculture (USDA) surveys—the Continuing Survey of Food Intakes by Individuals, 1985 and the Nationwide Food Consumption Survey, 1977–78—diets of more than 1,500 women 19 to 50 years of age in 1985 were compared with diets of an equivalent group of women in 1977. Diets compared were for one day in the spring of 1985 and one day in the spring of 1977. In personal interviews, women in nationally representative samples were asked to recall food eaten on the previous day using similar, but not identical questions.[1]

This comparison of diets in 1985 and 1977 shows how food and nutrient intakes changed during a period of high public awareness and concern about diet and health. It shows change since the presentation of Federal dietary goals in 1977 and dietary guidelines in 1980. Changes are not necessarily a result of increased knowledge and concern about diet. Socioeconomic and other factors also affect food selections. For example, women in 1985, on average, may have been more pressed for time. Compared to 1977, the women surveyed in 1985 were more likely to be employed full time or part time (60 versus 52 percent).

Food Selection

Food selections by women in 1985 and 1977 were alike in many ways. Most women in both years had some food from four major food groups on the day reported. About 90 percent had one or more vegetables or fruits; one or more grain products; and one or more meat, poultry, or fish items. Only about 75 percent selected milk or a milk product in both 1985 and 1977.

Some rather dramatic differences in women's diets, however, are indicated by results from the two surveys, only some of which may be attributed to women's changing perceptions of "what's good for you."

Move to Mixtures. Women reported eating more food as mixtures of two or more ingredients in 1985 than in 1977. For example, the amount of meat mixtures, such as stews, casseroles, sandwiches (including hamburgers), and frozen dinners was up by one-third. Grain mixtures, which include items such as pizza, spaghetti with sauce, and macaroni and cheese, were up over two-thirds. Milk in the form of milk products such as cheese and milk desserts was up one-sixth. These mixtures may have been commercially prepared, made at home, or prepared away from home in a restaurant or other food establishment.

Where's the Meat? As women shifted toward mixtures with some

[1] For more information, see *Continuing Survey of Food Intakes by Individuals:* NFCS, CSFII Report No. 85-1, Human Nutrition Information Service, USDA, November 1985.

meat in them, they shifted away from eating meat separately. The average amount of beef eaten separately in 1985 was 45 percent lower than in 1977, and pork eaten separately was 22 percent lower than in 1977. These lower intakes in 1985 may be partly made up by the greater use of beef and pork in mixtures. Poultry intakes were about the same in the 2 years while intakes of fish and shellfish, although relatively small, were a little higher in 1985. Like meat, actual intakes of poultry and fish would probably be increased somewhat if amounts in mixtures were added.

On the day studied in 1985, the category within the meat, poultry, and fish group reported by the highest percentage of women was meat mixtures (37 percent). Next highest was frankfurters, sausages, and luncheon meats (25 percent), although the amounts reported were relatively small. Then came those groups of items that were eaten separately: beef (23 percent), pork (20 percent), poultry (19 percent), and fish and shellfish (12 percent). Percentages choosing beef and pork separately were down from 35 percent and 24 percent in 1977.

Foods sometimes used in place of meat at meals—such as legumes, nuts and seeds, and cheese—were reported by more women in 1985, but average intakes were only a little higher than in 1977. Average intake of eggs in 1985 was down over one-fourth from 1977.

Grain Products Gain. Women chose more grain products, on average, in 1985 than in 1977. Categories of these products showing the greatest intake gain were grain mixtures (up 72 percent) and cereals and pastas (up 25 percent). On the day studied in 1985, the most women (70 percent) selected yeast bread and rolls, followed by other baked goods (53 percent). Cereals and pastas were reported by 32 percent and grain mixtures by 26 percent.

Milk Choices Change. The amount of milk women consumed as milk and in milk products and the percentage of women having milk in some form during the day were about the same in the 2 years. The form of milk consumed, however, changed—average intake of lowfat and skim milk was 60 percent higher and intake of whole milk 35 percent lower in 1985 than in 1977. In 1985, 51 percent of the women chose fluid milk, with about one-half choosing whole milk and the other half choosing lowfat or skim milk. Next in popularity was cheese (34 percent), cream and milk desserts (25 percent), and yogurt (4 percent).

No Gains in Vegetables, Fruits. Intakes of vegetables and of fruits were about the same in 1985 as in 1977. In 1985, 83 percent of the women chose at least one vegetable, with 44 percent choosing white potatoes and 29 percent choosing tomatoes. Only 47 percent chose one or more fruits, with 25 percent choosing citrus fruits and juices.

Beverage Intakes Up. Women's average intakes of carbonated soft drinks, of fruit drinks and ades, and of alcoholic beverages were about 50 percent higher in 1985 than in 1977. Coffee and tea showed no change. The percentage of women choosing carbonated soft drinks increased from 42 to 54 percent, equaling coffee in popularity. Regular soft drinks remained the favorite with 36 percent selecting them in 1985, while 20 percent had low-calorie types—double the percent in 1977.

Nutrient Intakes

Shifts in intakes of various foods, by themselves, are neither good nor bad.

Only the diet, as a whole, can be assessed for nutritional quality. Women's diets were assessed with respect to their content of 28 nutrients. To do this, the nutrient intake from those foods women reported eating was estimated using information on the nutrient content of foods developed by USDA for assessing survey data in 1977 and in 1985. Then the nutrient intakes were compared to the Recommended Dietary Allowances (RDA) for women for the 15 nutrients for which RDA have been set.

RDA are amounts of nutrients considered to be adequate to meet known nutritional needs of practically all healthy persons. To be safe, the RDA are set above needs of most people so intakes below the RDA are not necessarily inadequate. The risk of having an inadequate intake, however, is greater for people with intakes well below RDA.

Vitamin and Mineral Intakes Improve Slightly. Average nutrient intakes by women in 1985 were above the RDA for 8 nutrients: protein, 6 vitamins (A, thiamin, riboflavin, niacin, B_{12}, and C), and 1 mineral (phosphorus). Intakes were below the RDA for 7 nutrients: 3 vitamins (B_6, folacin, and E) and 4 minerals (calcium, iron, magnesium, and zinc). Average levels were 51 to 78 percent of RDA for these nutrients, except for vitamin E, which averaged 97 percent of RDA. Average intakes of vitamin B_6, folacin, calcium, iron, magnesium, and zinc were below RDA for women sorted by income, race, region, or urbanization.

Compared with 1977, intakes in 1985 were as high or higher for food energy, protein, and all vitamins and minerals studied. Of the nutrients below the RDA, calcium showed the greatest gain—from 69 percent of RDA in 1977 to 78 percent in 1985. Gains in calcium intakes were apparent for women with high, but not low incomes, and for white, but not black, women.

Fat Down, Carbohydrate Up. Most calories come from fat, carbohydrate, and protein in diets. Women's intakes in 1985 were lower in fat and higher in carbohydrate, both in average grams of fat and carbohydrate and expressed as a percentage of total calorie intake than intakes in 1977. In 1985 the average fat intake in grams was 5 percent lower and the carbohydrate intake 20 percent higher than in 1977. Protein intake was about the same. In 1985 fat in women's diets provided 37 percent of total calories—down from 41 percent in 1977. Carbohydrate provided 46 percent of calories in 1985—up from 41 percent in 1977. Awareness that lower fat diets are desirable and some increased questioning by interviewers to get more precise information about fat in the 1985 survey may have influenced the results somewhat toward lower fat diets.

Dietary Fiber Intakes Estimated. Dietary fiber intakes, estimated only in 1985, are considered tentative because of limited information on the amount of dietary fiber in foods. Women's average intakes were 12 grams a day. Intakes were slightly higher for women in high- rather than in low-income households and for white rather than black women.

Sodium. Sodium in diets is difficult to assess. The sodium content of many commercially prepared foods is not available. Also, women surveyed often do not know how much salt and other sodium-containing products they use in preparing foods and at the table. Excluding sodium added at the table, intakes in 1985 were estimated at 2,600 milligrams a day. The RDA safe and adequate range for adults is 1,100 to 3,300.

Eating Practices

The frequency with which women ate, snacked, and ate away from home changed between 1977 and 1985. Women ate more often in 1985 than in 1977—four times a day was most frequently reported in 1985 and three times a day in 1977. In 1985, 38 percent ate five or more times as compared to 24 percent in 1977.

Snacks were reported by 76 percent of the women in 1985 but only by 60 percent in 1977. In 1985, snacks contributed 16 percent of total calories with carbohydrate providing more and fat and protein providing less of these calories. They contributed 10 to 15 percent of the day's intakes of vitamins and minerals. Snacks contributed 15 percent of total intakes of calcium and magnesium—nutrients that were below recommended levels in these women's diets.

In 1985, 57 percent of the women obtained and ate some food away from home, but only 45 percent in 1977. In 1985, food away from home contributed 28 percent of total calories and about the same proportions of protein, fat, carbohydrate, and of most vitamins and minerals. On the whole, the food women ate away from home was of about the same nutritional quality as food they ate at home.

Vitamin and Mineral Supplements

The 1985 and 1977 surveys assess diets in terms of nutrients contributed only by food. But information obtained on vitamin and mineral supplements indicated that usage in 1985 was up substantially from 1977. In 1985, 58 percent of the women took a vitamin or mineral supplement, or both, either regularly or occasionally, compared with 39 percent in 1977. It appears that more women in 1985 than in 1977 were concerned that the foods they selected were not providing enough nutrients—a concern not supported by their reported intakes.

Women's Diets and the Dietary Guidelines

Some of the shifts in dietary behavior between 1977 and 1985 may reflect attempts to modify diets in ways certain guidelines suggest. Assessments indicate the continuing need for change to improve diets.

The Dietary Guidelines recommend that people:

- *Eat a variety of foods.* The variety of foods women selected in 1985 did not provide recommended amounts of several nutrients. Although diets were no worse in this regard than in 1977, little improvement was noted.
- *Avoid too much fat.* The amount of fat in women's diets in 1985 was 5 percent lower than in 1977. The percent of calories from fat declined from 41 percent in 1977 to 37 percent in 1985.
- *Eat foods with adequate starch.* In 1985, total carbohydrate (starch and sugars) in diets was up by 20 percent over 1977. The percent of calories from carbohydrate increased from 41 percent in 1977 to 46 percent in 1985.
- *Eat foods with adequate fiber.* The intake of dietary fiber by women in 1985 was about 12 grams a day. Comparable data are not available for 1977. Further research is needed to define a recommended level of dietary fiber, but generally, increases are suggested.
- *Avoid too much sugar.* Intakes increased for certain sugar-containing foods such as candy, soft drinks, fruit drinks, and ades.
- *Avoid too much sodium.* Sodium intakes by women in 1985 were slightly below the top of the safe and adequate range suggested, but

they do not include sodium from salt added at the table. Actual intakes may well exceed suggested levels. Comparable data are not available for 1977.

- *If you drink alcoholic beverages, do so in moderation.* Alcoholic beverages are usually underreported in surveys. Intakes reported in 1985 were one-half higher than those in 1977.

Nutrition Monitoring Research

USDA conducts Nationwide Food Consumption Surveys about every 10 years—the last in 1977–78 and the next in 1987–88. The Continuing Survey of Food Intakes by Individuals was begun in 1985 to provide some information about dietary behavior between the decennial surveys. Both surveys are a part of the National Nutrition Monitoring System that covers Federal nutrition monitoring activities, mainly in USDA and the Department of Health and Human Services (DHHS). USDA surveys focus on the dietary status of Americans while DHHS surveys focus on the nutritional status of the population, as measured by physical examinations. The national monitoring of dietary status requires three major types of research-based information: nutritional requirements of individuals; nutrient content of foods; and food consumption by Americans.

Current Research. USDA's Agricultural Research Service (ARS) conducts research to define nutrient requirements at all stages of life and to study the interactions of nutrients and other factors that affect the availability of nutrients to the body. The Food and Nutrition Board of the National Research Council uses results from ARS research and research from other sources in setting the RDA, which are used in assessing the nutritional adequacy of the diets reported in these surveys. Quantitative standards that define levels of food components—such as fats, cholesterol, dietary fiber, and sugars—that are consistent with minimum risk of certain diseases await further research.

The Human Nutrition Information Service (HNIS) compiles and evaluates information from government, industry, and university laboratories on the nutrient content of foods and sponsors research to fill data gaps. Data are processed through a National Nutrient Data Bank and disseminated in machine-readable and published form. HNIS is the primary national resource for information on the nutritive value of foods.

HNIS also conducts surveys of food consumption and analyzes and reports results. The decennial Nationwide Food Consumption Surveys provide comprehensive information on food use and food cost by households and on food intakes by individual household members. The new Continuing Survey attempts to assess usual dietary status over a year for selected groups of the population and to report those results quickly. Methodology studies for this survey have been under way since 1981.

Research for the Future. Improved monitoring of dietary status depends on future research to help answer many questions:

1. Standards of dietary status.
   - What new nutrients and food constituents are of importance to nutritional well-being and prevention of disease?
   - What is the risk of nutritional deficiency and disease associated with diets containing different amounts of nutrients and food constituents?
   - How do nutrients interact and what is the effect of these inter-

actions and other factors on absorption of nutrients in the body?

2. Composition of foods.
   - How much of food constituents newly identified as potentially important to nutritional health do the thousands of foods Americans now eat contain?
   - How much of all food constituents are in those foods newly available to Americans?
   - What causes the nutrient composition of a food to differ—where it was grown, the length of time it was stored, etc.?
   - How can analytical procedures be simplified and improved?
3. Food consumption.
   - What types and combinations of national surveys will provide priority information on dietary status in a timely and cost-effective manner and will be compatible with physical examination surveys conducted by DHHS?
   - What are the best methods for measuring usual food consumption?
   - How can data collection and processing procedures be modified to improve data accuracy and timeliness?
   - Could a simplified questionnaire be developed to monitor progress in achieving diets that follow the Dietary Guidelines?

USDA has monitored the dietary status of Americans through periodic national surveys for 50 years. Also, estimates of the nutrient content of the U.S. food supply are available for each year back to 1909. USDA uses food and nutrient consumption information from this research in programs that relate to the production and marketing of food and in targeting and developing food assistance and nutrition education programs. Monitoring dietary behavior of Americans now and in the future is essential to carrying out USDA's nutrition mission—to assure that a sufficient, wholesome, and nutritious supply of foods is available to all Americans and to provide information with which healthy Americans can select good diets.

Dietary Guidelines for Americans

Susan Welsh, *director, Nutrition Education Division, Human Nutrition Information Service*

What should you eat to be healthy? Answers to these questions are everywhere. They come from doctors, dentists, nurses, dietitians, the Federal Government, State and local health departments, extension agents, teachers, popular books, magazines, TV, and radio. Much information is available. Some of it is sound and sensible, but some is not and many people remain confused.

Health depends on many things, including heredity, lifestyle, personality traits, mental health and attitudes, and environment, in addition to diet. The life expectancy, average body size, and general good health of Americans seem to indicate that most diets are adequate. We have a varied, plentiful, and wholesome supply of foods from which we can choose. Food alone, however, cannot make you healthy, nor can dietary guidelines guarantee health. But good eating habits based on moderation and variety can help keep you healthy and even improve your health.

Dietary Guidelines, 1980

Government has a special role in assuring the health and safety of the American people. Providing information that healthy Americans can use to select a good diet has been part of the U.S. Department of Agriculture's (USDA) mission since its beginning. To help people deal with the confusion of nutrition fact and fiction, USDA and the Department of Health and Human Services published *Nutrition and Your Health—Dietary Guidelines for Americans* in 1980.

Dietary Guidelines, 1985

In 1983, a nine-member Dietary Guidelines Advisory Committee of nutrition experts selected from outside the Federal Government reviewed the latest scientific data and reported their findings to the two Departments. Their recommendations formed the basis for the second edition of the Dietary Guidelines published by the Departments last September.

The second edition of the Guidelines is similar to the first edition. Some changes were made for clarity; others added guidance about nutrition topics that have been more prominent since 1980, such as following unsafe weight loss diets, using large-dose supplements, and drinking of alcoholic beverages by pregnant women.

These guidelines are for healthy people who want to reduce risks of nutritional deficiency diseases and of certain chronic diseases. They are not for people who need special diets because of diseases or conditions that interfere with normal nutritional requirements. These people may need special instruction from registered dietitians, in consultation with their own physicians.

They also are meant to be applied *together* to form a good diet. Because the guidelines refer to the total diet, they do not suggest that any single food or group of foods be eliminated. They emphasize variety, balance, and moderation. And they are not quantitative, but general and directional in approach. The first two guidelines on variety and weight maintenance form the framework of a good diet. The other five guidelines are specific characteristics of a good diet.

In addition, the Human Nutrition

Information Service staff with advice from the Extension Service, has prepared a series of 14 bulletins in support of these guidelines. The first seven bulletins give information about the guidelines; the next seven show how to use the guidelines while eating out, shopping, planning and preparing meals.

Eat a Variety of Foods. This simple guideline represents a complex food selection pattern. The intent is to eat the kinds and amounts of foods that will provide the protein, minerals, and vitamins your body needs. No one can be expected to keep track of the more than 40 different nutrients and food components needed for good health. Most foods provide more than one nutrient, but no single food provides everything. But most people can satisfy their nutritional needs by eating a balanced, varied diet that emphasizes the major food groups—fruits; vegetables; whole-grain and enriched breads, cereals, and other foods made from grains; dairy products; and meats, poultry, fish, eggs, and dry beans and peas.

For example, dairy products such as milk are a source of protein, fats, simple carbohydrates, vitamin A, riboflavin, and other B vitamins, calcium, phosphorus, and other nutrients. But they provide little iron, zinc, or vitamin C. Meat provides protein, several B vitamins, iron and zinc but little calcium or vitamin C. Vitamins A and C, folic acid, fiber, and various minerals are obtained from fruits and vegetables. Whole-grain and enriched breads, cereals, and other grain products provide B vitamins, iron, protein, and fiber.

A varied diet based on these food groups will satisfy the nutrient requirements of most healthy individuals without the need for supplements. The guidelines state that there are no known advantages and some potential harm in consuming excessive amounts of any nutrient and that large-dose supplements of any nutrient should be avoided.

There are a few exceptions to this general statement about supplement use. Women of childbearing age may need iron supplements. Pregnant and lactating women need amounts of several nutrients beyond what their usual diets may provide. Infants, 4 months and over, especially those who only breastfeed, may need supplemental iron—iron added to foods such as cereal or taken as supplements. Elderly people who use medication for treatment of disease may need supplements because drug and nutrient interactions reduce absorption of some nutrients in the body.

USDA has several publications available from the Government Printing Office that focus on the importance of variety in food selection. *Food*, published in 1979, is a colorful example of dietary guidance featuring balance and moderation as characteristics of a nutritious diet. It presents the "Hassle-Free Guide to a Better Diet," similar to the basic four food guide used since the 1950's. *Ideas for Better Eating* gives specific information on implementing the guidelines. It provides recipes for a variety of foods that incorporate all the guideline principles.

USDA cooperated with the American Red Cross in developing a six-session nutrition course, *Better Eating for Better Health,* that focuses on implementing the Dietary Guidelines and other timely nutrition messages. It is being offered by Red Cross chapters across the country.

The USDA family food plans at four different levels of cost, which were revised in 1983, control fat, cholesterol, sugars, and sodium at moderate levels and provide recommended amounts of vitamins and minerals. The least costly of these food plans is the thrifty food plan used by USDA as the basis for benefits in the Food Stamp Program. *Your Money's Worth in Foods* focuses on ways of obtaining a nutritious diet while economizing on cost. A publication entitled *Making Food Dollars Count* provided sample meals for a family of four and was part of a campaign targeted to community leaders who work with low-income people. A new bulletin, *Thrifty Meals for Two: Making Food Dollars Count*, shows how to plan, buy for, and prepare low-cost meals and includes menus and recipes based on the nutritional needs of a couple over 51 years of age.

Maintain Desirable Weight.

Many people want to lose weight to look better, but other reasons are even more compelling. If you are too fat, your chances of developing some chronic disorders are increased. High blood pressure, increased levels of blood fats (triglycerides) and cholesterol, heart disease, strokes, diabetes, and many other types of ill health are among these chronic disorders. The weight of most adults should be no more than it was when they were about 25 years of age.

To maintain your weight—no loss and no gain—calorie intake from the food you eat needs to balance the calories you expend. To lose weight, you must take in fewer calories than you use. A more appropriate approach for most of us is to increase activity and use more calories than we take in.

Increased exercise has several payoffs: (1) You'll feel better; (2) exercise allows higher calorie intake with which to get needed nutrients, without unwanted weight gain; (3) exercise improves fitness which may help prevent heart disease; and (4) weight-bearing exercise may help prevent osteoporosis—a bone problem especially common among older white women.

In addition to increased physical activity, cutting down on high-calorie, low-nutrient foods is the best means of reducing calories. Cutting down on food across the board may be risky, because you need significant amounts of nutrient-providing foods daily to get recommended amounts of nutrients. Almost all foods have some calories. But some—often the ones we like best—have more than others. Foods high in fats are the most caloric. Every gram of fat has about 9 Calories—over twice as much as a gram of starch or sugar. A gram of alcohol has about 7 Calories. Fats, oils, sugars, and sweets as ingredients in foods or added to foods can be cut back to reduce calories; they are not nutrient providers. Also, the fat parts of animal foods such as meats and milk can be avoided to further cut calories. And alcohol, of course, can be avoided, too.

Severely restricted low-calorie diets make it extremely difficult to obtain the nutrients essential to maintaining good health. They also can have other adverse effects. Diets of less than 800 Calories a day can be hazardous and should be followed only under medical supervision. The guidelines warn that some people have developed kidney stones, disturbing psychological changes, and other complications while following such diets. A few people have died suddenly and without warning. Frequent use of laxatives, induced vomiting, and other extreme measures should not be used to lose weight. Such actions can cause chemical imbalances that can lead to irregular heartbeats and even death.

In addition to being hazardous, quick weight-loss schemes usually fail. Long-term success in losing weight and maintaining a desirable weight depends on adopting new and better habits of eating and exercise. USDA has prepared two publications that are helpful to dieters—*Calories and Weight* and *Food 2: A Dieter's Guide*.

USDA

USDA publications provide nutrition information to consumers.

Avoid Too Much Fat, Saturated Fat, and Cholesterol. The American diet, which is relatively high in fat—especially saturated fat and cholesterol—goes with high blood cholesterol and heart disease. Studies show that, for many people, eating extra saturated fat, high levels of cholesterol, and excess calories will increase blood cholesterol. Extra saturated fat appears to be the biggest factor. If you have a high blood cholesterol level, your chances of a heart attack are greater. High blood pressure and cigarette smoking are risk factors, too. And heredity seems to play a big role.

The association of cholesterol with heart disease has been highly publicized for more than three decades. But much confusion remains about blood cholesterol versus dietary cholesterol, and food sources of cholesterol and saturated fatty acids.

Your blood or serum cholesterol, measured by the doctor, is most important. If it's above 200–240 milligrams per deciliter—depending on your age—your doctor may suggest a special diet or a diet and medication. The special diet will limit foods with saturated fat and dietary cholesterol, and possibly calories as well, if you're overweight.

Dietary cholesterol—or the cholesterol in food—is found in large amounts in egg yolks and organ meats; it is in both the fat and the lean of meats, and the fat in milk. Poultry has nearly as much cholesterol as red meats. Cholesterol is not in foods of plant origin.

Fats in foods are mixtures of different types of fatty acids—but animal fats have more saturated fatty acids than do vegetable fats. Exceptions are palm and coconut oils, which are high in saturated fats. Red meats have more saturated fats than poultry and fish. A diet designed to reduce blood cholesterol by reducing fat intake will stress the use of poultry and fish.

Many animal foods that contain saturated fat and cholesterol, such as milk, meat, and eggs, also provide high quality protein and certain hard-to-get minerals such as iron, zinc, and calcium. So it is important to choose low-fat kinds of meats and milk and milk products most of the time. Some specific tips on how to avoid too much fat, saturated fat, and cholesterol are:

- Choose lean meat, poultry, and fish. Trimming the fat from a beef rump roast can reduce fat by two-thirds. Removing the skin from a roasted chicken breast can cut the fat in half.
- Use skim or low-fat milk. A cup of whole milk has 8 grams of fat; a cup of skim only about one-half of a gram.
- Moderate use of egg yolks and organ meats because of their high concentration of cholesterol.
- Limit use of fats and oils. They provide mainly fat and few vitamins and minerals.
- Avoid fried foods, especially breaded ones. One half of a batter-fried chicken breast is about equal to one-half of a roasted chicken breast plus 1 slice of bread and 2 teaspoons of fat.
- Look at labels of commercially prepared bakery goods and other mixtures. Many show the amount and kind of fat contained.

More information about this guideline is available in *Food 3: Eating the Moderate Fat and Cholesterol Way*, developed by the Human Nutrition Information Service, USDA and published by the American Dietetic Association.

Eat Foods with Adequate Starch and Fiber. Eating foods high in fiber can reduce symptoms of chronic constipation, diverticular disease, and some types of irritable bowel. Some evidence suggests that diets low in fiber may increase the risk of developing colon cancer, but further research is needed to be certain.

Starch and fiber are complex carbohydrates found in foods like breads and cereals, dry beans and peas, vegetables, nuts, seeds, and fruits. In addition to carbohydrates, these foods contain many essential nutrients and, except for nuts and seeds, have little or no fat. They also contain no cholestrol; no foods of vegetable origin contain cholesterol. With the exception of fruits, these foods also contain little of the simple kind of carbohydrate—sugar.

A moderate increase in dietary fiber of different types is desirable. This means, for most of us, eating more whole-grain products, fruits, vegetables (including the edible skins and seeds), and dry beans and peas. There is no need to take fiber supplements or to add fiber to foods that do not contain it. Studies show that too much fiber may prevent certain hard-to-get minerals, such as iron and zinc, from being absorbed by the body.

To eat more starch and fiber, substitute starchy foods—breads, cereals, and starchy vegetables such as beans, peas, and potatoes—for foods high in fats and sugars. Also, choose foods with different kinds of fiber every day—some whole-grain breads and cereals and some fruit with edible skins or seeds, for example.

Avoid Too Much Sugar. If you choose sweet pastries, jam on toast, and sweetened cereal for breakfast; if you use sugar in your coffee and tea or hit the soft drinks regularly; if you find the meal incomplete without a sweet dessert or the day incomplete without cookies or candy—you are a sweets junkie, like many other Americans.

You should avoid too much sugar because (1) sweets may replace foods that are more nutritious and (2) too much sugar causes tooth decay. The form in which you eat sugar and *when* you eat it is important, too. Sticky sweets are the worst kind, and eating them often adds to the problem. Guard against between-meal sweets. Of course, brushing and flossing your teeth immediately after eating helps combat decay, as does fluoride in the water or in toothpaste and mouth rinses.

There are many types of added sweeteners—sucrose, glucose, dextrose, sorbitol, fructose, maltose, lactose, manitol, honey, corn syrup, molasses, maple syrup. Some ways to control the amounts in your diet are:

- *At the store*, look at ingredient labels on foods you buy. Try to avoid foods that have one of these ingredients listed first or second (ingredients are listed in order by their content in the food) or that have several of these ingredients listed.
- *In the kitchen*, adjust recipes by cutting back on sugars a little at a time. Plan meals without soft drinks, other sweetened beverages, sweet desserts, and baked goods.
- *At the table*, cut back on the sugar, honey, jams, jellies, and syrups added to foods.

Avoid Too Much Sodium. Sodium is essential to the human body, but most Americans consume far more than they need. The principal concern with high-sodium consumption is for people with hypertension (high blood pressure) and those who may be susceptible to it.

For both the 60 million Americans who have high blood pressure and the rest of us who may get it, avoiding too much sodium is sensible. Table salt is not the only source, for a wide variety of sodium compounds is used in many processed foods and beverages.

To avoid too much sodium:

- Learn to enjoy the flavors of unsalted foods.
- Cook without salt or with only small amounts.
- Add little or no salt at the table.
- Cut down on salty foods—chips, salted nuts and popcorn, condiments (soy sauce, steak sauce, garlic salt), pickled foods, cured meats, some cheeses, and some canned vegetables and soups.
- Read labels for clues on amounts of sodium in processed foods.

USDA's *Sodium Content of Your Food* and the *Nutritive Value of Food* contain information about the sodium content of food. USDA and the Food and Drug Administration have published *Sodium—Think About It*, which provides information on how to reduce dietary sodium.

If You Drink Alcoholic Beverages, Do So In Moderation. From a nutritional standpoint, alcoholic beverages are high in calories but provide little else of nutritional benefit. Overweight people should be aware that alcohol adds calories. Heavy drinkers especially can suffer appetite loss, and this can lead to nutritional deficiencies and other health problems, such as cirrhosis of the liver and some types of cancer. This dietary guideline also supports the national effort to discourage drinking and driving.

The National Institute on Alcohol Abuse and Alcoholism advises pregnant women to refrain from using alcoholic beverages because excessive consumption may cause birth defects or other problems during pregnancy. The level of consumption at which risks to an unborn child occur is not known.

In summary, we define a nutritious diet as one composed of a variety of foods (some vegetables; fruits; breads and cereals; milk products; and meats, poultry, fish, eggs, and dry beans and peas) in amounts to result in desirable body weight, selected to include some starchy and fiber-containing foods, but one that avoids too much fat, sugars, sodium, and alcohol.

Future Research

Effective nutrition education depends on three major areas of research:

1. *Research to establish the standards of a good diet.* Studies of nutrient requirements and the association between dietary factors and health and disease help us to identify the features of a good diet. These features become the goals of dietary behavior in nutrition education efforts. For example, studies that determine the level of dietary iron needed to prevent anemia and related conditions help establish the standard for recommended iron intake.

2. *Research to determine current dietary status.* Dietary surveys such as USDA's Nationwide Food Consumption Surveys tell us how successful Americans are in meeting dietary standards. These research findings allow nutrition education efforts to focus on the most important issues and to be targeted to those at the greatest nutritional risk. For example, intakes of dietary iron by women of childbearing years and young children that do not meet standards suggest an obvious focus for nutrition education efforts.

3. *Research to determine the most effective methods of nutrition education.* This area of research helps us to know how we can best get from where we are to where we should be in dietary behavior. Further research in nutrition education will focus more attention on:

- Understanding the process of nutrition education. This type of research focuses on the thought processes in developing interest, understanding, and acceptance of nutrition education messages.
- Identifying for target audiences the characteristics and attitudes that have a bearing on the success of nutrition education efforts.
- Developing improved methods of measuring the effectiveness of nutrition education efforts.

This research has a single goal—the development of effective nutrition education materials and programs. Some nutrition education activities are the responsibility of USDA and other Federal agencies. Increased coordination among government, health professionals, academia, and industry, however, could lead to a network of nutrition education activities that are more effective in improving the American diet.

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VIII
Our Forest Resources

Forests of the Future

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As the United States becomes more urbanized and affluent, and its society more specialized, it has become easier to take for granted the adequacy of its food and fiber supply. Perhaps nowhere is this more obvious than in the lack of consideration and appreciation of the contributions of our forests. The connection is rarely made that writing paper, houses, and furniture are usually made from raw materials supplied by forests. Nor is the link made between water supply or enjoyment of wildlife, or the esthetic quality of the outdoor environment to the condition of the forests.

Perhaps one of the great luxuries of our affluence is not having to worry about the Nation's potential to grow food or fiber. This is in striking contrast to parts of the world where years of misuse of the forests, accompanied by less favorable rainfall than ours, has brought in wood fuel shortages, the destruction of watersheds, and even climate changes.

These problems are geographically distant from the United States, but it would be wrong to assume that there will always be enough forests of the right kind in North America, or that this Nation will not be affected by shortages of such resources elsewhere in the world.

Forests—A Renewable Resource

One outstanding characteristic of the forest resource is its renewability. Unlike many of the possible substitutes for wood, a forest can be grown, harvested, and regrown. In some respects, consumers can have their cake and eat it again in a few decades. This contrasts sharply with the nonrenewability of mineral resources such as coal, or steel, or other commodities used for fuel or construction.

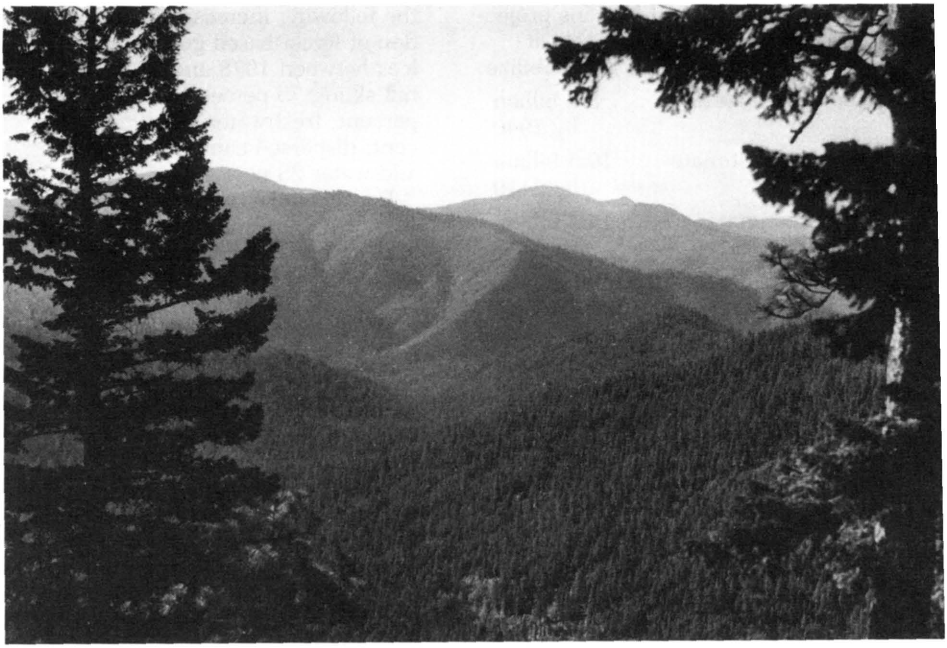
Renewability has two important consequences. First, through science and management, people can influence the long-term supply of forest products made available. Second, because supply can be manipulated, long-term demands on renewable forest resources are likely to increase substantially relative to the fixed supply of nonrenewable resources—that is, along with the normal growth in demand from increases in population and overall economic growth, increased substitution of forest resources for nonrenewable resources must be watched.

The Long-Term Character of Forestry

To examine the needs for, and contribution of, research on forest resources, it is necessary to look beyond the requirements of next season or even next year. The time between planting a forest stand and harvesting its products ranges from almost a decade to a century. The impacts of many forest management practices may not be fully realized for 10 years or so. Similarly, investing in research does not provide quick payoffs.

A study of the contributions of research to forestry by the Forest Service a few years ago pointed out two important conclusions: (1) The returns from investment in research are unexpectedly high, and (2) the time from the inception of a researchable idea to the implementation of research findings averages well over a decade.

The need to look beyond the turn of the century to evaluate the needs


J. Louise Parker, FS

Forests provide scenic beauty, basic raw materials for many products, a link to our water supply, and a home for wildlife.

for forest resources and the implications for research is of considerably more than academic interest. Taking the long view is necessary in formulating informed investment strategies.

Some Future Trends

Investigators have delineated several trends that will influence the demand on forest resources over the next couple of decades and from which conclusions about the adequacy of these resources can be drawn.

It is absolutely necessary to think in global terms. While there will be continuing political debate over the extent to which free trade or protectionism vis-à-vis global interdependence should be encouraged or discouraged, evidence overwhelmingly points to the conclusion that increasing the sharing of resources and technology would lead to a world both economically better off and more secure and stable. In this belief, the discussion of the following trends moves freely between domestic and global considerations.

- **Domestic and global population growth will increase demands on forest resources.**

Recognizing that the rate of population increase has been declining both in the United States and the world, medium-level estimates indicate that the United States will have 260 million people by the turn of the century and the world, 6.1 billion. These figures represent increases of 30 million and 1.4 billion, respectively.

From the global view, population change relative to available resources is probably the single most important trend influencing the demand on our forest resources. The world population in 1980 was approximately 4.4

billion people. United Nations projections indicate a range of levels at which world population will stabilize:

Low estimate........	8.8 billion by 2040
Medium estimate ...	10.5 billion by 2110
High estimate	14.2 billion by 2130

Recent estimates of world population have been smaller than earlier ones. Although differing, they all lead to the conclusion that world population will approximately double over the next 50 years. Even if per-capita income remains constant, there will be need for more resources to feed, clothe, house, and nurture a population of this size.

Although experts may debate the actual magnitude of increase in demand for forest resources, no one denies that the increase will be substantial. Also, it seems inescapable that the competition for good land from agriculture, forestry, urbanization, and improving infrastructure must increase.

- **Per-capita real income will increase with a concomitant expansion in the demand for forest resources.**

A look at past growth in per-capita gross national product as a rough measure of increasing welfare of a nation may serve as an indicator of economic growth trends. In the United States, for example, gross national product will reach about $2,690 billion (1972 dollars) by the year 2000, double what it was in 1977. The rate of growth worldwide is more rapid than that of the United States. Not only more people but more people with purchasing power greater than that of today can be anticipated.

As one example of the impact of this growth on our forest resources, the Forest Service estimates, in *An Assessment of the Forest and Rangeland Situation in the United States,* the following increases in consumption of forest-based goods and services between 1978 and 2000: Downhill skiing 75 percent; timber 65 percent; freshwater fishing 40 percent; dispersed camping 35 percent; and water 25 percent.

For resources such as timber and water, the rates of growth for the rest of the world will be considerably greater than those for the United States.

- **Maldistribution of resources will lead to severe scarcity in some countries and increase the need for international trade.**

It is difficult even for the well-informed to reach a reasonable conclusion about the magnitude of possible world shortages of natural resources in the near future. Is the world running out of wood, oil, ground water, tillable soil, or strategic minerals? Is population growth outstripping our ability to feed, clothe, and house that population?

Do not look for a simple answer. The pessimists are concerned about pending world resource shortages, and the optimists see no immediate problem of meeting our food and fiber needs.

All parties agree, however, that population growth and resource availability do not match geographically. In many instances, the resources are not located where the people are. There is maldistribution of resources both within and among countries.

What does this imply about the demand for U.S. forest resources? It is obvious that countries will produce and market those things that they can do best and cheapest, or, in the economist's terms, for which they have a comparative advantage. Several trends suggest a shift towards countries such as the United States having a growing comparative advantage at both ends of the economic spectrum—basic resource activities such as agriculture and forestry and the high-technology and information sectors.

(1) The largest component of economic growth in Western Europe and the United States has been and will continue to be in the information and service sectors. Some have gone so far as to call this the beginning of the end of the industrial age in the Western World.

(2) Technological advancements will make smaller manufacturing plants competitive and more available to the developing world.

(3) Differentials in wage rates between low-income and developed nations will become even greater than they are today, driving labor-intensive industries toward the developing nations.

(4) Countries with low-density populations, productive soils, and moderate climates will supply an increasingly larger share of the total world food and fiber supply.

One implication of these trends is that countries like the United States may supply a relatively larger share of basic agricultural and forest resources along with an increased share of the service sector, while countries earlier classified as medium or low income will supply relatively more manufactured goods than they have in the past. The magnitude of these shifts will be influenced more by political than economic affairs. Whatever the changing role of countries and regions, the demand for U.S. forest resources will increase significantly. Only the magnitude is debatable.

- **Technological advances will exert a major influence on both products desired and their supply at reasonable costs.**

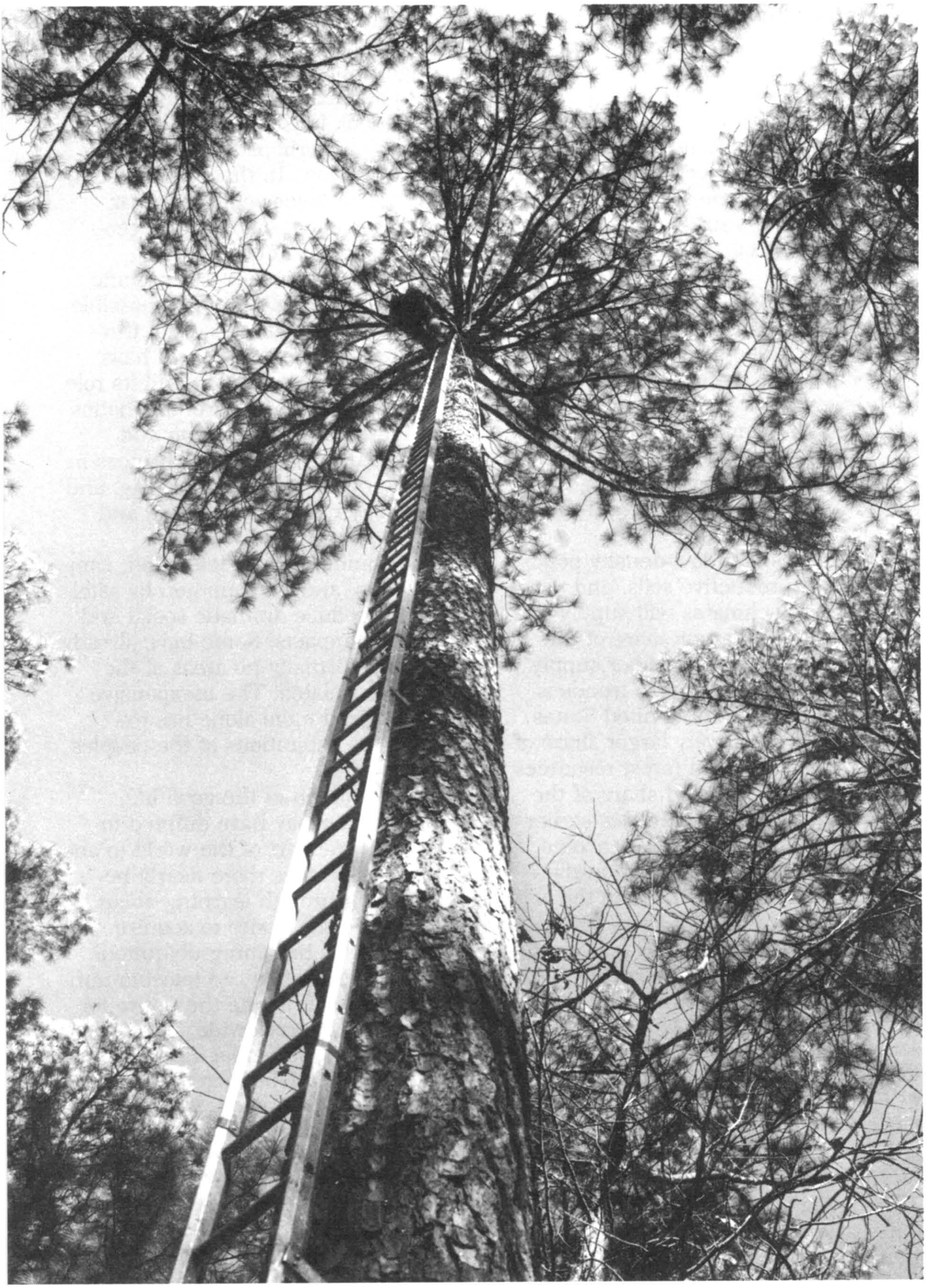
Technological change occurs on a daily basis, usually in such incremental ways that it is not obvious, except perhaps when a Sputnik circles the globe or a lunar module lands on the moon. So why be concerned about technology? Certainly, this Nation has shown it can adapt to change. But to consider the development potential of forestry, there is a need to look beyond the end of the century—to perhaps 30, 40, or 50 years from now. In that period, technological changes could be so far reaching it could cause major economic and social change.

It is difficult to point out specific technological breakthroughs possible in the next few decades. Still, three broad areas undoubtedly will have major impacts on forestry and its role in development. They are: telematics (changes in communication and manufacturing related to advances in computers), genetic engineering, and technology related to resource and product substitution.

The combination of television, computer chip, and transmission by satellite will produce dramatic social and economic impacts. Some have already been felt. Virtually no areas of the world are isolated. The inexpensive transistorized radio alone has expanded the aspirations of the peoples of the world.

The definition of the good life, which earlier may have differed totally from one part of the world to another, has become more nearly homogenized through learning about each other. The desire to acquire more goods is becoming ubiquitous. One impact of advanced telecommunications is to stimulate the desire for material goods worldwide.

At the same time that advances in telecommunications increase the demand for material goods, telecommunications will be a major contributor in improving the domestic ability to supply those goods. The time needed to spread technology will be decreased severalfold. Whether our problems are agricultural, industrial, or health related, the prospect of using a global electronic extension service to solve them during our lifetime



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A field technician high in this genetically superior loblolly pine collects cones for seed for tree breeding experiments.

is almost assured. Access to information is no longer limited to the few but becomes available to many, transported at the speed of 186,000 miles per second.

A third impact of the computer chip is its influence on heavy industry. Advances in telecommunications, improved sensors, robotics, and other electronically driven devices will yield equipment cheaper and more mobile than mechanical and hydraulic predecessors. The combination of increased demand for material goods, improved information on available technology, and less costly, smaller scale manufacturing possibilities will promote tremendous economic development over the next several decades.

Another area of technological change that will have major impacts on forestry is advanced genetic engineering. Although genetic engineering is still in its infancy, it has grown far beyond the walls of the academic laboratory. In the United States, several hundred commercial firms have been incorporated to research and sell the results of genetic engineering.

In forestry the first breakthroughs are likely to be in the area of pest control—biological insecticides, pest-resistant trees, and so forth. In the longer run, however, there is every reason to believe that trees with combinations of characteristics unheard of in nature will be planted and managed.

Besides the direct impacts of genetic engineering of forest plants, indirect effects, through reduced land and capital requirements to accommodate improved agriculture, could be significant. For example, breeding grain crops that can better withstand stress from either drought or temperature extremes could significantly increase the effective climatic range of grain crops, brightening the picture for human nutrition in the decades ahead.

A third kind of technological improvement that will exert an impact on forestry is advances in understanding the physical and chemical attributes of wood and wood fiber. Unleashing this knowledge will lead to moving away from the use of wood in traditional forms that required many trees of large size to produce solid wood products.

Use of reconstituted materials to replace lumber and plywood, paper processes that are less demanding on species mix for raw materials, expanded use of trees for chemicals, and expanded use of nontraditional species such as guayule will all be commercially common within the next couple of decades.

Critical Environmental Trends at Hand

These trends include tropical deforestation, desertification, and atmospheric deposition. Briefly, on each of these issues there is controversy over the present and future magnitude of the problem, its cause, and its impact. Although there may be debate over each of these, however, the focal point of environmental concerns on a global basis is directly related to the potential role of forestry as a tool for economic development. Although the magnitude of these concerns is arguable, they cannot be ignored.

Tropical Deforestation. The rate of harvesting commercial timber, converting forest land to agriculture, and cutting wood for fuel has exceeded the rate of natural or artificial regeneration of forests in the tropics. The *World Conservation Strategy* published in 1980 by the International Union for Conservation of Nature and Natural Resources (IUCN) cites the following:

An extreme view of the tropical deforestation issue is that at the current rate of felling and burning, this forest type will have disappeared within 85

	Total Closed Forests		**Operable Hardwood Forests**	
Region	**Area projected to be lost 1975–2000**	**Percentage of 1975 area**	**Area projected to be lost 1975–2000**	**Percentage of 1975 area**
	(1,000 ha)	Percent	(1,000 ha)	Percent
West Africa	6,600	47.1	6,600	54.7
Centrally planned tropical Asia	6,300	29.1	6,600	35.7
South Asia	16,400	23.0	13,600	27.9
East Africa and Asia	3,300	17.8	3,200	50.4
Insular Southeast Asia	21,600	16.5	20,000	26.3
Central America	10,900	13.4	4,600	23.9
Tropical South America	64,200	12.0	57,300	13.3
Continental Southeast Asia	4,100	10.6	4,000	13.3

years. In contrast, Sedjo and Clawson[1] claim, "The data suggest little possibility of the world running out of forests or even of major regions being dramatically denuded in any reasonable time horizon. However, there may be excessive rates of deforestation occurring in certain regions, particularly in some tropical areas."

Like most conclusions drawn on a global basis, this misses the more important point that variation between countries is tremendous. Many tropical countries will have major shortages of wood in the near future if limitations on clearcutting do not receive immediate attention. In some areas the problems are acute, the solutions are both difficult and costly, and the problem will continue for several decades.

Desertification. A counterpart to the issue of tropical deforestation is reduction of vegetation on drylands, where animals and plants live under stress from low rainfall and high evapotranspiration. According to IUCN, desertification currently threatens the welfare of 628 million people. "Regions already in the grip of desertification or at high to very high risk cover . . . an area twice the size of Canada."

The impacts of desertification are, of course, reduced food supply, elimination of locally available fuel, and siltation of waterways and reservoirs.

The relationship between desertification and development is insidious. Most of the countries classified by the United Nations as least developed are found in two areas called the poverty belts. One of these stretches across Africa from the Sahara to Lake Nyasa. The other area ranges from Afghanistan to South Asia including parts of Burma, Cambodia, Vietnam, and India. Much of these two belts lies in arid areas, which are most sensitive to misuse of the land and ultimately desertification.

The United Nations Conference on Desertification held in Nairobi in 1977 devised a plan to deal with the many ramifications of both prevention and rehabilitation of dryland areas. To date, progress in implementing that plan has not kept pace with the pressures on these lands. This problem too will remain well beyond the year 2000.

Atmospheric Deposition. Recently, much is being heard about decline in the vigor and growth of forests in North America and Western Europe. Little is known about this phenomenon, but it is being attributed to atmospheric pollution. The impacts of acidic deposition on plants range from interference with reproductive processes to increased susceptibility to stress and to damage to leaf surfaces and tissues that ultimately affect growth rates.

Although there has been documented evidence of reduced growth in forests and simultaneous mortality of all age classes of trees in a region, scientists disagree on the cause and effect and the potential magnitude of the problem. If the condition of forests in parts of Germany, Austria, and Switzerland declines further and if the decline expands into neighboring countries and in North America, this condition could have significant impact on wood supply, prices, and international trade.

It is impossible to predict the path this condition will take in the future, but, if there are potential wood-supply shortage problems in the future, they can only be exacerbated by forest decline resulting from atmospheric deposition. This problem has received much attention from the press. If a cause-and-effect relationship is convincingly illustrated, legal measures will likely be instituted fairly quickly.

Research—the Key to Expanding Forest Resources

Two conclusions from the previous trends are inescapable:

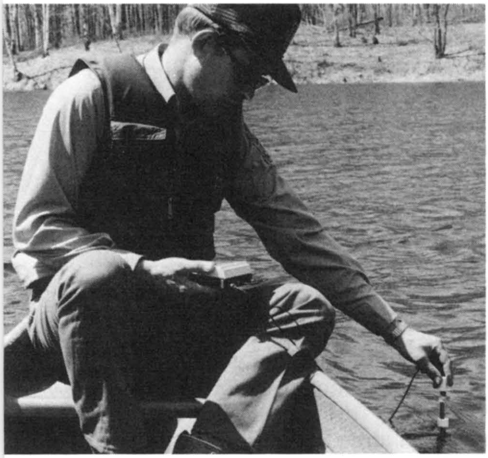
First, the world demand on forest resources will increase. Second, the United States, along with others, will play a critical role in meeting this demand. Yet if past trends in the supply of U.S. forest resources continue, the United States will fall short in its ability to meet this need. In fact, it will fall short in its ability to meet even domestic requirements without substantial increases in prices unless, as a nation, attention is turned to the improved management of our forests.

While much can be done through more intensive application of existing technology, there is also a need for research aimed at improving the availability of forest resources over time.

Three areas of research can significantly improve the availability of forest resources at reasonable prices.

The first area is that directly related to the improvement of growth of forest stands. This ranges from improvements in regeneration techniques to improve survival of young trees to development of improved genetic stock and to improved prevention of damage from fire and insect and disease pests. Gains from developing and planting genetically improved stock, for example, would increase timber yield per acre by about 25 percent over current rates of growth.

A second area of research deals with advances in the products manufactured from forest resources. Here the potential is limited only by the vision of the researchers. Substantial improvement in reducing the susceptibility of wood to decay could improve the useful life of products from housing to utility poles. Particularly exciting is the prospect of using wood as a basis for chemical feedstocks that would replace nonrenewable resources. Alcohol and other potential fuels are already being made from wood. Research is needed to make these processes economically competitive.



A research technician determines the pH of a lake in a study of the effect of acid precipitation on inland waters.

The third major area of research deals with understanding the impacts of nonforestry-related activities on forest land. Better techniques are needed for decreasing the impacts of tourism on the landscape while improving the recreation experience.

Already, interesting and productive work is being done on developing a better understanding of the effects of acid rain. This work will undoubtedly lead to solutions for mitigating the impact of this byproduct of industrial growth.

The direct and indirect impacts on our forest from an increasing population—more mobile, more industrial, more urban—cry out for the application of imaginative approaches to using and protecting our valuable forest resources. Through research and wise management, this cherished portion of our landscape will serve us well through future decades.

[1]Sedjo, Roger A. and Marion Clawson. *Global Forests.* (Unpublished discussion paper.) Resources for the Future, Washington, DC. 1983.

Forest Biology Research and the 21st Century

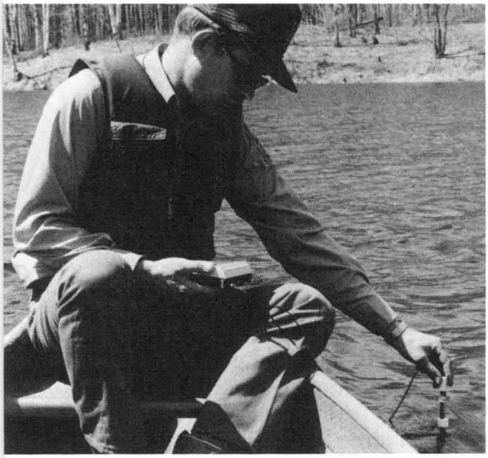
Stanley L. Krugman, *staff director, and* Stephen E. McDonald, *research forester, Timber Management Research Staff, Forest Service*

The modern forest manager must be increasingly sensitive to society's changing view of the forest resource. As lands that were forest are devoted to other uses such as agriculture or roads, the forest land base grows smaller. Yet the outlook is not bleak. Much of our forested land is producing at only 30 percent of its capability. So even in the face of declining forest acreage, there is plenty of room for improvement in the use of the land now growing trees. New forest products, such as flakeboard, use trees or parts of them once thought of as waste. Possibly just as important, research is providing new tools that will increase the efficiency of forest management.

New management direction from an enlightened, concerned populace, new uses for forest products, and new management tools, taken together, suggest that the 21st century will be the age of scientific, comprehensive forest management in the United States.

Selective Tree Breeding

For about 60 years scientists have been studying the genetic makeup of forest trees in the hope of learning how to breed them for faster growth, improved wood quality, improved species adaptability, and greater resistance to disease. Several break-



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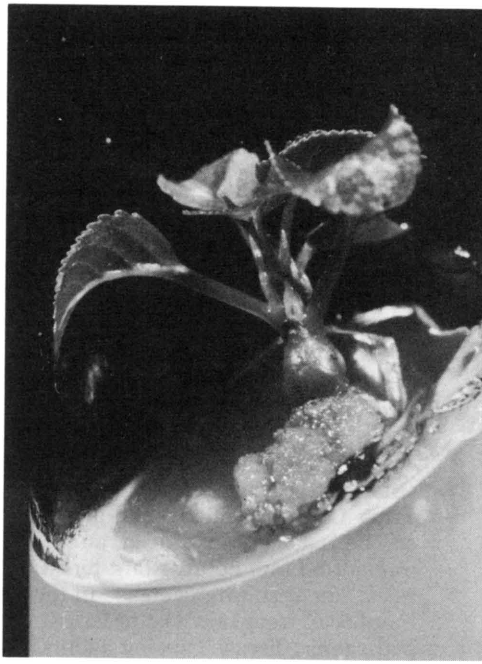
Now that genetics research has identified "super" trees in several commercially important species, breeding programs will enable the production of seed from these trees in quantity. Eventually all reforestation will be done with genetically superior stock. Growth gains of 60 to 70 percent should be possible. Through selective tree breeding, the forest of the 21st century will have increased resistance to pests.

The New Biotechnology

Trees are so big and take such a long time to reach reproductive maturity that improving their genetic makeup through conventional methods is time-consuming and expensive. Recent advances in genetic engineering—called the new biotechnology—will help short circuit the long breeding cycle of trees. Instead of relying on natural selection to improve the gene pool over centuries, they can isolate the genes that control desirable features in a superior tree and transfer that genetically coded material to ordinary trees.

One method for transferring desirable characteristics uses "Ti" plasmids from the soilborne bacterium *Agrobacterium tumefaciens*. The "Ti" plasmid is a natural carrier that routinely inserts new genetic material into plant cells and normally induces tumors in such plants. Through the new biotechnology, however, scientists can now insert useful genes into



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The node of a greenhouse-grown eastern cottonwood develops an axillary shoot and callus tissue in vitro. *Such cultures supply starting tissues for research about genetic engineering of specific traits such as herbicide stress resistance.*

the "Ti" plasmid and have the plasmid transfer them into a forest tree. There is good evidence that herbicide tolerance can be incorporated into forest trees directly by using genetic engineering techniques such as the "Ti" plasmids. If our research is successful, trees will grow that can survive exposure to the herbicides used to control competing vegetation.

In the last few years, "osmoprotectant" genes have been identified and isolated in cells of bacteria. These osmoprotectant genes allow certain organisms to cope effectively with drought and cold stress. In the future, it will be feasible to transfer osmoprotectant genes into forest trees, making it possible to extend the commercial range of certain species into areas too dry or cold for them now.

Genetic engineering will help boost growth rates in pines and firs by tricking them into fixing their nitrogen requirements out of thin air! Some tree species can fix atmospheric nitrogen naturally, but this is not a characteristic of conifers. If scientists find a way to pass this capability to pines and firs from species that already possess the trait, they will be making an improvement on nature that would greatly reduce the cost of fertilization and forest management in general.

Soon it will be possible to identify the gene or genes responsible for resistance to certain forest tree diseases. Once identified, such genes can be isolated, reproduced, and transferred into nonresistant forest trees. The resulting decrease in the number of trees now lost to forest pathogens (disease-causing agents) will go a long way toward improving that 30 percent production capability of our forested land.

Understanding Tree Physiology

Advances in the science of tree stress physiology are changing our understanding of how trees resist cold, drought, and disease and insect attack. Such knowledge helps us understand not only how plants function but also why certain plants grow where they do and why they respond to different environments as they do. That information, in turn, helps in the selection and development of trees that are resistant to drought, cold, insects, and diseases.

Stress physiology is related to the broader field of ecophysiology of trees—the study of the interactive relationship between trees and their environment. In other words, ecophysiologists try to determine how the environment influences the placement, nature, and function of the plants in it. Forest scientists are only beginning to understand these complex relationships and how they alter them when they manipulate forest stands, for example, by thinning or fertilization. The operating procedure in the past has been primarily to change the forest environment through vegetation manipulation and then observe the reaction of the vegetation.

Ecophysiology examines the direct effects of the manipulation—changes in water relations, energy balances, temperature, air movement—and relates these factors to the reaction of the vegetation. Through ecophysiology, forest managers can expect to accurately predict how plant life will react to treatments on specific sites. Knowing those reactions in advance will help in choosing management alternatives that precisely match objectives.

New Research Trend

Forest biology research is advancing rapidly along several fronts in the late 20th century. However, the trend is definitely away from research that concentrates on specific treatments at a specific site with extrapolation of results to the whole area, type, or habitat.

Instead, modern measurement, analysis, and the use of computer modeling are enabling forest biologists to measure basic physical factors that control or prompt changes in the forest. Then changes in these factors can be directly related to forest development. Better understanding of these physical forces in the environment and how to manipulate them to change the response of plants will take us to a level of forest management sophistication not even contemplated just a decade ago.

Techniques for Future Decision-making in Range, Wildlife, and Fisheries Management

James M. Sweeney, *wildlife and fisheries specialist, and* Gale L. Wolters, *range scientist, Forest Environment Research Staff, Forest Service*

Commercial and recreational demands for wildlife, fish, and range resources have increased significantly during recent years, and the upward trends are expected to continue. For example, approximately 18 million fur pelts were harvested in the 1979–80 trapping season, 2.6 times that harvested in 1971. Annual salmon harvests reached over 600 million pounds in the late 1970's and early 1980's, considerably above the 200 to 400 million pounds common in the preceding 25 years. The number of hunting and fishing licenses purchased has increased almost 50 percent in the last 20 years. Similarly, the demand for forage on public rangelands has increased about 15 percent since 1980. The legal mandates to protect wild horses and burros and conserve threatened and endangered plants also intensified the demand for rangeland resources, as did the growing concern for an adequate supply of quality water, clean air, and open space.

Loss of Forests and Rangelands

The intensified use of forests and rangelands for production of other goods and services such as urban development, transportation systems, and extraction of minerals and fossil fuels is having a significant impact on our wildlife and fish habitat and range resources.

The Environmental Protection Agency estimates that as much as 2 million acres of wildlife and fish habitat will be lost annually between now and the year 2,000. Nearly half of the wetlands that once existed in the continental United States are gone, and quality of many of the remaining areas has been seriously compromised.

More than half of the rangeland in the lower 48 States is in unsatisfactory condition and producing less than 40 percent of its natural, potential forage, wildlife habitat, and water. Intensive timber production, which harvests stands at younger ages, reduces plant species diversity and diminishes habitat for wildlife dependent on older, less vigorous forest communities. Approximately 180 vertebrate species in the United States are listed as actually or potentially in danger of extinction, as are nearly 80 species of terrestrial plants.

These numbers may increase drastically unless specific management strategies are implemented to successfully interweave wildlife, range, and fish goals with other land-use objectives.

Multiple-use Management

In the face of increasing demands for all forest and rangeland products, including timber, fiber, energy, wildlife, grazing, fisheries, water, and recreation, and a decreasing land base for the production of these natural resources, managers can no longer afford the *laissez faire*, single-resource approach to management that was typical in the past. Planning and management for any single resource must include consideration and adjustment for associated resources. This managerial strategy was made binding by a series of recent laws aimed at resource integration: National Environmental Policy Act of 1969, Wild Horses and Burros Protection Act of 1971, Endangered Species Act of 1973, Forest and Rangelands Renewable Resources Planning Act of 1974, National Forest Management Act of 1976, Federal Land Policy and Management Act of 1976, Public Rangelands Improvement Act of 1978, and Fish and Wildlife Conservation Act of 1980. As a result, managers are now in an era of coordinated, intensive forest and rangeland management in which interdisciplinary planning is an important element, if not a legal mandate.

Multiple-use is not a new theory, nor is it a difficult concept to grasp. Initiating such a program, however, involves addressing a maze of social, political, and biological concerns and alternatives. This decision labyrinth is so complex and continually changing that it almost defies solution. But this challenge must be met.

Research for Better Management

Research conducted by the U.S. Department of Agriculture's Forest Service and State agricultural experiment stations is providing an ever-expanding wealth of new knowledge and management guides on the relationships between differing land uses and probable consequences of alternative management prescriptions. For example, they are collecting information on the influences of various forest and range management strategies on short- and long-term timber and forage production, water yield and quality, sediment yield, wildlife and fish habitat value, and local socioeconomic stability. This and other detailed technical information is being compiled and stored in computer systems, making the information readily accessible to managers. In addition, numerous models or computer-based tools are being developed using these newly quantified relationships that allow resource managers to manipulate this new knowledge base and present it in a comprehensive form for analysis of management alternatives.

These models differ greatly in style and complexity. The more complex simulation models rely on a complete understanding of vegetation growth patterns and responses to management to project future plant communities, successional stages, and habitat conditions. STEMS and its microcomputer counterpart, TWIGS, are forest stand simulation models developed to help small landowners predict what will happen to their forest stand if they harvest trees. FORPLAN (*For*est *Plan* Simulator) is a larger, more complex forest simulation model used to predict results of forest management on entire National Forests. By including wildlife habitat capability models in STEMS or FORPLAN, landowners also can predict influences on wildlife such as squirrels, woodpeckers, deer, and turkey.

Habitat Capability Models.

These models include specific information on the relationships between resources (such as how soil, plants, and animals are affected by the amount and quality of each resource), and measure the ability of a specific forest, rangeland, pond, or stream to support a mixture of renewable resources. Habitat capability models, when driven by accurate and complete technical information databases and combined with simulation models, are powerful tools for natural resource managers. They can quickly examine a wide variety of management alternatives and correctly project the influence of management of each individual renewable resource, including wildlife and fish species, over a broad spectrum of forest and rangeland ecosystems. In addition, tables and graphs produced by these models allow resource managers to more clearly document and describe recommendations and anticipated resource responses to colleagues, superiors, and the public.

Research Challenges. Long-term forecasting of resource outputs using these tools assumes that plant community simulations and animal-to-habitat relationships are fully understood and accurate enough to let managers reach reasonable conclusions about the multiple-resource productivity of forest and rangeland conditions.

The underlying basic ecological relationships, however, have not been fully tested in some community types and successional stages. An eminently imposing research challenge is to develop a comprehensive understanding of how plant growth is regulated and how it responds to environmental extremes. Also, little is known about the specific habitat requirements of many rare or particularly secretive wildlife and fish species.

These gaps in our information data base pose the challenge research must meet in the next decade. Existing models must be tested and refined, and new models developed where none exist. Inherent in this objective is continued examination of water, soil, plant, and animal relationships in forest and rangeland ecosystems.

Forest Service scientists are investigating new methods for efficiently and accurately monitoring wildlife and plant communities to provide the tools to test and refine our models and management practices. Other scientists are testing, refining, and retesting habitat models for anadromous fish, song birds, and endangered species by studying in ever greater detail where these animals live, feed, and reproduce.

The computer models of tomorrow will then produce results that are consistent and accurate enough to serve as valid tools for the display of multiple-resource tradeoffs. In their current state of development, these computer tools provide only general management direction. Management of the forests and rangelands of tomorrow, however, will require the use of more sophisticated models containing increasingly detailed data and ca-

Computer models help resource managers estimate future conditions of plant communities and wildlife habitats like this native grassland in Montana.

pable of more critical analyses of management alternatives.

Challenges to Managers

More sophisticated models do not mean that the range manager or the wildlife or fisheries biologist of the future will simply be a mechanic punching keys at a computer terminal. On the contrary, the life of the professional natural-resource manager will be more exciting and challenging because of the vastly superior information base to work with and the tools to use that information properly. Data bases, habitat capability models, and simulation models will supplement the resource manager's knowledge, not replace it.

There will still be hard choices to make. Natural resource managers will still face a dilemma: how to arrive at the best decision when many of the socioeconomic variables, so important in the decisionmaking process, remain intangible. They can't have more of everything. Compromise will remain a must. Effective integrated management requires decisions which implement Federal and State laws and balance resource outputs with public needs and desires.

Resource management will not be integrated without soul searching, conflict, and goal setting. Data bases and models will vastly help with sorting information, identifying alternatives, evaluating consequences of those alternatives, forecasting, and so forth. But they are only tools; they alone will not integrate the management process. Professional, trained resource managers are still the operative element. Only through a concerted effort by the trained manager will all resources be integrated and true multiple-use management be realized. Through research today, the resource manager of forests and rangelands of the future will have the tools to breach the maze.

Forest Land-Management Decisions

Nelson S. Loftus, Jr., *principal research silviculturist, Timber Management Research Staff, Forest Service*

One-third of our Nation's total land area is covered by forests, and nearly two-thirds of this forest is capable of growing continuous crops of trees and other forest products. The full benefits from this renewable resource, however, cannot be realized without proper forest management supported by a dynamic research program. Management programs are often judged to be good or bad based on how they affect development of a forest and whether this forest provides the mix of goods and services required by our society.

Forest land managers have long wished for a view of the future forest that reflects the consequences of their management decisions. Today, the application of computer technology to the quantitative analysis of the forest resource gives the land manager that look into the future. Future advances in mathematical modeling and our understanding of the biological aspects of the forest will increase the precision and reliability of this forecasting.

Computer Models

To a large measure, forest land management has historically been based on our ability to estimate changes in tree growth and volume yield (productivity) in response to specific silvicultural treatments. In the last two decades, research has developed growth and yield prediction methodology using new computer technology pable of more critical analyses of management alternatives.

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Information Needed. What information about a forest is needed to model its growth and yield? The future of a forest depends on regeneration—the establishment of seedlings; tree growth as expressed by diameter, height, and volume measurements; and tree mortality. Development of these models also requires knowledge of forest dynamics and the analytical tools for summarizing, analyzing, and recording the complex biological interactions that characterize the forest ecosystem. The task of simulating the growth and development of the forest becomes even more complex when managers want to see what may happen if they engage in various management activities.

Fortunately, numerous models have been developed to describe the present forest and predict its response to change resulting from human activities and natural events. Using these computerized models, an inventory of the forest, and a "what if" approach to the decisionmaking process, forest land managers can now generate alternative forest-management solutions to many complex problems. But, the selected course of action is still based on the manager's expertise; the model and computer program are only tools facilitating the decision process.

Future Model Uses. In the future, forest managers will use models to characterize the resource, predict the future growth and development of the forest, and examine the likely consequences of management activities with greater and greater precision. In addition, models will predict the impacts of insects and diseases on forest development. These will allow the manager to evaluate quickly and economically the cost and potential benefits of alternative pest-management methods, including the use of genetically resistant planting stock. The integration of pest-management and forest-growth models will permit the manager to compare both forest-management and pest-control strategies in terms of volume growth over time.

Genetics research will develop procedures to quantify improvements in tree growth and pest resistance in such a way that they can be incorporated into yield-prediction systems. Inclusion of genetic gain information into growth and yield models will permit estimates of increased production based on differences between genetically improved and nonimproved planting stock growing under various cultural treatments. With these genetic gain benefit estimates, forest land managers can assess the potential value of improved planting stock ("super" trees) in their operations and determine how and when to modify management practices to maximize economic returns.

Increasingly, regeneration establishment models will be used to predict expected results of regeneration prescriptions and project the growth and development of seedlings into the mature forest. Combined with appropriate growth models, managers will be able to test site-preparation treatments, evaluate the need for supplementary planting or seeding, and project not only the number of seedlings surviving but also the species composition of the new forest.

Other models will become available that tie silviculture to wildlife and watershed management concerns, including descriptions of the predicted understory species, animal habitat requirements, and hydrologic relationships. Use of such models will permit land managers to consider (1) how the planned management of the trees will affect the wildlife habitat values of the forest and the hydrologic characteristics of the watershed, and (2) how managing for these resources will affect the development of trees.

Finally, the usefulness of these advanced models as tools for making land-management decisions will be greatly reinforced when they are linked with economic models. Here the manager of the future will supply the current resource values and the related costs of management and the computer will calculate revenues. Economic analyses will include discounted costs and incomes, net present value, the benefit/cost ratio, and internal rates of return for the various management strategies.

Decision-Support Systems

Currently, computer applications in forestry are typically data-processing oriented; that is, data are processed to provide information used to make a decision. For example, a manager calculates the volume of timber on an area as a basis for planning and implementing a harvest schedule. In the future, however, computers will be used more to analyze the processed information for the purpose of making decisions, that is, decision support. Complete stand analysis and prescription procedures will be developed that not only provide a systematic way of measuring and evaluating critical conditions but also use data to arrive at recommended treatment alternatives. Using forest inventory information, a computer program will do the entire job of analysis, prescription, and report preparation. Such a decision-support system, like other forestry tools, will help the manager to decide among the alternatives for treating the forest on the basis of the best projections of the results of a decision.

In the 21st century, computers will provide increasingly valuable assistance to the forest land manager in analyzing the data necessary to perform inventory, appraisal, economic analysis, management planning, harvest scheduling, pest management, regeneration, and other tasks. These models of the future will make it possible to comprehend and analyze the complex biological and economic relationships found in the forest. As a result, forest land-management decisions will be easier, better, and based on the best available scientific knowledge.

At the Threshold of Scientific Reforestation

Stephen E. McDonald, *research forester, Timber Management Research Staff, Forest Service*

The term, reforestation, includes both tree planting or seeding and natural establishment of seedlings from wild seeds or sprouts coming from other trees. In the near future, both artificial and natural reforestation will take place with a much greater degree of precision and reliability than has been possible in the past. In addition, the trees that do become established will exhibit higher survival rates and grow faster than now.

Both forest industry and Federal agencies are putting considerable research emphasis on more reliable, precise reforestation for the simple reason that the cost of reforestation is rising rapidly. Not only are labor, machines, and tree seed and seedling costs going up steeply, but the cost of borrowing money also has risen sharply in recent years. The need is great to accomplish reforestation inexpensively, quickly, and reliably, and to assure that trees grow rapidly following establishment.

Reforestation Today

In the United States, pioneering research on reforestation began in the 1920's with U.S. scientists adapting and refining German reforestation practices. The body of information that constitutes U.S. reforestation practice at the present time is based on important research advances from the 1930's and 1940's. Today's methods, conscientiously applied following time-tested rules, will almost guarantee successful plantations of trees under average conditions. But even when these rules are followed to the letter, often disturbing and costly variations in reforestation success occur.

Reforestation in the 21st Century

In contrast, consistently reliable establishment of fast-growing plantations at a reasonable cost will characterize reforestation in the 21st century. Reforestation will no longer follow rules for average sites extrapolated from controlled studies and repeated experience. Each reforestation project will be *designed* to ensure success. This design will be based on detailed physiological, ecological, and meteorological knowledge about a specific planting site and the specific seedlings to be planted.

This informed, detailed, site-specific approach to each reforestation project will be feasible because of rapid advances in several scientific fields.

Improved Methods of Measurement and Data Analysis.

First, improved methods of measurement together with modern data storage, manipulation, and interpretation are revolutionizing our ability to relate causes to effects. Forest scientists can measure some things more accurately, and can quantify others for the first time. These measurements are pooled for computer analysis that allows comparisons of different variables or combinations of variables in ways impossible in the past. These advances mean that soon foresters will be able to define in detail the reasons for plantation successes or failures. As their data bases accumulate information and their experience grows, they will be able to predict accurately what needs to be done in each reforestation project to assure a high probability of success, even when conditions deviate from the norm.

Knowledge of Plant Physiology. Second, we are now in a period of revolutionary advances in the biological sciences. New breakthroughs in our knowledge of plant physiology (function) are part of this revolution. Dr. Cleon Ross, Colorado State University, has estimated that the present "half-life" of plant physiology knowledge is only about 3 years. As part of this phenomenon, more complete understanding of many aspects of plant physiology applicable to forestry and forest regeneration is rapidly evolving. An example is the potential application of the new biotechnology to forestry discussed earlier in this chapter. Increased understanding of tree stress physiology, mycorrhizal relationships, and interplant competition holds great promise of rapid technical advancement in reforestation in the near future.

Knowledge of Environment and Ecology. Finally, researchers are learning much about the interaction between seedlings and the site they inhabit. Site conditions are being measured and characterized in ways and with a precision impossible only a few years ago. Site-condition variation at both the microclimatic and macroclimatic levels can increasingly be analyzed and predicted. New climatological models can characterize forest sites on an acre-by-acre basis. Seedling source and morphology are, increasingly, being selected to precisely accommodate the environment at the planting site.

New Scientific Era

When all three of these avenues of advancement in reforestation research—improved methods of measurement and data analysis, plant physiological knowledge, and environmental-ecological knowledge—are brought together, we will have entered a new era in reforestation. It will be characterized by insights into the complex interrelationships between environment, seedling condition, and seedling genetics that are the keys to a regeneration process to provide the highest probability of reforestation success and rapid tree growth. Currently, the system requires artistic application of rules of thumb to specific situations. In the future, we will apply specific, scientific prescriptions to specific environmental situations. The present art will transform into science, with excellent results produced time after time by precisely adjusting our techniques to each given planting site, year, and seed and seedling crop.

Integrating Advances into Present System

Achieving scientific reforestation is within our grasp with present technology. Learning to use this technology properly, accumulate the data, and interpret it will take time and research. It is worth remembering, however, that a tried and true system is in operation now. Over 1.8 billion trees were planted in the United States in 1985. The task is not only to do the research needed to develop the new technologies for reforestation improvement in the future, but also to meld these advances into the immense system already in operation.

Costs of Change. Changing to a scientific reforestation process will be gradual. It will also be expensive, but this does not mean the effort will not be cost affective. Right now, each year, millions of planted tree seedlings die after planting, thousands of acres of careful site preparation are lost, many trees that do survive grow poorly, thousands of acres of plantations where trees did not survive have to be replanted. All these shortcomings in the present system are enormously costly and occur on all forest lands, without regard to ownership. Even the most rudimentary calculations show that an increase in survival rates of just 1 or 2 percent will justify a considerable research effort. Also, the costs of effective reforestation research are quickly recouped because the benefits are realized immediately.

Resistance to Change. Another barrier to the implementation of scientific reforestation is resistance to change. It is likely, however, that the driving forces for more efficient, effective reforestation described earlier will overcome such resistance as the benefits of new procedures become obvious.

Benefits of Change. Our collective stake in scientific reforestation is enormous. Our country is presently the largest importer of wood in the world. This is a completely unnecessary drain on our economy. The United States is easily capable of growing all the wood it will ever need if cutover lands are promptly reforested, if idle lands are reforested, and if the resultant young stands are properly managed. It has only to grasp the new technological tools at hand and have the discipline and will to change to become fully self-sufficient in forest products in the 21st century.

Managing Future Forests for Wilderness and Recreation

Robert C. Lucas, *project leader, Intermountain Research Station, Forest Service, Missoula, MT*

National opinion surveys have documented a trend of increased public interest in, and support for, wilderness and recreation management of our forest resource. This shift toward a larger role for wilderness and recreation also will be speeded by increased efficiency in commodity production from forests, especially timber production. New knowledge and technology will enable the Nation to meet needs for timber and other commodities on fewer acres and with less impact on the environment.

Increased Diversity

Future forests will provide a wide variety of recreational opportunities in settings that range from primitive to highly developed and include everything in between. The in-between settings, in particular, will need to be better defined and more intensively managed. Such settings include nonwilderness lands for uses such as hiking, horseback riding, bicycle riding, ski touring, trailbiking, hunting, and fishing. These settings will help meet important needs that are relatively neglected now and provide needed alternatives to recreational use of wilderness.

The whole range of opportunities will be planned and managed within the Recreation Opportunity Spectrum framework developed over the last decade by Forest Service research scientists. The distribution of opportunities across the spectrum will be better poorly, thousands of acres of plantations where trees did not survive have to be replanted. All these shortcomings in the present system are enormously costly and occur on all forest lands, without regard to ownership. Even the most rudimentary calculations show that an increase in survival rates of just 1 or 2 percent will justify a considerable research effort. Also, the costs of effective reforestation research are quickly recouped because the benefits are realized immediately.

Resistance to Change. Another barrier to the implementation of scientific reforestation is resistance to change. It is likely, however, that the driving forces for more efficient, effective reforestation described earlier will overcome such resistance as the benefits of new procedures become obvious.

Benefits of Change. Our collective stake in scientific reforestation is enormous. Our country is presently the largest importer of wood in the world. This is a completely unnecessary drain on our economy. The United States is easily capable of growing all the wood it will ever need if cutover lands are promptly reforested, if idle lands are reforested, and if the resultant young stands are properly managed. It has only to grasp the new technological tools at hand and have the discipline and will to change to become fully self-sufficient in forest products in the 21st century.

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The whole range of opportunities will be planned and managed within the Recreation Opportunity Spectrum framework developed over the last decade by Forest Service research scientists. The distribution of opportunities across the spectrum will be better balanced and more clearly articulated. As a result, alternatives will be clearer to the public, and they will be better able to match opportunities to their needs and desires.

Shift from Wilderness Designation to Management

Although debate will continue over appropriate uses of specific tracts of land, the current emphasis on wilderness allocation (determining which lands will be designated wilderness) will decrease in the future. As values and technology change, ideas about what lands should be wilderness will continue to evolve. But more and more of the major wilderness designation decisions will have been made by the end of this decade.

Management of lands selected as wilderness will become critical as emphasis shifts away from the wilderness designation process. Protection of natural wilderness conditions and provision of opportunities for high-quality wilderness experiences will be essential to do what was intended by wilderness designation.

Operation of Natural Processes. Allowing dynamic natural processes to operate freely, with minimal human interference, is critical to perpetuate natural conditions in wilderness. Fire, in particular, needs to play its natural role more fully, and this will require continued advances in wilderness fire-management planning. Research on fire regimes and fire management will be needed to support future planning. More research also will be needed if manager-ignited fires are to become a sensitive tool to complement lightning fires in areas where such natural fires must be limited.

Limiting Recreational Visitor Impacts. Also essential is limiting impacts to the wilderness environment caused by recreational visitors. We must build upon and extend current knowledge of the impact process, of the relative vulnerability of different types of locations, and of how different visitor actions affect resources. Research so far has shown that limiting amount of use is often less effective in managing wilderness than changing the type of use, user behavior, and distribution of use.

Limits of Acceptable Change. The Limits of Acceptable Change (LAC) approach to managing wilderness carrying capacity recognizes the need to focus on ecological and social conditions resulting from use, rather than just on the amount of use. Using LAC, managers take a variety of actions to respond to identified specific problems in contrast to focusing on controlling the amount of use. LAC, very recently developed by scientists based on past research, will need testing and further development, but it offers a practical way of dealing with carrying-capacity concerns. LAC will likely become the general approach to managing recreational use of wilderness in the future.

High-Quality Recreation

Management of recreational use, not only in wilderness but all across the recreation opportunity spectrum, will require more cooperation between managers and visitors. Information and education are keys to involving the public more in protecting resources and reducing user conflicts in the areas they visit and treasure.

Information Could Limit Regulation. New technology can make information about alternative areas to visit more readily available to the public. Computers have already been used successfully on an experimental basis to display information to help


Robert C. Lucas, FS

Research will enable backpackers and other National Forest visitors to enjoy beautiful scenery even as surrounding areas are intensively managed for timber production and other forest-related commodities.

people choose places to go based on their interests and preferences.

Regulations will become less common and less obtrusive. Educating our visitors about proper behavior on public lands and communicating effectively with them will be the foundation for making them partners in management, not passive recipients of authoritarian regulation and control.

The public also can become more involved in management planning, helping set goals and select strategies for achieving them. Initial efforts in this direction in the management of the Bob Marshall Wilderness in Montana are promising.

Use of Fees. Fees for using public land for recreation will become more common. If fee systems are properly developed, they can enhance cooperation between the public and managers. If most fees are used to protect and manage areas people care about, support for these charges is likely. Fees can become an effective way for the public to help achieve their goals. Fee income might also highlight the growing value the public places on recreation and wilderness.

Integrating Uses

Commodity uses of future forests, such as timber production and grazing, can be more effectively integrated with many types of outdoor recreation. Visual resources (scenery) also can become more harmoniously related to commodity uses. Research must develop better ways to create and enhance recreation and scenic values while managing timber and other forest commodities, so that managers can go beyond mitigation of adverse effects. Silvicultural techniques, for example, will be developed to enhance scenery and recreation opportunities while managing for timber production. Improved knowledge

Recreational use of National Forest Lands not set aside as wilderness is likely to increase over the coming decades; settings that are neither primitive nor highly developed will see more intensive management.

can lead to more positive relations between commodity production and recreation, making them complementary rather than competitive. Better identification of key recreation values and sites is one essential element of more effective integration among uses.

More Stable Use?

Many types of outdoor recreation are growing more slowly than in the past. Hunting, fishing, wilderness use, and many other activities appear to have plateaued after decades of rapid growth. Newer activities, such as snowmobiling, cross-country skiing, and hang gliding, grew very rapidly at first but now have leveled off. Changing population and social structure suggest that recreational use in the future may be more stable than in the past.

If use stabilizes, managers will have an opportunity to solve important problems and make progress rather than just struggling to keep up with escalating patterns of use. Some new activities, however, probably will develop to surprise us.

Visitor Expectations Higher

The number of recreationists may not be skyrocketing in the future, but visitors are likely to be more discriminating. Their expectations for quality are likely to change and generally become higher, as the average visitor becomes more experienced and committed. Most types of use will still grow, although more slowly than in recent years.

Continuing substantial use by visitors seeking quality experiences will provide managers of recreation and wilderness in future forests with a difficult challenge. Meeting it successfully will require continuing advances in scientific knowledge and technology.

Protecting Forest Resources From Disease

Harry R. Powers, Jr., *chief research plant pathologist, Forestry Sciences Laboratory, Forest Services, Athens, GA*

Nations that fail to protect their forests risk serious economic and social consequences. That is why conservationists work hard to protect forests from overexploitation and unwise use.

Many people do not know, however, that forest tree diseases can be even more devastating than misuse. Diseases carelessly introduced from Europe and Asia have caused billions of dollars of lost revenue from America's forests, and modern forest-management practices have worsened the impact of some of our native tree diseases. Perhaps the worst examples of introduced diseases are chestnut blight and white pine blister rust, which were brought into the United States around the turn of the century. The former destroyed our most valuable native hardwood species, and the latter decimated white pine stands from New England to the Pacific Northwest. Before the advent of high-yield plantation forestry, fusiform rust of southern pines was not much of a problem. Now it is causing over $128 million a year in damage to southern forests.

Costs Must Be Low

The devastation of forest diseases is easy to recognize; the appropriate corrective action is less apparent. Although a forest may be worth a great deal, each individual tree in it is worth little. Even in the South, where can lead to more positive relations between commodity production and recreation, making them complementary rather than competitive. Better identification of key recreation values and sites is one essential element of more effective integration among uses.

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Costs Must Be Low

The devastation of forest diseases is easy to recognize; the appropriate corrective action is less apparent. Although a forest may be worth a great deal, each individual tree in it is worth little. Even in the South, where trees grow very rapidly, it takes 25 years for a pine to reach pulpwood size and 35 years or more to reach sawtimber size. In the West, trees in managed forests typically are harvested when they are 80 to 120 years old. These are years of waiting for returns on investment. They are also years during which the trees are at risk from disease and insect attack.

How can our forests be protected from diseases at a reasonable cost? Years ago foresters came to the scientific community with that question. The research has been long and difficult, but answers are emerging. The answers will be somewhat different for each disease, but often they will include some tree breeding for disease resistance. Chemical treatments in forest situations are not economically feasible: the individual trees just aren't worth that kind of investment. Yet, as a group, those planted trees represent much of the Nation's timber supply for the 21st century.

Most of the economically important diseases of forest trees are caused by fungi, and trees often vary in their resistance to infection and damage by these fungi. Breeding of trees for disease resistance has proven practical for some diseases, particularly the rust diseases that produce cankers on stems and branches. As knowledge of the genetics of hosts and pathogens (disease-causing agents) increases, the number of diseases that can be controlled in this manner is likely to increase.

Breeding for resistance to tree diseases is most advanced in loblolly and slash pines, the two most commonly planted tree species in the Southern United States. The purpose has been to reduce the devastation of fusiform rust. In the next century, the experiences with these species and this disease are likely to be repeated for other trees and other diseases, so a review of progress with these southern pines is instructive.

Progress With Fusiform Rust

The fusiform rust fungus spends part of its life on oaks and part on southern pines. In the spring, spores produced on oak leaves are released in huge numbers. When such a spore alights on young, succulent new growth of a pine, an infection results that develops into perennial galls or cankers. These attacks are most damaging on pines less than 10 years of age. Fusiform rust deforms stems and kills trees, causing huge economic losses. Infections also occur on older trees, but the results are not as serious.

Although fusiform rust has always been around, it was little more than a nuisance before 1950. Now its effects have reached epidemic proportions in parts of Alabama, Georgia, Florida, Mississippi, and South Carolina. Entire pine plantations are often destroyed, and the risk of newly planted seedlings becoming infected has increased steadily for many years.

Why the increase? The culture of loblolly and slash pines in the South has proven to be profitable, and millions of acres of intensively managed plantations have been established. Unfortunately, the conditions that are ideal for the rapid growth of these pines in single-species plantings also appear to be ideal for the spread of the disease.

Programs for the genetic improvement of pine seedlings for reforestation were begun in the 1950's, before the rust threat was recognized. Rust resistance was not a major factor in the selection of superior trees at that time. As a result, the first superior pines made available for reforestation in the South usually were not superior in their resistance to fusiform rust.

By the late 1960's, increasing damage from rust became apparent, and research on the problem was accelerated. Cereal rusts, caused by a similar fungus, are controlled almost entirely through breeding of resistant strains of wheat, oats, and barley. The same approach appeared possible for pines. The first order of business was to develop a system for rapidly testing the rust resistance of large numbers of seedlings under standardized conditions. Satisfactory techniques for artificial inoculation were developed, and a reliable system was operational within 5 years. Now almost all loblolly and slash pines that have been selected for superior traits of all sorts have been tested for their ability to produce rust-resistant offspring.

Fungi Adapt

Results of artificial inoculations also taught us much about the rust fungus. The fungus is highly variable in its ability to cause disease on different pine selections. An individual pine selection often is resistant to some races of the fungus but not to others. Races of the rust from different geographic areas vary in their ability to cause disease. This information helps to determine which pine seed sources to plant in specific areas.

The great variation was no surprise. It also occurs in the wheat rust fungus. Nevertheless, it is bad news for foresters. It means that no single form of resistance can be relied on for a long time over a large area. Seedlings with such resistance will be protected for the first few critical years after planting. But within a few years, a new strain of the fungus is likely to emerge with the ability to overcome the factor for resistance. Once this strain develops, additional seedlings of that type planted in the area will no longer be resistant. That is what happened to a strain of sugar pine selected and planted for its resistance to white pine blister rust in the Pacific Northwest. In resistance research and development work, plant pathologists must work with two biological systems—the fungal pathogen and the pine host.

Types of Resistance

Large-scale efforts are being made to locate as many new resistant trees as possible. Several different forms of resistance have already been found. One type seems to prevent the rapid spread of the fungus from a needle or branch into the main stem. A second form of resistance occurs when the fungus is walled off by dead host cells after infection takes place. Research is under way to discover other resistance mechanisms to include in breeding programs.

When the forms of resistance of pines and the types of virulence of the fungus are understood, planting strategies can be developed. In the next century, pathologists will deploy resistant strains of trees as generals deploy troops for a battle. By constantly developing new strains of pines and by deploying them to best advantage, it will be possible to stay a step or two ahead of the rust fungus.

To do so, the process for getting some forms of resistance into the genes of seedlings used for reforestation must be speeded. At present, that process takes up to 15 years in pines; to cut that down to 5 years will not be easy. Remember that in breeding, disease resistance is only one of many desirable traits to improve. Growth rate, stem form, wood properties, and other characteristics may be equally important.

Tissue culture is one promising technique for speeding the improvement process. Tissue culture makes it possible to develop large numbers of clonal plantlets without going through the normal reproductive cycle. Another technique, enzyme analysis, may enable us to detect resistance in a tree in few days instead of the 1 to 5 years needed with cur-

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Tree breakage and death are common after fusiform rust infection sweeps through a stand. This 14-year old slash pine plantation shows heavy damage.

rent techniques. Gene splicing is another promising approach, but there is much to learn before fully using the techniques of new biotechnology.

At present, the planting of resistant trees is our first line of defense against fusiform rust in pine plantations. Strains of loblolly and slash pine now producing seeds in a rust-resistant seed orchard in Georgia have reduced fusiform rust incidence by 50 percent in experimental plantings. Seedlings from this orchard are now being sold to private landowners and being planted over large areas. Additional breeding promises to reduce rust incidence by 75 percent, which will make reforestation investments attractive again in areas where the rust hazard is high.

Using Chemicals

Fungicides have seldom been used to control diseases in forests, not because they were ineffective but because treatment costs have exceeded the value of the potential benefits. That situation may change in the years ahead. The value of forest products has been rising and will contiue to rise. At the same time, the effectiveness of treatments has been increasing. Eventually, treatment of diseases in the forest may become common, as it is now in fruit orchards.

For years, fungicides have been used to control diseases in forest tree nurseries, where millions of the trees are grown on a few acres. New compounds are increasing the effectiveness of these treatments. For example, a recently developed systemic fungicide has proven effective for rust control in nurseries.

Formerly, rust infections were prevented with topical sprays. To be effective, these sprays had to cover the entire surface of susceptible plants. To maintain protection during the entire spring rust-infection period, seedlings had to be sprayed 35 to 40 times.

Systemic fungicides are absorbed by the plant and move through all tissues, providing protection for tissues formed after they are applied. Unfortunately, currently available systemics are effective for only a few weeks after application. Even so, 3 or 4 systemic applications take the place of up to 40 topical sprays, and they are even more effective.

Research indicates that systemics also might be used to protect seedlings for up to 1 year after planting. In the next few years, new systemic formulations may be developed that will protect seedlings for the first few critical years after planting.

Protecting Investments

Until the 20th century, Americans paid little attention to the health of their forests. They took what they needed and gave nothing in return, worrying little about how diseases might be lowering yields. That attitude has changed drastically.

Over the past 40 years, high-yield plantation forestry has developed in the South and the Pacific Northwest to provide the wood and fiber that our lifestyle demands. Intensive forestry, including planting of huge acreages with a single species on well-prepared sites, is necessary to produce the timber needed. In such plantings, however, the risk of disease losses is high, and the losses are more costly because of increasing timber values. The 21st century will see more intense forest management, because of the need to produce more and more wood on a shrinking land base.

In the 21st century, there will be increasing numbers of forest disease problems. As plantation forestry spreads, some diseases now thought of as minor may become major enemies. You can be sure, however, that researchers will be fighting tree diseases harder than ever and using new technologies as fast as they are made available. This Nation cannot afford to share our forest yields with fungi.

Protecting Future Forests From Insects

William J. Mattson, *principal insect ecologist, North Central Forest Experiment Station, Forest Service, East Lansing, MI*

Protecting our world's future forests from insects may be far more important than it is today because burgeoning world populations will place much greater demands on forests for both recreation and raw materials. As a result, a unit of loss to insects in these more precious forests will be far more costly to society than today.

To combat future insect problems, innovative insect management methodology that stresses prevention rather than cure, and, at the same time, is inexpensive, long lasting, and environmentally safe must be developed. Future research on forest insects will focus on:

- Developing and enhancing inherent plant resistance.
- Deploying resistant plant varieties in a manner that minimizes the evolution of adaptations by insects to overcome resistance.
- Employing sophisticated integrated pest-management strategies that more effectively use inherent plant resistance, natural enemies, pesticides-biocides, and behavior-modifying practices that reduce insect host finding and acceptance.
- Developing more accurate knowledge about the relationship between crop losses and insect abundance so that forest managers know precisely when it is necessary to suppress insects.
- Maximizing the activities of all those beneficial insects that contribute positively to the vital process of forest ecosystems.

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Developing and Enhancing Inherent Plant Resistance

Increasing basic understanding of how plants resist insects will continue to be an important area of research because plant resistance is clearly the ideal method for combating insect problems. Once developed, it is inexpensive to employ, it is environmentally safe, and can be long lasting if used wisely.

Revolutionary developments in methods for altering plant genomes will allow for more rapid development of resistant plants through insertion of those genes affecting the expression of resistance traits. Moreover, mass propagation of these new, more resistant plants through new methods such as tissue culturing and optimal growth techniques will speed up their widespread planting in the field.

Once the mechanisms of resistance have been identified, it will be possible to enhance their effectiveness by planting trees carrying these desirable traits in those particular soil and climate combinations where their expression will be maximal. Furthermore, if expression of resistance also is affected by plant age and other factors such as moisture stress, this information will be valuable to forest managers in determining the need for insect suppression when plants may be temporarily susceptible.

Successful Use of Resistant Plants

The measure of success in resistant plants is their ability to hold up at least until they are ready for harvest. In other words, the goal is to prevent insects from evolving counter adaptations that allow them to overcome the resistance. Deployment has at least two components. One is the diversity of the tree varieties or the number of different kinds of resistance simultaneously employed against the insect. The second is the density and dispersion of these different varieties. For example, how many trees are planted per unit area, and what is the pattern of planting these different varieties? Should they be randomly mixed, grown in checkerboard-like patches, or in some other pattern?

The stability of resistance—its life of usefulness against a pest insect—depends on how the resistant plant varieties are deployed in the forest. For example, plant pathologists are learning how multi-lines of grains lower losses to pathogens (disease-causing agents). Likewise, agricultural entomologists are learning how the deployment of various varieties of resistant wheat affect the Hessian fly.

Improved Integrated Pest Management

The integrated management of tree pests such as insects is a valuable concept that has not yet been well grounded in practice. In the future, however, it will be standard operating procedure for dealing with both insect and pathogen pests in forest environments. Such integrated pest management (IPM) will start with the close matching of resistant trees to the climate and soils where they are best adapted. It will be followed by sophisticated planting strategies that mix varieties of resistant trees at spacings and clusterings that disfavor the principal pests.

Next, IPM will employ practices that enhance the effectiveness of natural enemies (parasites, predators, disease organisms) of the principal insect pests. For example, it may be necessary to establish a nectar-bearing plant species among the forest trees for the purpose of feeding parasites and predators to lengthen their lifespans and increase their effectiveness in killing the pest insect. Judicious use of pesticides and biocides that are more pest specific and safer in the environment also are part of the IPM framework. Research into the bioengineering of more virulent insect pathogens such as viruses and bacteria may contribute significantly to this tactic. Likewise, the bioengineering of more resistant plants whose biochemical compositions will lower the immunocompetence and suppress the detoxification systems of pest insects is also part and parcel of this tactic. Furthermore, greater use will be made of behavior modifying tactics such as:

- Chemicals, colors, and shapes that attract pest insects to traps.
- Chemicals that repel and disrupt pest insects in their host and mate finding activities.
- Modifications in tree and forest structure so that light, temperature and other conditions are nonoptimal for insect oviposition, feeding, mating, and resting.

Relationship Between Losses and Pest Abundance

To successfully manage pest problems, knowing the relationship between crop losses and pest densities is necessary. This information is not yet available in a substantial form for any major forest insect. Why? Because in the case of trees, which can live for hundreds of years, it is costly to measure insect density and the concomitant impact over the long term.

In the future, such research may be easier to do because most future forests will be grown for shorter periods before they are harvested. It also may be easier to measure insect densities as new insect monitoring techniques such as pheromone traps are more effectively employed. Currently, these techniques show great promise for estimating insect densities, especially when populations are seemingly sparse. Research on novel methods for monitoring and measuring insect populations will be as important in the future as it is today.

Research into the impact of insects on forest resources may be more appropriately done through computer simulation studies with supporting research in key areas of plant nutrition and physiology and silviculture. Developing realistic models of insect impact on forests undoubtedly will become a major thrust in future years and will serve to energize and focus experimental research on the relationship between tree losses and pest density.

Maximizing Effects of Beneficial Insects

Although one usually thinks of insects as detrimental to forest ecosystems, quite the opposite is true. There are far more beneficial and innocuous species than pests. In the future, there will be even greater need to know about the beneficial contributions of insects and the means for enhancing them.

Parasites and predators of pest insects have already been identified as one group of beneficial insects whose biology, ecology, and effectiveness must be enhanced.

Another group often overlooked is the pollinating insects in forest ecosystems. The seed crops of many temperate and tropical deciduous trees, shrubs, and herbs are vitally dependent on adequate populations of pollinators. Because some forests may be more important for their recreation and wildlife resources than for their wood, berry-producing trees and shrubs and their pollinators should be studied.

Soil invertebrates as a group, along with soil micro-organisms, release nutrients and energy that are trapped in the organic debris that accumulates on the forest floor as litter. Without their activities, forest growth would decline and eventually come to fluctuate about a much lower average level of productivity. So their contributions need to be much better understood and managed. Methods for deciding whether soil communities are indeed fully stocked with the proper numbers and kinds of different organisms to get maximal nutrient and energy turnover are needed. For example, are there adequate numbers of large, soil-litter mixing species such as the various kinds of worms, craneflies, termites, and so on? If not, should some new species be introduced to the forest system?

Finally, the role of invertebrates in forest stream and river systems needs to be better addressed. They, along with micro-organisms, are the foundation for all sport fishery resources in our Nation's forests.

Protecting Forest Resources From Fire

James B. Davis, *research forester, Forest Fire and Atmospheric Sciences Research Staff, Forest Service*

Fire has always been with us. It has periodically burned forests and grassland as long as flammable vegetation has existed on earth. Today in the United States, on the average, 250,000 wildfires burn almost 5 million acres of forest, brush, and grass-covered lands each year. Protection services cost more than $0.5 billion annually. Losses approach $2 billion. These costs do not include the services of thousands of volunteer fire departments, nor do they include the expenses of the many city fire departments that fight fires on undeveloped lands within or near their jurisdictions. Yet few activities, public or private, have had such a high degree of success as fire prevention and management.

The average size of wildland fires has been reduced from 120 acres in 1925 to about 20 today, in spite of the fact that the risk of fires starting, as determined by various types of land use, has increased more than 10 times.

Research has had an important hand in this success. At the beginning of this century, foresters found themselves managing a wild, remote area in which the causes, behavior, and effects of fire were poorly understood, if at all.

Early fire research was essentially engaged in management science—trying to determine the needs of a fledgling fire-control organization and developing a policy for its activities.

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The average size of wildland fires has been reduced from 120 acres in 1925 to about 20 today, in spite of the fact that the risk of fires starting, as determined by various types of land use, has increased more than 10 times.

Research has had an important hand in this success. At the beginning of this century, foresters found themselves managing a wild, remote area in which the causes, behavior, and effects of fire were poorly understood, if at all.

Early fire research was essentially engaged in management science—trying to determine the needs of a fledgling fire-control organization and developing a policy for its activities.

Since World War II, fire research has expanded to include the physical, biological, and social sciences. Current programs draw heavily on the fields of meteorology, engineering, administration, and operations research.

Forest Service Research Organization

While the U.S. Department of Agriculture's (USDA) Forest Service conducts fire research at six of its nine forest experiment stations, the nature of many fire research projects requires the support of specialized scientific facilities and equipment such as wind tunnels and combustion chambers. Most of these specialized facilities are located at three forest fire laboratories located at Macon, GA; Missoula, MT; and Riverside, CA. Two out of every three Forest Service fire scientists work at one of the laboratories, resulting in an important pooling of talent and skills. Each laboratory has two principal responsibilities: to perform applied and basic fire-related research to meet national needs and to conduct other research, mostly of an applied nature, on current fire problems peculiar to the part of the country where the laboratory is located.

The laboratories work together on a national program of forest fire research in cooperation with other forest experiment stations; universities; scientific groups; and private, State, and Federal agencies.

While much of the research is aimed at today's problems, fire scientists also are directing their efforts toward solving the problems of the 1990's and 2000's. Scientists don't do this alone, but in cooperation with others in the scientific community and the user group. The latter includes Federal, State, and local fire-management officials—those people who must put the results of the research to practical use.

Scientists and users, applying futuring techniques, have jointly identified the following nine high-priority areas where much future research will be concentrated.

Fire Management in the Wildland and Urban Interface. A major demographic trend from urban to suburban living, begun after World War II, has greatly expanded the wildland and urban fire problem. This area, where people build their homes and live in the midst of flammable forest vegetation, occurs at thousands of locations across the Nation. In these areas, people and their property are at risk from forest fires, and the loss has been increasing rapidly as more and more people build in these high-hazard areas. In Virginia, for example, the number of homes exposed to wildfire loss has increased fourfold in the last 5 years. Major loss of life is possible—in fact, inevitable.

The task of protecting lives and property from fire in the wildland and urban interface area poses one of the most critical and elusive problems for fire researchers and managers today. If fire managers are to save property and lives, they need better knowledge and information on how to help homeowners, community planners, and builders design fire-safe communities.

Integrated Fire Behavior and Fire Danger Rating System. Fire managers use one analytical system to estimate fire danger for day-to-day planning and another for on-the-fire tactical decisionmaking. Even experienced firefighters get the two systems confused. Fire danger rating and site-specific fire behavior prediction are both based on knowledge of the physics and chemistry of wildland combustion. But current systems for predicting fire danger and behavior involve different resolutions of time and geographical area. Research needs to provide a single system that would accommodate the full range of requirements and save considerable money, time, equipment, and training.

Prescribed Fire for Wilderness Management. Current Forest Service policies allow fire to resume a more natural role in those areas set aside as part of the National Wilderness System. More than 75 years of fire protection, however, have materially changed wilderness ecosystems and allowed an accumulation of forest fuel that is difficult to manage. Land managers look to research to provide ways to define the natural role of fire in wilderness and criteria for deciding when planned or unplanned ignitions (such as lightning fires) are appropriate.

Evaluation of Aircraft for Fire and Forest Management. Wildland management agencies own or lease a wide range of aircraft types for their fire and forest-management operations. These range from light observation helicopters to high-elevation, remote-sensing aircraft to jet transports for fire crew transport.

Managers need means for evaluating the effectiveness of various types of aircraft. They need to translate the operational requirements of fire and forestry activities into desired aircraft performance. Research can help provide the guides to use these aircraft in the most cost-effective manner.

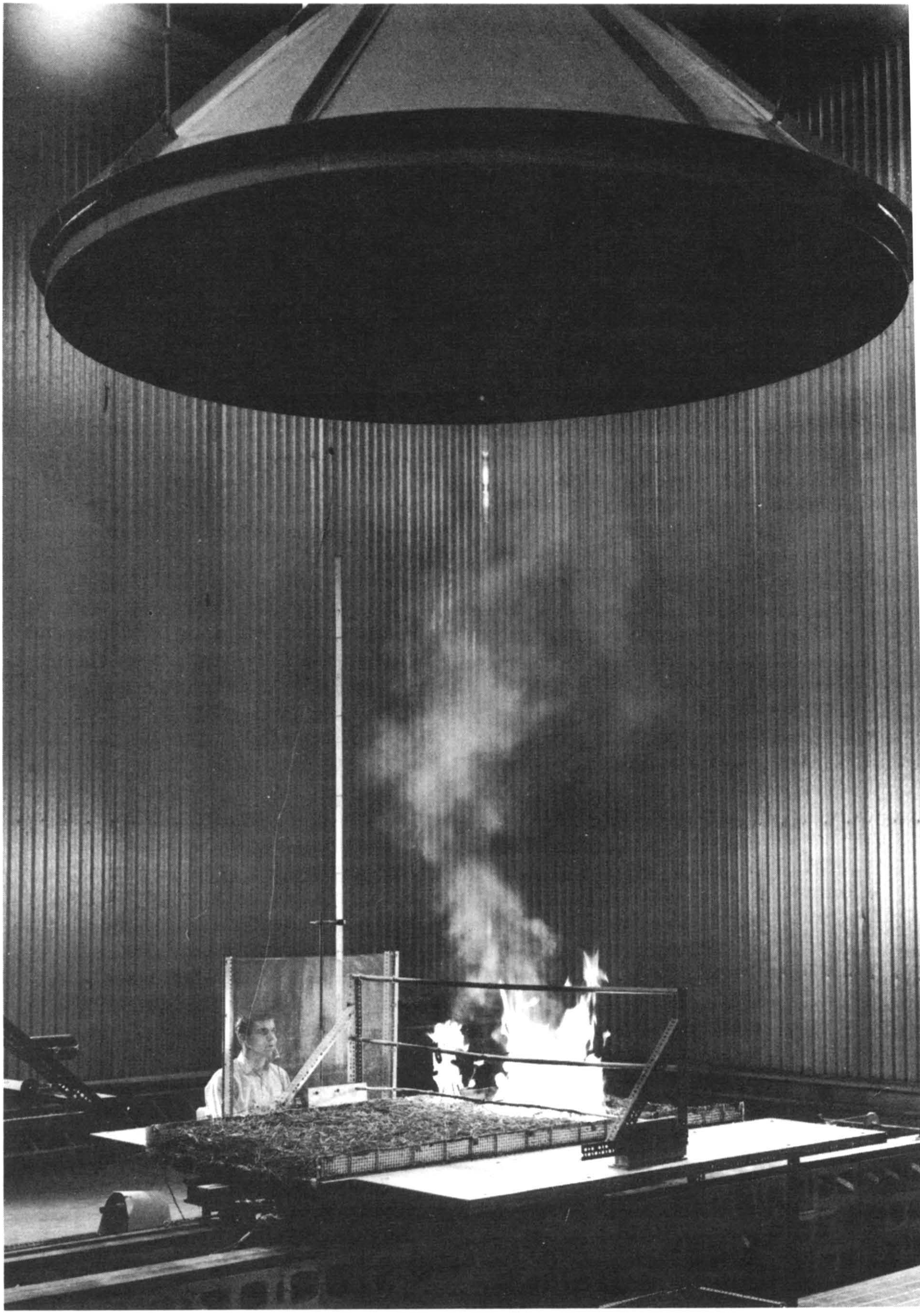
Social, Political, and Economic Values in Fire Management. How do you measure the worth of a sunset? It is difficult perhaps, but not impossible. Over the past decade, major progress has been made in developing economic analysis methods that relate investments in fire protection to the anticipated changes in resource values resulting from wildfires. In spite of this progress, it is still difficult to incorporate political and social considerations into fire-management planning processes. As a result, decisionmakers have limited ability to evaluate alternatives in terms other than economic efficiency. Social and political attributes are still treated qualitatively, often resulting in inconsistent and sometimes unacceptable programs.

Improved understanding is needed of the relationships among social, political, regulatory, and other factors with respect to decisions about fire-management investments.

Fire Suppression Productivity and Effectiveness. Foresters have been fighting fire for 80 years, yet they still do not have all the answers about how fast or well they do the job—partly because the job is much more complex than it used to be.

The most important reason is that almost every task must be evaluated in terms of cost effectiveness. Fire research must provide an improved understanding of the factors governing fireline building and holding success, tradeoffs and interactions among different fire control actions, and a better understanding of human physiology and motivation.

Alternatives to Herbicides. Use of chemical herbicides to prepare sites and control vegetation for the establishment and release of forest stands has become progressively less practical as a result of undesirable environmental effects and stringent regulation. Land management agencies and private forest enterprises are faced with significant reductions in commercial forest productivity—25 to 35 percent or more—without adequate site preparation and effective means of controlling competing vegetation. Alternative methods of vegetation management, including the use of prescribed fire, are needed to im-



Herman Wittman, FS

Scientists at the USDA Forest Service's fire laboratory in Missoula, MT, conduct instrumented test fires in a specialized combustion chamber.

FS

Where urban and wildland areas meet, fire is a rapidly increasing problem. In some parts of the United States, the number of homes at risk to woodland fires has increased fourfold in the past 5 years.

prove regeneration success and enhance growth and yield of established stands.

Effects of Atmospheric Change on Forest Health and Productivity. The effects of changes in the atmosphere on forest health and productivity are not always known. Some weather impacts are sudden and dramatic such as windthrow in a storm. Drought or excessive moisture also are readily observable. Some effects caused by gradual changes in normal conditions are not as obvious but are generally understood. Examples are early and late frosts and impacts of recurring severe winters.

Yet another category involves climatic changes because of increasing levels of pollutants, including particulates, carbon dioxide, and acid rain. The effects may include degradation of visibility, lowered water quality, and reduced tree growth.

The opportunity for managers to deal with these effects is severely restricted by a lack of knowledge about the processes which translate atmospheric changes into forest effects.

Long-Term Forecasting of Fire Weather Severity. Fire management depends on maximum mobility of firefighting resources to provide satisfactory forest fire protection while restraining cost. Effectiveness of mobility is directly related to ability to determine where and when resources will be needed. Prudent financial management requires no overinvestment during normal periods of fire occurrence, but, when existing resources are strained, mobilizing an adequate number of firefighters and their equipment must be possible. Managers need reliable weekly, monthly, and seasonal fire weather severity forecasts.

Research must develop systems to provide information on geographic variation of fire severity potential on at least a biweekly basis for resource allocation purposes.

Fire research, like most activities of government, can expect budget reductions over the next few years. By concentrating efforts on anticipated high-priority needs, however, fire research should continue to make valuable contributions in the future as it has in the past.

Research To Protect Wood

R. C. De Groot, *project leader, Forest Products Laboratory, Forest Service, Madison, WI*

In a forest, fallen branches and dead trees are naturally recycled into the ecosystem by myriad insects and micro-organisms. A similar, natural process of wood degradation occurs in fresh water and in marine environments, but by a different array of micro-organisms and small animals. These biological systems and fire play a significant role in recycling carbon within natural ecosystems. But when termites, fire, or wood rot (caused by fungi) occur in houses or other construction, whole structures or parts of structures may be destroyed, occupant safety may be endangered, and economic losses result.

Protection From Nature

To protect wood-in-use from these natural forces, principles of sheltering wood from rain and excluding other moisture sources from wood have been used in building design to prevent rot. Paints block exposure of exterior wood to sunlight. Mechanical barriers between soil and buildings, in the form of metal shields or elevated supports, have been used to retard termites, but termites are equal to the challenge of bypassing barriers. So additional means for preventing termite attack are required. Many wood products, such as siding on houses, railroad ties, utility poles, and farm fenceposts, are used where they cannot be shielded from the elements. There, naturally durable wood or wood treated with preservatives has been used to achieve long-lasting performance.

Trend Away From Broad-Spectrum Pesticides

The public will always need affordable, safe, durable housing and other wood construction. Public interest in the esthetic qualities of wood products and in environmental safety of related industrial processes will also continue. Chemical treatments will be needed in the future to protect some wood products, but the trend will be toward lessened dependency on broad-spectrum pesticides; that is, pesticides toxic to a wide range of living creatures. Narrower spectrum, wood-preserving pesticides will be developed by focusing research on physiological differences between wood-degrading organisms and nontarget organisms, including humans. Greater research attention will be given to environmental aspects of treated wood products throughout their total life cycle, from tree to recycling or disposal.

As a consequence, wood protection options of the future will be ever more precisely targeted and more carefully designed to meet exacting performance requirements. More consideration will be given to processing schedules that minimize opportunities for biological deterioration, to engineering options for protecting products and houses without pesticides, to potentials for biocontrol such as using antagonists, antibiotics, or ecosystem manipulation. Treatments which modify the chemical structure of wood cell walls so that microbial enzymes can't degrade them and other innovative concepts that don't rely on toxicity will be evaluated for uses where minimal toxicity is a primary requisite. Where chemical treatments are required, integrated, multiple-purpose systems are likely to be developed to achieve more economical protection with less reliance on chemical intervention.

Implementing Trend

To envision how these trends will be implemented, let us follow trees from forest to products:

Reducing Losses From Wood Decay. Pulp and paper mills use vast quantities of logs and wood chips in the production of paper products. Decay in logs stored for long periods of time after they are cut is a problem. Some companies by using computerized scheduling to match harvest with mill production eliminate large inventories of stored wood. Consequently, losses from wood decay in wood supplies coming from forests have been substantially reduced. This practice will become more widely adopted and also will be employed in future wood-fueled energy-generating plants.

Drying Wood. In warm weather, freshly sawn lumber needs protection from beetles and stain fungi. Protection can be achieved by quickly drying the wood in mechanical driers without any chemical treatment or by applying chemical treatments to the surface of the lumber and allowing it to dry naturally. Chemical control is the less costly option because it requires less equipment and less energy. New options for low-cost protection will include development of less toxic chemicals for stain control and new biotechnologies that use beneficial organisms to prevent insect and fungal attack.

Eliminating Termites. A barrier of chemically treated soil under and around house foundations is the customary practice for protecting houses from attack by subterranean termites. Research will develop new approaches to achieve protection with less pesticide.

One possibility is feeding stations with bait that is palatable and not acutely toxic to termites so that worker termites take the bait back to their colonies. As workers in the termite colony feed upon this bait, the vigor of the colony is slowly reduced until it succumbs to natural bacterial or fungal diseases. The chemicals used in the baits might be insect hormones, which would disrupt egg laying by the queen or would increase the percentage of dependent, nonfeeding individuals in colonies; biochemical blocks, which would prevent formation of chitin in exoskeletons of molting termites; or antibiotics that kill the microflora which digest cellulose within the termite gut. There are at least two advantages to these systems: small amounts of chemical are required, and the active ingredients are specific for lower forms of life.

Integrated Treatment Systems. For wood used above ground level in residential and other construction, research will devise integrated systems so that one treatment will provide protection from several potential hazards. For example, the same treatment that provides fire retardancy to wood shingles also will retard decay and moss and protect against sunlight degradation. Multipurpose finishes for exterior siding and millwork will protect wood from degradation by sunlight and will contain other ingredients to prevent decay, mildew, and mold. Additional preservatives that provide a dry, esthetically pleasing surface for treated wood will become available for treatment of walkways, patios, and other load-bearing structures used above ground.

Recycling Heavily Treated Wood. Wood used in contact with the ground and in marine environments requires more protection than does wood used above ground. Consequently, these products have been the most heavily treated and are often the most difficult to dispose of or recycle after use. New systems will address both the requisite durability for those products and subsequent requirements for disposal or recycling. Potential preservatives will be tested, and new biotechnologies for accelerating breakdown of toxic components in used materials will be incorporated into recycling programs that will provide meaningful alternatives to disposing of treated products in landfills.

Water-based Preservative Treatments. A major, recent accomplishment in wood protection has been the development of water-based preservative systems that are odorless and leave wood with a dry surface. These features have contributed to the use of treated wood in a variety of new applications besides railroad ties and utility poles, and in bridges, wharves, piers, and agricultural buildings. During the last decade, increasing consumer appreciation for this esthetically pleasing, durable wood has resulted in greater demands for preservative treatments for lumber produced from our pine and other softwood forests. Demand for durable wood products is anticipated to grow, but the forest resource that provides those goods is changing. Within the next 30 years, U.S. forests, as a whole, will be comprised of greater percentages of hardwoods and of smaller diameter trees.

This change in the forest resource presents several challenges to meeting anticipated growth in consumer needs for durable wood products. The growing proportions of small-diameter trees means more reliance on composite flake and fiber products, for which most currently used batch-treating processes aren't applicable. Furthermore, hardwoods are more difficult than softwoods to protect with the esthetically pleasing, water-based preservatives.

Treating More Wood Species. New technologies for protecting and treating more wood species may turn out to be the greatest contribution to forestry from wood-protection research. New methods for treating previously underutilized softwoods in the Midwest and Northeast will increase potentials for forests in those regions to complement southern and western softwood forests in meeting consumer needs for durable solid wood products. Innovations for protecting hardwoods, along with new processes for preservative treatment of flake and fiber products as they are being manufactured, will permit production of durable products from small-diameter species present in our eastern forests.

By extending the longevity of some wood products, these innovations will allow for more uses of other wood products without excessive demand upon our forest resource. Additionally, innovations that allow use of more tree species will give professional foresters greater freedom to include a diversity of tree species in their management programs, with attendant benefits to wildlife, watershed, and recreation.

Managing and Protecting Forest Water Resources

Dale S. Nichols, *principal soil scientist, North Central Forest Experiment Station, Forest Service, Grand Rapids, MN*

One of the most important functions of forest land is the delivery of fresh water for drinking and sanitation, for agriculture and industry, and for recreation and wildlife. Where water is scarce and the demand is high, water may be the single most valuable product of forest land. Managing and protecting forest water resources is becoming an ever more difficult, more complex, and more important task.

Forests cover about 30 percent of the total land area of the United States, but an estimated 75 percent of the Nation's water supply originates on this land. In the Western States, high-elevation, largely forested watersheds produce some 90 percent of the usable water. With growing populations, especially in the West, the demand for water is increasing.

Besides water supply, forests are used for timber production, mining, grazing, waste disposal, recreation, and numerous other purposes. These activities may adversely affect forest water resources. The water resources of many forest lands are already impaired. U.S. timber demand in the year 2030 is predicted to be double that of 1976. Increased demands for other forest resources are anticipated as well. In addition, the total forest area is expected to decrease as forested land is converted to other uses.

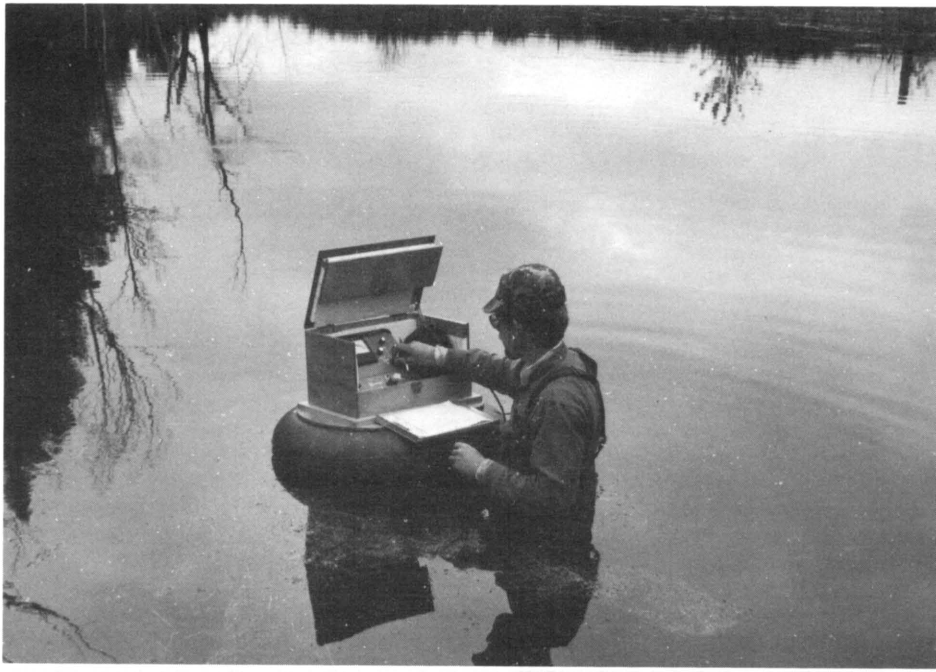
Researchers have an interesting challenge—to provide the new information and technology necessary to protect and manage water in the face of ever-increasing pressure on all the forest's resources.

Public concern for water was responsible, in part, for the establishment of our National Forest System. Some 154 National Forests contain about 190 million acres of federally owned forest land that were reserved from the public domain or purchased for the protection of critical timber and water resources. In addition to its many other uses, this land has served for more than 50 years as a vast open-air laboratory for the study of forests and water. The research branch of the U.S. Department of Agriculture's Forest Service maintains for research purposes about 90 designated experimental forests on National Forest lands.

Water Supply

While much of the United States has abundant water, water supply in some areas is far less than the demand and is a limiting factor in resource development and economic growth. Water-supply projections indicate that by the year 2000, people living in 17 major river basins in 11 Southwest and Midwest States and in some localized areas in the Northeast and East will suffer serious water shortages. Demands for water for nonconsumptive purposes such as fish, wildlife, and recreation also will increase.

Watershed scientists are studying ways to increase the production of water from forest lands. It was once thought that forests conserved water, making more water available for streamflow. Researchers have found that this is not true. In general, trees need and use more water than do other types of vegetation. Forested lands yield water simply because forests tend to develop on those lands where water is most available.



Dwight Streblow, FS

Maintaining high-quality water for fish and wildlife is an important aspect of forest management. North Central Forest Experiment Station technician measures dissolved oxygen and temperature in an experimental wildlife impoundment.

A large share of the water falling onto a forest as precipitation is returned to the atmosphere as water vapor. Trees take up large quantities of moisture from the soil that is then lost to the air by transpiration through the leaves. In addition, water evaporates directly from the soil, and some rain and snow is intercepted by the tree crowns and evaporates before it ever reaches the ground. The water that is left over flows from the forest in streams or as ground water and is available for other uses. The water leaving an area as streamflow is called runoff and is measured in units of depth. Ten inches of runoff, for example, means that if all the water leaving as streamflow were spread evenly over the area from which it came, it would be 10 inches deep.

Runoff from forest land has been measured on dozens of experimental watershed areas in the United States. Where precipitation is barely enough to support tree growth, such as along the boundary between the eastern forests and the prairies, and in many places in the West, annual runoff may be as low as 1 or 2 inches. Average runoff from the eastern forests and from the high-elevation forests in the Rocky Mountains is about 10 to 20 inches a year. In the Appalachian Mountains and in the coastal mountains in the Pacific Northwest, this figure is 20 to 50 inches or more.

Numerous studies on forested watersheds have shown that when the trees are cut down, annual runoff as streamflow increases because losses of water by transpiration and interception are reduced. If most of the yearly precipitation occurs as snow, as

FS

In 1956 Rocky Mountain Forest and Range Experiment Station scientists began a long-term study of the effect of forest-cutting practices on water yields by cutting a steep slope in a pattern of strips and patches. Snow accumulates in the openings, and the water yield from cutover areas is higher than from uncut control areas.

is the case at high elevations in the Rocky Mountains, runoff can be increased further by cutting trees in a pattern of small clearings, where snow then accumulates.

The greatest increases in water yield occur where precipitation is the highest. Increases are generally proportional to the percentage of the tree cover that is removed. Clearcutting in the high precipitation zones of the Southern Appalachian Mountains can increase annual runoff by as much as 16 inches. Water yield increases usually decline rapidly as new trees grow back. Flows may return to normal in as little as 5 years. Where streamflow comes mostly from snowmelt, water yield increases may persist for 20 years.

Where water is scarce and the demand is increasing, it may become practical in the future to harvest timber to increase water yield. The first application of this technique would probably be in the headwaters of the Colorado River. In the more humid East, timber harvest to augment low summertime flows may be considered in some areas.

Many questions, however, remain. Researchers need to learn more about the effects of changing snow deposition patterns on snowmelt and streamflow, the long-term stability of stream channels with increased flows, the identification of those combinations of soil, geology, and tree species that will give the largest increases in water yield, and much more. Also, timber harvesting must be planned and carried out in such a way as not to increase sedimentation or otherwise degrade water quality.

Erosion and Sedimentation

As the United States was being settled, the best lands—those most level and most fertile—were put into agricultural uses. Today, many of the remaining forests occupy land that is too steep to farm. Steep slopes make this land highly susceptible to erosion. When undisturbed, forest cover protects the soil from erosion. Disruption of the forest cover by timber harvest, road construction, mining, heavy grazing, or wildfire can increase erosion rates by a factor of 10, 100, or even more, compared to undisturbed sites. Erosion has a double effect on the forest: it depletes the soil, and the deposition of eroded materials as sediments in lakes and streams degrades the water resource.

Sediment is probably the greatest cause of water-quality degradation on forested land. The highest rates of sediment production from U.S. forest land are in the Northwest and the Southeast. Sediment destroys aquatic habitat and impedes human use of the water. Many kinds of fish need clean gravel beds for spawning, and aquatic insects on which fish feed live among the pebbles and cobbles on the stream bottom. When sediments bury these areas, the effects on aquatic life can be severe. In the Pacific Northwest, for example, the impacts of forestry-related sediment on the salmon fishery is a serious problem. Numerous reservoirs, large and small, store water from forested areas for municipal use, irrigation, power production, flood control, and recreation. Sediment from poorly managed forest land can fill these structures, reducing their usefulness. Sediment suspended in the water increases the cost and difficulty of water treatment for municipal use.

Researchers are studying in detail the erosion process on forest land and are finding new ways to reduce erosion and sedimentation. In timber harvesting, for example, in areas where landslides do not occur, simply cutting trees does not significantly increase erosion. The machinery and logging roads needed to move the trees from the forest, and sometimes preparation of the site to establish the next stand of trees, are the major problems. Road surfaces and cut-and-fill slopes erode rapidly. In addition, poorly designed roads intercept, concentrate, and channel water, increasing its erosive power. New road designs and techniques for revegetating cut-and-fill slopes will help to alleviate this problem, as will advances in machinery and logging methods. Where surface mining is carried out on forested lands, scientists are investigating ways to reshape the land to minimize sediment production, and to revegetate barren lands as quickly as possible. Computer modeling of erosion and sedimentation will point out problem areas where additional care is needed.

In some forests dominated by steep, unstable slopes, timber harvesting can trigger landslides that deliver large amounts of sediment to streams. This is common in the Pacific Northwest and coastal Alaska. Here, tree roots are especially important in helping to hold the soil in place on the slopes. When the trees are cut, the roots decay within a few years and landslides occur. Scientists have investigated this process and developed techniques to identify those areas most susceptible to landslides, where trees should not be cut.

Temporary increases in sediment are almost inevitable when forest cover is disturbed, especially on steep slopes. But if forest activities are carried out carefully and research findings are applied, sediment can be held to a minimum.

Plant Nutrients

Trees and other plants require various chemical nutrients to grow. As fallen leaves and other dead plant materials decay, the nutrients they contain are released to the soil, from which they are taken up again by living plants. Some nutrients, such as nitrogen and phosphorus, are in relatively short supply and are recycled efficiently. Only small amounts escape from the system to enter lakes and streams. When trees are harvested, nutrient uptake by the vegetation is temporarily decreased, and the leaching of nutrients into the water increases. In certain situations, it can significantly affect water quality.

The production of algae and other plants in forest lakes and streams is normally limited by the small amount of phosphorus available. Nitrogen may sometimes be limiting as well. Additional phosphorus and nitrogen reaching the water from timber harvesting or other forest disturbance can trigger increased production of aquatic plants. In infertile, unproductive waters, some increase may be desirable, but larger nutrient inputs can result in thick blooms of algae that make waters unsuitable for municipal or recreational use and cause undesirable changes in aquatic ecosystems. High concentrations of nitrogen in the form of nitrate are deleterious to human health and harmful to aquatic animals as well.

Researchers are finding ways to reduce these nutrient losses from the forest, thus maintaining the fertility of the soil while protecting the water resource. As more forest land is being fertilized with phosphorus and nitrogen to increase timber production, this protection becomes increasingly important.

Wastewater Treatment

Forest land can be used for wastewater treatment. Even after treatment at a conventional sewage treatment plant, municipal wastewater contains high concentrations of phosphorus and nitrogen. Cities and towns are often located near rivers and lakes, into which this treated sewage is dumped. Nuisance growths of algae, premature aging of lakes, fish kills, and general degradation of water quality are typical results.

Research has demonstrated that municipal wastewater can be applied to forest lands with many beneficial results. Nitrogen and phosphorus are retained by the forest, where they increase tree growth. When precipitation is scanty, the forest also benefits from the additional water. And, lake and stream water quality is improved. As demands for both timber and clean water increase in the future, application of wastewater to forest land will become more common.

Pesticides and Other Chemicals

A variety of chemicals are applied to forest lands in the United States, including insecticides, herbicides, fungicides, rodenticides, bird repellants, and fire retardants, to favor the growth of desired tree species and to minimize the undesired effects of some environmental factors. A major concern is the prevention of water pollution from these chemicals.

Scientists have found that such chemicals can enter the water by several means. They may be applied directly to lakes or stream channels during broad-scale operation, if care is not taken to prevent it, or they may drift on the wind from applications to nearby areas. Water flowing over the surface during a storm or snowmelt may wash applied chemicals from the land, either dissolved in the water or attached to sediment particles. Chemicals also may be leached through the soil by water, but this is the least likely pathway since most chemicals such as pesticides are tightly held by soils.

As forest management becomes more intensive to meet the increased demands for timber, the use of chemicals on forests will likely increase. Future research will show where and how these chemicals can be used effectively while still meeting water-quality standards and protecting aquatic and riparian habitat.

Acid Rain

The smelting of sulfur-bearing ores and the burning of fossil fuels release sulfur and nitrogen oxides into the air that return to earth in precipitation as sulfuric and nitric acids. The popular term for this phenomenon is acid rain. Where the deposition of acids is high and the capacity of the landscape to neutralize acids is low, lakes and streams become acidified. Populations of fish and other aquatic organisms become stressed and ultimately die out. Various toxic metals that may be present in the watershed dissolve more readily in acidic water. If this happens, acidified water may become unfit for drinking.

Many areas in the United States are forested today because the land is too poor for agriculture. Soils may be thin and underlain by bedrock or may consist of coarse, infertile sands. These lands may have little ability to neutralize acids in rain and snow. Scientists are assessing the impacts of acid deposition on the water resources of these forests.

In the 1950's, acidic precipitation in the United States was limited to New England and the mid-Atlantic States. Since then, acidic precipitation has spread. Today, the most acidic precipitation still occurs in the Northeast, but most of the eastern half of the country and some isolated areas in the West now receive acidic rain and snow. Lake acidification in the United States was first seen in New York's Adirondack Mountains. Researchers have now found evidence of lake and stream impacts over a much wider area. A study of lakes in the forests of Minnesota, Wisconsin, and Michigan shows that lake acidification across this region is occurring in direct proportion to the acidity of rain and snow. Changes in stream water chemistry related to acid precipitation have been noted in the mountains of North Carolina. Sensitive, high-elevation lakes in the Rocky Mountains are being studied, as well as the forest water resources near population centers on the West Coast.

Researchers are investigating the complex interactions among precipitation, vegetation, soils, geology, and lake and streamwater chemistry. By understanding these processes, they can predict how forest water resources will be affected by future levels of acid deposition, whether deposition increases, decreases, or stays the same. This information will help legislators to set reasonable and responsible acid-deposition standards.

Determining the Effects of Atmospheric Deposition

David L. Radloff, *staff specialist, Forest Environment Research Staff, Forest Service*

What Is Atmospheric Deposition?

The quality of the air can affect trees and forests in many ways. Through the air, trees receive water, nutrients, and gases (such as carbon dioxide) that are essential for their growth. During recent years, forest managers and the public have become concerned that polluted air may be adversely affecting the health of trees and forests in large regions of the United States.

This concern is a part of the important environmental issue known as acid rain. Acid rain (or snow or fog) is literally precipitation that contains abnormally high concentrations of acids (especially sulfuric acid and nitric acid). These acids may end up in streams, lakes, soils, and plants—possibly changing the ecological balance and causing detrimental changes in terrestrial or aquatic ecosystems. In addition, acids (or chemicals that can be converted to acids) may be deposited on the land in dry form, and potentially harmful gases also may be deposited. All these chemicals may influence the health of forests. Considered together, these chemicals are called atmospheric deposition.

Why Is There Concern About Forest Health?

Scientists have long known that atmospheric deposition of certain polluacidity of rain and snow. Changes in stream water chemistry related to acid precipitation have been noted in the mountains of North Carolina. Sensitive, high-elevation lakes in the Rocky Mountains are being studied, as well as the forest water resources near population centers on the West Coast.

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Why Is There Concern About Forest Health?

Scientists have long known that atmospheric deposition of certain pollutants in high enough concentrations damages and kills trees. Examples are the death of trees in many square miles of forests from high sulfur dioxide concentrations near metal smelters and high fluoride concentrations near aluminum production plants. These severe effects are seen only in the areas near the sources of pollutants, and so are important locally but not regionally.

Today, there is concern that atmospheric deposition may affect forests by compromising their health over large areas far from the sources of pollution. The chemicals that make up atmospheric deposition can be transported many hundreds of miles from their sources. Along the way, they may change from one chemical form to another, and their concentrations may alter as some are deposited on the ground. Although we know that eventually some of these chemicals are deposited in forested areas, we do not know what effects this regional atmospheric deposition has on forests. One goal of forestry research is to determine these effects.

Is There Evidence of Damage to Forests?

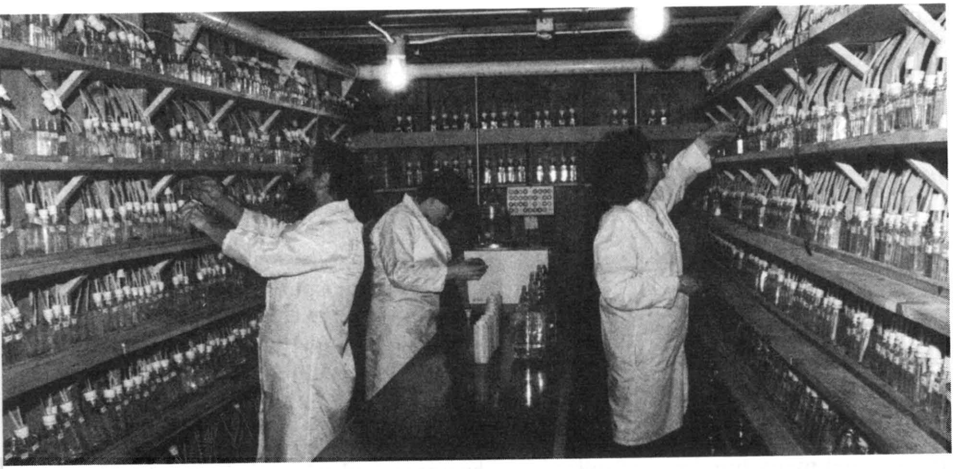
Major concern about adverse effects of atmospheric deposition on forests was first expressed in Europe. In Sweden, France, Switzerland, the Federal Republic of Germany, and other countries, forest managers and researchers have observed damage to forest trees from discoloration of needles and leaves through loss of foliage to premature death. In the Federal Republic of Germany, a 1985 forest damage survey showed that about half the forest area has some visible symptoms of damage; about 19 percent of the area shows moderate to severe symptoms. Although the causes of these changes in forest conditions in Europe are not known with certainty, biological research has implicated atmospheric deposition as a possible cause. Indeed, during the past several years, a consensus has developed among many European scientists that atmospheric deposition is a major contributor to forest health problems in Europe.

This European evidence has sensitized U.S. forest managers and the public to the possibility of forest damage from atmospheric deposition in this country. Several observations about forest conditions in the United States have heightened the concern.

First, in the San Bernardino Mountains east of Los Angeles, trees of several species have been damaged by ozone and other oxidants—highly reactive chemicals that form when nitrogen oxides, hydrocarbons, and sunlight interact. The trees have shown symptoms of leaf tissue damage and discoloration, early leaf fall, reduced productivity (photosynthesis), and reduced growth. The most sensitive species is ponderosa pine, and the most sensitive trees may be weakened enough so they are ultimately killed by other contributing factors, such as insects. The result has been a change in the composition of this mixed forest ecosystem.

The San Bernardino situation is a rather special case of atmospheric deposition damage to forests because this forest ecosystem has been exposed to high concentrations of a known damaging gas for more than 40 years. No other forest area has had this kind of regional exposure history. Controlled research studies over many years demonstrated that specific components of atmospheric deposition (namely oxidants) caused this observed forest damage.

Visible symptoms characteristic of ozone damage have been spotted in other forested regions, including the Sierra Nevada of central California and scattered stands of eastern white pine (a sensitive species) throughout the Eastern United States. Although



Atmospheric deposition might affect forests by causing changes in soil chemistry. Researchers collect samples from soil columns in an underground lab in long-term studies to better understand the relationships among forests, nutrients, soils, and atmospheric deposition.

the symptoms appear to link these cases with ozone, the damage is less severe than in the forests near Los Angeles.

Second, spruce and fir forests growing at high-elevation sites in the East seem to be decreasing in health and vigor. At locations from the southern Appalachian Mountains to New England, trees in these forests are showing symptoms of needle discoloration and loss, and some trees are dying at unexpectedly young ages. Research has shown that these high-elevation, mountain sites receive some of the highest rates of atmospheric deposition in the Eastern United States. It is not known if this relationship between acid rain and forest damage is merely coincidental or based on cause and effect. Future research will discover the cause of spruce and fir decline in the East.

Third, Forest Service surveys and research studies have shown that some eastern forests are growing more slowly than expected. The rate of diameter growth of red spruce trees throughout much of the range of this species has decreased since the 1960's, on both high- and low-elevation sites. Loblolly pine, shortleaf pine, and slash pine in the important commercial forests of the Southeastern United States also appear to be growing less rapidly than they were several decades ago. This could be the result of changes in any of the many factors that influence forest health and growth, including weather, climate, insects, diseases, competition from other plants, forest age, forest-management practices, and atmospheric deposition. Again, research must be conducted to sort out these factors and determine the causes of the observed forest conditions.

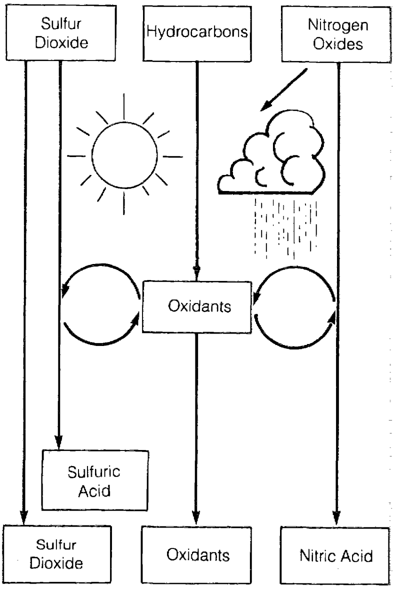
What Research Is Needed?

Several important decisions hinge on knowing whether atmospheric deposition is having a widespread, adverse effect on U.S. forests. Forest managers need to know how forests are likely to grow in the future so the forests can be managed to yield the greatest benefit to the public. Regulatory agencies, such as the Environmental Protection Agency, need to know if forests are being damaged so effective clean air laws can be implemented. Congress needs to know what resources are being affected to determine if new legislation should be passed requiring stricter control of air pollution to reduce atmospheric deposition.

These decisions will influence actions that may involve millions to billions of dollars each year. Research on trees and forests will provide results that enable decisionmakers to select the correct course of action.

The goal of the research must be to answer three broad questions: (1) Do current or expected levels of atmospheric deposition decrease the health and productivity of our forests? (2) What physiological and ecological mechanisms are influencing the effects of atmospheric deposition on forests? (3) What changes in future forest conditions can be expected under different levels of atmospheric deposition?

The research to answer these questions will involve a blend of statistical analysis of trends in forest conditions and atmospheric deposition, empirical experiments to determine simple cause/effect relationships, mechanistic experiments to understand the relationships, and modeling to predict future forest conditions.



Sulfur dioxide, nitrogen oxides, and hydrocarbons are put into the air when fossil fuels (coal, gas, oil, gasoline) are burned in power plants, vehicles, factories, and homes. These interact in the air to form other chemicals—acids and oxidants. Together, these chemicals comprise atmospheric deposition. (Figure adapted from the 1984 Annual Report of the National Acid Precipitation Assessment Program.)

What Research Is Being Conducted?

The Federal Government began a focused research program on the effects of atmospheric deposition in 1980 with the creation of the National Acid Precipitation Assessment Program (NAPAP). During the first several years, research concentrated on atmospheric chemistry, meteorology, and effects on lakes and streams and agricultural crops. In 1984, research began in earnest on acid rain's effects on forests. This forestry research program expanded considerably in 1985 and again in 1986.

USDA agencies that are contributing to the research effort are the Forest Service, the Agricultural Research Service, the Cooperative State Research Service, and the Office of Grants and Program Systems. The Environmental Protection Agency is cooperating with the Forest Service in managing and implementing the major part of the forestry research program. The National Council of the Paper Industry for Air and Stream Improvement (NCASI) is participating with these two agencies in supporting the program.

The forestry research effort is being implemented in four major forest regions: eastern spruce and fir forests, southern commercial (pine) forests, eastern hardwood forests, and western coniferous forests.

Correlation studies are being conducted to relate forest-condition variables (e.g., growth rate, visible symptoms) with atmospheric deposition variables. These studies will refine our understanding of the possible extent of the forest problem. Although such studies cannot prove or disprove cause and effect relationships, they will screen, strengthen, and suggest hypotheses that can be tested experimentally.

Empirical, controlled experiments are being conducted on effects of ambient, reduced, and increased levels of atmospheric deposition on trees. These controlled exposure experiments will answer specific questions about the relationship between atmospheric deposition and tree health. Because of the need to carefully control the environmental conditions, these experiments can be conducted only on seedlings. To begin to understand relationships between atmospheric deposition and larger trees, experiments will be conducted using controlled exposures of parts of mature trees in the forest or using grafted mature branches in controlled environments.

Mechanistic studies of chemical, physiological, and ecological processes are being conducted to test specific hypotheses of effects of atmospheric deposition on trees and forests. These studies will provide the most definitive answers to questions about cause and effect relationships. The mechanistic studies will help extend the results of the more restricted empirical studies and will make it possible to develop models to predict future forest conditions.

What Results Are Expected?

The correlation studies and empirical studies will produce results over the next 2 to 5 years that will help to clearly define the scope of the atmospheric deposition problem with respect to forests. The empirical studies will further help to confirm or refute hypotheses about specific components of atmospheric deposition that may have adverse effects on certain tree seedlings. Studies that test direct effects of deposition on aerial parts of plants will produce results in 1 to 2 years. Tests of indirect effects, such as effects on soil nutrients, may require many more years to produce meaningful results.

The mechanistic studies and modeling studies will, in general, begin to yield results over the next 5 to 10 years. Studies of some currently well-defined hypotheses, however, can be expected to produce results in less than 5 years. The mechanistic studies and the modeling efforts will ultimately answer the question of how and why atmospheric deposition affects the health and growth of forests.

This is only a part of a larger question that this forestry research will help to answer: "How do forest ecosystems function, and how do environmental variables influence the functioning of forest ecosystems?" As research answers this question, forest managers will increase their abilities not only to protect forests from atmospheric deposition but also to manage forests more effectively for the benefit of all users.

Soil Erosion and Management Activities on Forested Slopes

Robert R. Ziemer, *project leader and principal hydrologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, Arcata, CA*

Some of the most productive forests in the Western United States grow on marginally stable mountainous slopes, where disturbance increases the likelihood of erosion. Much of the public's concern about, and, consequently, most of the research on, erosion from these forested areas is related more to the degradation of stream resources by eroded material than to the loss of soil and nutrients from hillslopes. Erosion from these upper watersheds is a composite of surface, channel, and mass erosion processes. The relative importance of each process is determined by interactions among climate, soil, geology, topography, and vegetation and is the subject of much of the current research on erosion. A change in any of these elements can increase or decrease the rate of erosion.

Predicting Erosion

The best-known method for predicting erosion is the Universal Soil Loss Equation developed for agricultural lands in the Midwest by the U.S. Department of Agriculture's Agricultural Research Service. Attempts to apply the equation to steepland forest areas generally have been unsuccessful—mainly because of inappropriate basic assumptions. Most erosion from forests is not the result of sheet overland flow. In undisturbed forested steeplands, mass erosion is the dominant mechanism by which soil is transported from hillslopes to stream channels. In mountainous areas, the erosion research most needed is on the causes of natural and human-induced landslides and subsequent sediment transport.

Under natural conditions, as the amount of stress on a site increases, the amount of erosion also increases. A major source of stress is increased rainfall, which can be expressed in terms of storm return period—the frequency with which a storm of a particular magnitude is expected to occur. Increased stress also could be caused by soil water pressures, seismic loading during earthquakes, or other factors.

Erosion can be expressed as the amount of river sediment, or surface erosion, or frequency of landslides. Disturbance by land-management activities, such as logging, road construction, and burning, generally increases erosion rates. The location and magnitude of the effects of land management on erosion rates, however, cannot be predicted accurately .

Human activities have their greatest relative effect on erosion rates during periods of low stress. Research is beginning to suggest that management-induced erosion rates tend to converge on natural erosion rates as the magnitude of the stress increases, but the relationships are not yet understood. Similarly, erosion-control activities are most effective during low stress conditions and become relatively less effective as the magnitude of stress increases.

The natural condition often represents the minimum erosion rate, and attempts to further reduce erosion are generally ineffective. But there are exceptions. During low stress, effective erosion control activities can reduce or even eliminate erosion. For example, control structures in stream channels can reduce sediment transport to below the natural rate until their storage capacity is exceeded; hillside buttresses and check dams on recent natural landslides can reduce slope movement and surface erosion from the landslide scar; horizontal drains and vertical wells, which remove ground water, can reduce the natural landslide erosion rate. Usually, however, erosion-control activities are used to bring an accelerated erosion rate down near the natural rate.

Erosion Control

In general, preventing erosion is more effective than controlling it. Also, the potential for increasing erosion rates by land-management activities is greater than that for reducing erosion by using erosion-control techniques. Although these principles are well documented, virtually no research on the effectiveness of erosion control over the long term has been done.

If control activities reduce erosion during low stress periods, under some conditions that stored or controlled material may be available to be eroded during high stress periods. For example, when small check dams in steep streams are effective in controlling sediment transport during small runoff events, sediment accumulates in the channel. During large runoff events, the material stored behind unstable check dams can be mobilized, leading to a debris torrent—a much larger and more destructive erosional event than if that material had been transported during less stressful events. Permitting small, sustained transport of debris during normal events is believed to lessen the probability of a major debris torrent. Future research is needed to verify this potentially important theory.

Under such circumstances, erosion-control activities might simply shift the stress-erosion relationship so that less erosion occurs during small events and more erosion occurs during large, infrequent events. This may be an acceptable alternative because people and property could be protected during small events with expected frequencies of perhaps once in 1 to 10 years. Loss of lives and property are inevitable in a large erosional event, but society may be able to tolerate this amount of damage providing such events occur only infrequently, perhaps once every 100 to 200 years. Also, the relative increase in erosion rate during a large event might not cause significantly increased destruction.

Similar value justifications are commonly used for road drainage design. Road drainage is not designed to pass the largest imaginable event but is based upon economic and social costs. The selected moderate design allows the road to be used during all events except those exceeding some specified magnitude.

Researchers need more studies that address whether erosion controlled at one place or time can defer the problem to some later time. Not only are our models of the effectiveness of erosion control inadequate, but also the expected frequency of mass erosion events is not known.

For example, slope failures often originate in filled swales, and current research suggests that human activity accelerates the failure rate. If the swales are filled with periglacial deposits, then once the material is removed, subsequent failure would not be possible. Human activity would simply compress the time scale of failure, which would be followed by a reduction in failure rate to less than the expected long-term natural rate. If, however, the swales are filled with colluvial deposits and human activity increases the filling rate, then both the short-term and long-term failure frequency would increase. The geomorphic denudation rate and the corresponding sediment transport rate also would increase. Without adequate knowledge of these erosional mechanisms, experts cannot devise appropriate management strategies.

Management of Erosion

The cumulative impact of management activities on erosion is a growing concern. A common assumption is that if a small proportion of an area is logged, the rest will buffer the effect of the logging on downstream values. But the proportion of a catchment that can be logged without undue degradation of the stream resource is a matter of conjecture and is based on the assumptions that erosion sources are uniformly distributed with an equal probability of erosion occurring at all locations. In fact, most upper watershed erosion occurs in a few areas, with the remaining area producing only a small amount of erosion. Studies suggest that to minimize erosion effectively in the upper watersheds, it is more important to specify where land is to be treated than to be concerned with how much land is to be treated.

In evaluating the cost effectiveness of erosion control, a longer time line should be used. In general, the current period of concern of land management-related erosion and its control is short—several years at most. This may be acceptable for surface erosion, but channel erosion and mass erosion can follow land treatment by decades. Understanding of the timing of erosion relative to land-management activities must be increased.

The key to successful management of erosion and sedimentation is to increase our ability to (1) identify potentially erodible sites, (2) correctly assess appropriate activities on those sites, and (3) have a political or regulatory system that fosters the appropriate action. In some cases, the only appropriate action is to do nothing. The cost required to correct management-induced erosion is often far beyond the benefits obtained from the land-management activity or the costs required to follow a more sensitive alternative.

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A tributary to Cedar Creek on the Siuslaw National Forest near Mapleton, OR, experienced a debris flow in a clearcut, logged area that scoured the channel to bedrock.

Using Weather in Forest Management

Michael A. Fosberg, *project leader and research meteorologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, Berkeley, CA*

The summer of 1933 in northwest Oregon had been exceptionally hot and dry. When in mid-August, hot, dry winds blew in from the east, all the fire crews were ready. But there were not enough of them. Scattered fires that started in the coast range merged into what became known as the Tillamook Burn.

In 1986, the Forest Service is researching procedures to forecast severe fire-weather conditions like those of 1933 far enough in advance to move fire crews and equipment from where little fire activity is expected to areas where conditions point to high fire danger and a shortage of equipment and manpower. The goal is to rapidly deploy fire crews while the fires are small and more readily controlled.

Current Weather Forecasting

Weather forecast support for fire-severity outlooks currently covers a 30-day period. A mix of the 30-day forecasts for precipitation and temperature, a forecast of drought and soil moisture, and an assessment of the potential energy release of fires is currently being used to forecast potential fire severity for the country. Fire management uses these severity forecasts at the national level to make the public aware of potential problems as part of fire-prevention programs and to work with Congress in requesting resources to meet above-normal demands on fire-suppression funds. Nationally and regionally, these 30-day forecasts and forecasts of shorter range (3–5 days) are used to alert underutilized crews and equipment for potential mobilization and deployment to different portions of the country.

Improving Weather Forecasts

There are three steps in improving use of weather forecasts in forest management. First is to improve the science of weather forecasting. Second, weather observations need to be collected at locations from which these data can be effectively extrapolated to predict weather in areas where no data are available. Learning how to design a weather station network that provides required information and is justified by the economies of the use of those data must be considered. The third way is by developing analytical tools to process the weather forecasts. Such analysis transforms a weather forecast into estimates of, among other things, potential fire severity, transport of pollutants or pesticides, and airborne transport of pests. With these analytical tools, managers can translate a weather forecast into a quantitatively useful form for decisionmakers.

Science of Forecasting. The current forecast system has gaps, such as 5 to 10 days in the future, where needed information is not available. Managers need to know that once a decision is made to stage and deploy crews and equipment, they will actually be needed when they arrive at the fire. Likewise, if there are limited crews and equipment to dispatch, managers need to know which fires they should be sent to.

Research on weather forecasting

Fire crews fell trees and line them up in parallel rows to slow the progress of small forest fires.

holds much promise in three areas: (1) Improving the precision of weather forecasts and, as a result, the accuracy of short-range (3–5 days) fire-severity outlooks; (2) developing the capability to forecast fire severity in the medium range (5–10 days); and (3) developing more precise, physically based forecasts in the extended range (10–30 days). Accompanying this basic research are programs to use the forecasts in management decisions. Quantitative assessment of the probabilities of forecast events and confidence in those forecasts will be processed through models of fire ignition and behavior.

How does this research benefit forest management, the forest user, and the consumer? First, improved use of personnel and equipment in controlling forest and brushfires will reduce costs. Second, forest and brushfires will be attacked with adequate resources at an early stage, resulting in better protection of life, property, watersheds, and other forest resources.

Weather Observations. Many weather observations are now made manually and, therefore, are limited to those places where we have personnel. Because forest facilities are staffed along roads, which tend to follow river drainages in mountain areas, and in rural communities and at the occasional fire lookout, manual weather observations and forecasts are based on data limited by human demographics.

To effectively support a weather intelligence and forecast operation for forest management, meteorologists need to observe weather at those locations where its impacts influence decisions and where they can effectively estimate what will take place between weather stations. Research on techniques to incorporate weather data into geographic information systems (i.e., provide weather intelligence where needed, not just where staff are) is being conducted. The engineering developments in automated weather stations that telemeter data through geostationary orbiting satellites made this possible.

As a result of this research, weather station networks can be designed for fire management, air-quality assessment, and a variety of other activities. The number of weather stations and their locations will be objectively determined. An estimated error is determined for any given number of weather stations. As a result, a manager may determine the acceptable error or risk and be assured that the network meets the management accuracy requirements on a cost-effective basis.

These newly designed weather station networks will provide improved intelligence on weather aspects of fire severity and an improved data base on which to make fire-severity forecasts.

Quantitative Analysis Tools. Analysis of weather with high geographic resolution, particularly in the case of winds, is needed to assess the impacts of pollution transported to the Nation's forests. Equally important is the requirement to predict the pattern and amount of pesticides reaching an area being sprayed. The management of air resources to minimize adverse effects of smoke from prescribed fire also requires that high-spatial-resolution analysis of meteorology information be generated.

Research has focused on developing these analytical tools for use in mountainous areas because mountain wind patterns are extremely variable and less understood than wind information over level ground.

Results of this research will be applied in air pollution evaluations, such as transport of oxidants or acidic particulates into forest areas.

Also, with the introduction of gypsy moths into the mountainous West, predictability is needed to pinpoint where airborne transport of the larvae might occur. Use of these analysis tools will suggest likely areas to set out traps for assessment of the infestations and will help to minimize the area requiring pesticides. This latter use has both economic and environmental consequences—pesticides are expensive and not particularly selective and their impact on population of desirable species, such as bees, can be minimized.

These quantitative analysis tools are designed to (1) use observed weather to provide a current assessment, and (2) forecast weather to quantitatively assess the future. Research has focused on mathematically mimicking physical and biological processes so that, as observations of weather and forecasts of weather improve, the tools available to the decisionmakers and policymakers will increase in accuracy.

Forest Harvesting, Wood Utilization, and Products of the Future

H. M. Montrey, *deputy director, Forest Products Laboratory, and* John I. Zerbe, *manager, Energy from Wood Program, Forest Products Laboratory, Forest Service, Madison, WI*

In the United States, wood is still a major construction and industrial material. Wood housing has been the mainstay of the American family from the time of the first European settlers, and it remains important to our way of life. Today most of our housing is predominantly wood framed. Even single-family houses and low-rise apartment buildings with masonry walls often have wood framing behind the masonry veneer and framing in floors, partitions, and roofs. Results of today's research in improving the use of wood from foundation to rooftop will ensure an adequate supply of comfortable housing at a reasonable cost of construction in the future.

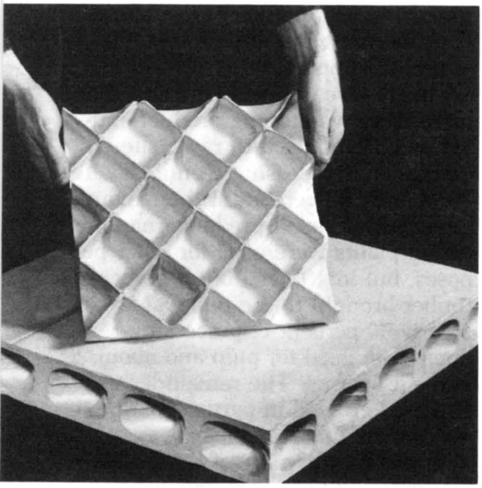
The United States is fortunate that it also has adequate wood supplies. Improvements in harvesting methods and forest-management practices are helping hold costs of timber to affordable levels. Production of this versatile, renewable, and abundant material now exceeds harvest, and available supply is increasing by 1 percent a year. Today much of the excess is in lower grade hardwoods (broad-leaved trees), but research also is leading to ways of making these trees attractive for use in products of tomorrow. More efficient use also is contributing to an effective extension of timber supplies.

Future research will be focused on more closely matching product end-use requirements with raw material quality and processing technology. In 1952, only 60 percent of the residues generated at forest-products manufacturing plants were used for other purposes, but in 1976 all but 4 percent of timber brought to the mill was used. Nearly 60 percent of processing residues were used for pulp and about 20 percent for fuel. The remainder was exported or used in particleboard and a variety of other products.

In the future, more of the residues are expected to go into composite panel products that may be used in structural applications which previously required boards or plywood. Research over the past decade has accelerated the manufacture of nonveneered structural panels such as oriented strandboard and waferboard. As for other particleboard and fiberboard products, manufacturing of these nonveneered structural panels does not require large or straight-growing trees. Composite panel also can be made from a large variety of species, including hardwoods, which are often produced in excess.

Growth and use of forest products may be managed to enhance the environment through resisting erosion by water and damage by wind. Well-managed forests also may help in soil conservation by maintaining a desirable soil nutrient balance. Harvest revenues may pay for better forestry practices as well as other forest uses such as recreation. Research and development efforts can lead to improved harvesting methods, higher levels of forest land management, and increased benefits.

Just as housing construction has been based on wood, U.S. industry has long depended on wood as an important raw material. In 1972 the Na-



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Spaceboard—a molded structural sandwich product made from paper—will be used for a variety of applications, including wall and ceiling panels and decking.

tional Commission on Materials Policy found that, of the 21 tons of material per capita required annually in industrial operations, 9 tons were for fossil fuels, ⅔ ton for metals, and 1⅓ tons for forest products. Comparing dollar values for these materials is difficult, but the value of primary forest products is clearly comparable to that of metal products.

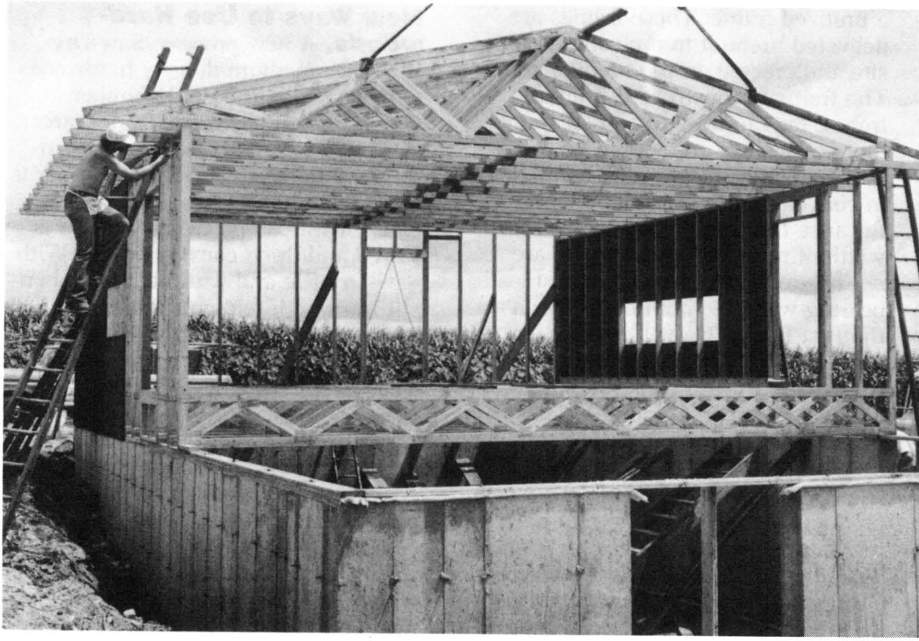
Besides its obvious uses in industrial and consumer products, wood has several intriguing applications in national security and emergency preparedness. Wood is not comparable to metals in importance for armaments and ammunition, but it can replace scarce metals in other applications and has some unique uses for which metals cannot compete. Last year marked the first time since World War II that the Department of Defense awarded a contract for minesweepers, and these ships will be made entirely of wood. Successful large wind electrical generators, which have been designed since the energy crises of 1973 and 1979, generally use blades made of wood.

Wood Use in Housing

One of the most innovative uses of wood in housing construction and one likely to grow significantly in the future is wood foundations. Historically, builders have contended that durable foundations have to be built of masonry. But research has shown that suitably treated wood and plywood foundations with proper drainage of water away from the foundation wall can provide some economic, structural, and esthetic design advantages. Wood foundations should prove to be particularly beneficial in colder climates where they may be erected during most of the year and easily fitted with insulation.

Wood Floor Framing. Wood floor framing has been improved recently with the acceptance of a construction method in which floor surfacing, such as plywood, is glued to load-carrying floor joists to provide composite structural action. The result is more stiffness and strength with less material. Increased use is being made of parallel chord trusses and I-beams, particularly for long spans, as availability of wide lumber decreases. In the future, floor joists may be molded into structural shapes, such as I-beams, from available particulate material as is used in the manufacture of oriented strandboard. Already, the first plant is being built to construct framing members with an inner core weaker material and an outer web of stronger material. The plant will manufacture Com-Ply®, which forms a rectangular cross section like conventional lumber studs and joists but has a particleboard core and veneer surface layers.

Wall Framing. Future wall framing for houses will likely see more appli-



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The Truss-Framed System uses less lumber and requires fewer supports than conventional framing.

cations of composites and other improved structural shapes that may be fabricated from more abundant lower-value materials such as strands from hardwoods. A new product type from pulp fiber being studied at the Forest Products Laboratory shows promise for building modules as well as improved paperboard containers. This product—Spaceboard—is a molded structural sandwich that has superior strength-to-weight characteristics and is not as limited in orientation to load application as conventional framing materials. Engineered paperboard structures could become a reality and make better use of our wood resources if adverse effects of moisture and humidity can be overcome.

Oriented strandboard is a new product that fulfills a need for a composite panel board with mechanical properties equivalent to those of structural plywood. Oriented strandboard is composed of three layers of aligned strands bonded together with a liquid phenolic resin. The wood strands in the top and bottom layer lay parallel to panel direction; those in the core lay perpendicular to the panel direction.

In 1980, there was only one structural flakeboard plant in the United States. Today, there are over 15, and construction of other facilities has been announced. Future research will lead to molded oriented strand products tailored for specific end-use application.

Prebuilt Frames. A new development gaining acceptance for floor, wall, and roof framing is the Truss-Framed System developed by Forest Products Laboratory engineers. The system incorporates an open-webbed floor truss, an open-webbed roof truss, and conventional wall studs in a unitized frame. These frames are delivered prebuilt to the construction site and erected on the foundation. The frame is constructed primarily from 2 by 4 lumber instead of the more expensive and less available 2 by 8 and 2 by 10 lumber common in conventionally designed homes. Because the trusses can span the width of most homes, supports are not needed in the basement and load-bearing walls are not necessary on the first floor. This will provide for more flexibility in using space to best advantage. Future construction practice will incorporate increased use of this and other innovative modular systems.

As pressures build within the wood-products industry to penetrate new markets, innovative building systems will be developed to allow wood to substitute for steel in nonresidential construction.

Exterior House Materials. Although the use of wood for exterior house siding has decreased, exterior forest-products finish materials will continue to be used extensively in house construction and their characteristics will be improved. Since some type of finish is generally preferred for protection, performance, and appearance of the wood itself whenever wood is used outdoors, research efforts are aimed at developing more reliable pretreatments and finishes to increase wood's longevity. Better paints, stains, water repellants, and other preservative treatments will be developed as well as better wood and wood composite substrates on which to apply these products.

Processing Improvements

Increased benefits should come from improvements in processing wood raw materials to make the products better and more economically.

New Ways to Use Hardwoods. A new process, Saw-Dry-Rip, uses medium-density hardwoods to make structural-grade lumber, which is normally made from scarcer and more expensive softwoods. Currently, little or no structural lumber is made from hardwoods, in part because it warps and twists when it is sawed and dried conventionally. With Saw-Dry-Rip and with additional benefit from high-temperature drying, stresses in the wood are relieved and warp is reduced. This means the wood is cut straight and stays straight.

Press drying of paper will also permit the use of hardwoods for more conventional purposes. Traditionally, papermakers prefer softwoods because their fibers bond more easily than high-density hardwood fibers, which are short and stiff. By applying heat and pressure to a wet web of wood fibers simultaneously rather than separately, press drying produces strong paper from 100-percent hardwood pulp.

Steam Injection Pressing. In the manufacture of waferboard, particleboard, and medium-density fiberboard, a new steam injection pressing process will reduce press time up to 90 percent on thick boards. With this new process, resin-coated flakes are formed into a mat and loaded into a press as in conventional processes. Then, under computer control, saturated steam is injected into the mat. This permits the center of the board to quickly attain high temperatures as the board is compacted, and the high temperature accelerates the resin cure. Besides reducing the press time significantly, the process also permits use of smaller equipment. The end result is large savings in energy and capital costs. Steam injection pressing also can incorporate additives for greater durability and fire resistance.

Automation of Lumber Production. Perhaps the greatest improvement in wood processing will be full automation of lumber production, since lumber is the most important manufactured solid wood product. Wood processing centers will depend less on human decisionmaking and physical labor. Skilled technicians will monitor the automated operations using advanced computerized devices. These techniques, coupled with state-of-the-art processing techniques such as laser cutting and use of advanced cutting materials, show much promise for the future.

Advanced Drying Technology. For wood to perform satisfactorily in many applications, it must be dried to a moisture content in harmony with the environment where it is used. Otherwise, splitting, twisting, shrinking, swelling, and warping in place will cause problems. Advanced drying technology should result in improved quality and shorter drying times. Savings will then result from elimination of drying defects. conservation of energy, and reduction of storing and handling costs.

Design Improvements

Because of past utilization practices, much of the hardwood forest is composed of low-quality trees. So it is becoming increasingly important to use this lower value material more effectively. Harvesting removes only about half of the woody material, and each subsequent step in the processing chain generates additional residues. Even the best grades of wood are not used to maximum efficiency because we do not know enough about wood's material properties.

For the future, reconstituted panel and fiber products provide an opportunity to produce engineered materials that optimize particle or fiber properties to meet specific end-use requirements and reduce overdesign. Modern engineering design practices require a more precise estimation of lumber properties than can be achieved with current procedures. Today, strength properties are usually assigned by visual grading and correlating appearance with recorded values from tests of specimens that did not have apparent strength-reducing characteristics. In the future, we will see more improved systems for automated lumber grading in which structural pieces are nondestructively evaluated and assigned strength values. As characteristics of the softwood resource change because of increasing volumes of plantation-grown trees, automated lumber grading will become pervasive.

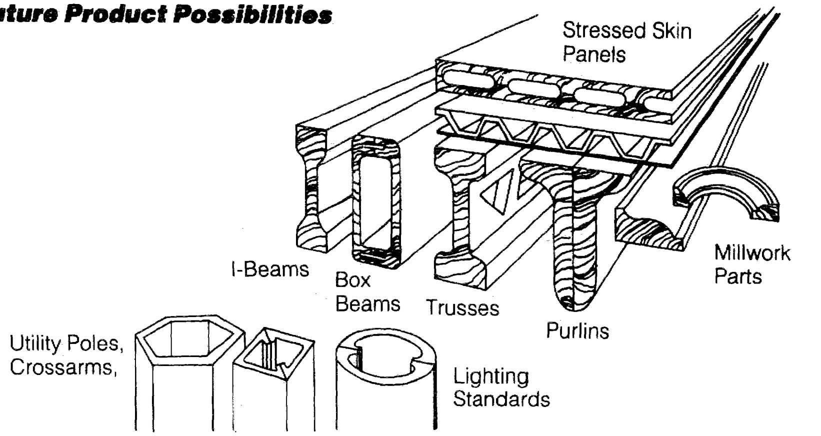
Industrial Chemical Products and Biotechnology

The promise for industrial chemical and biotechnology products from wood is bright. Industrial chemical products from wood have a long history and form the basis for the large pulp and paper industry and other significant segments of our economy. Research is building on this foundation to provide successful new products to replace those made from petroleum and other materials. Products from biotechnology are just beginning to leave the laboratory, but success in areas such as waste treatments is an indication that this technology will have a strong impact on our future progress.

Some industrial chemical products from wood are such diverse, long-established commodities as charcoal, rayon, and natural rubber. An example of a product from biotechnology that has penetrated the market is mushrooms grown on wood.

The potential for increased use of wood for industrial chemicals and products from biotechnology is closely tied to the productive potential of

Future Product Possibilities



wood biomass systems. Approximately 20 billion dry tons of standing ligno-cellulosic biomass in the United States could be doubled or tripled with intensive forestry. Each year about 6 million dry tons of wood are generated and recycled to the soil without further use. Shrubs, small trees, bark, foliage, and harvesting residues occur in large quantities in many localities. Much of this woody biomass is suited for use in industrial chemical or biological products.

Among the products that will be derived increasingly from wood are fuels, pharmaceuticals, adhesives, plastics, and resins. New chemical and biological modification of wood and paper will produce materials that are more moisture-,fire-, and decay-resistant.

Fuels. Fuels are an obvious outlet for some of the presently unused wood that can be chemically or biologically processed but is unsuited for lumber, veneer, paper, or other conventional products. Alcohol fuels for blending with gasoline are derived from wood in insignificant quantities (4 to 5 million gallons a year) but in the future this output is likely to increase many times.

Both chemical and biological processes are being improved to make this feasible. Extracting ethyl alcohol from wood is based on a hydrolysis process known for 150 years, but improvements in the common chemical reaction with water in the presence of acid catalysts are making the end product more competitive with ethyl alcohol from other sources and with other fuels.

A significant new development is the proven feasibility of biological enzyme hydrolysis of cellulose, which comprises about 50 percent of wood, to glucose. Glucose is a sugar that can be fermented readily to ethyl alcohol. Biological enzyme hydrolysis can convert 80 percent of the cellulose, while acid hydrolysis, in its present state of development, converts only about 50 percent.

Perhaps of even more significance, biotechnology research at the Forest Products Laboratory and elsewhere has shown how to ferment another sugar, xylose, to ethyl alcohol. Xylose is a common derivative of hemicellulose from hardwoods. (Hemicellulose makes up about half of the noncellulosic portion of wood; the other main constituent of wood is lignin.)

Other alcohols that are used increasingly as octane enhancers with gasoline are methyl alcohol and butyl alcohol. Another name for methyl alcohol is wood alcohol, as it was originally made from wood. Now it is manufactured more economically from natural gas, and it also may be made from coal. Nonetheless, methyl alcohol from wood is a potential fuel of the future, either for use in blending with gasoline or without mixing with other fuels. Even today, racing cars run on methyl alcohol or methanol, terms that are used interchangeably. It is now possible to ferment butyl alcohol from wood, and this product will likely become more competitive in the future.

Gases and Oils. In the future, gases and oils will be derived from forest products. Gases are obtained mainly through pyrolysis processes in which wood is heated in the absence of sufficient oxygen for combustion. Other products such as charcoal also may be produced, or the wood is converted almost wholly to gas. The gas is most commonly generated as a low or medium heat-value gas. A high heat-value gas comparable to natural gas could be obtained only through an additional enrichment process.

Hydrocarbon oils can be obtained through naturally occurring chemicals contained in some trees. One example is the seed of the Chinese tallow tree, introduced to the United States by Ben Franklin in 1763. It has become naturalized throughout most of the coastal South and in moist parts of southern California.

Pharmaceuticals and Cosmetics. Among the possible medicinal chemicals to be derived from wood in the future are steroids for such uses as contraceptives, corticosteroids, and geriatric drugs. Steroids are obtained from tall oil, an important extractive compound found in pines and some other softwood species. Tall oils contain phytosterol for steroid production, which can replace a similar chemical from more expensive soybeans, freeing up the soybeans for food and animal feed. Other related sterol compounds may be used as emulsifiers, emulsion stabilizers, viscosity modifiers, and emollients in cosmetics. The chemical L-dopa, for treating Parkinson's disease, also can be derived from trees.

It is impossible to tell how many diseases may be treated with pharmaceuticals derived from the forest, but species diversity in our forests must be maintained so that the potentially beneficial chemicals contained in different trees will not be lost through their extinction. Many of our medicines have originated from plants, including trees, and this pattern is likely to continue.

Adhesives and Other Products from Lignin. The lignin fraction of wood has long been a tempting, but mostly unproductive, subject of research in our quest for valuable chemicals. Today some 20 million dry tons of lignin from pulping operations go unused each year. The lignin byproduct of kraft pulping operations is used for fuel.

Waste pulping liquors are processed on a small scale to produce commercial vanillin, dimethylsulfoxide, and lignosulfonates, but in the future other products are likely to lead to more intensive utilization. Vanillin is important for flavoring, but it is used in such small quantities that it does not constitute a major market. Dimethylsulfoxides and lignosulfonates have greater established and potential markets as oil field chemicals, surfactants, dispersants, binders, concrete admixtures, and sequestering agents.

Among the most promising products from lignin are adhesives, phenolic compounds, toluene, and benzene. Adhesives derived from wood lignin are likely to be substituted for the durable phenolic adhesives now used in the manufacture of plywood.

Other adhesives may be produced from the tannins and carbohydrates in wood.

The study of biotechnical approaches to converting byproduct lignins to more useful products has only begun. In the future, lignin will be biodegraded to produce many diverse low-molecular-weight products. On the other hand, retaining the high-molecular-weight character of lignin without breaking it down while speeding other chemical interactions to provide useful compounds similar to plastics might turn out to be more advantageous.

Plastic and Plastic Fiber Products. Although wood is a magnificent competitor for many plastics in its own right, it is likely to be used more as a feedstock for synthetic plastics in competition with plastics made from petroleum. Today, polyethylene made from petroleum is the fundamental building unit for many plastic products, but wood is becoming more nearly competitive for this market. When oil prices were approaching $40 per barrel, it might have been practical to make ethylene and polyethylene from wood through an intermediate ethyl alcohol hydrolysis. As the technology for making ethyl alcohol from wood is improved, the feasibility of deriving polyethylene plastics from wood is enhanced.

Other plastic and plastic fiber products normally made from wood are cellophane, cellulose acetate, and rayon. Wood was originally used in the manufacture of nylon fiber and is likely to be used more in the future, if a precipitating agent such as furfural can be made economically from wood. Presently, wood hemicellulose can be used to produce this agent.

Rubber. Synthetic rubber also may be produced from wood. Normally this product is made from butadiene, which can be derived from ethyl alcohol. In another approach, butane-2, 3-diol is derived from wood through biological fermentation and used as a precursor for synthetic rubber.

Oleoresins. Oleoresins from tall oil and other wood extractive fractions are another reservoir of chemicals for the future. Among the products that can be derived from them in addition to the medicinals and cosmetics mentioned previously are adhesives, special plastics, and high-value fuels.

Food. The concept of feeding animals and people from wood is another area in its infancy. Today, the field is limited to yeast from some pulp mill wastes and molasses from hemicellulose obtained as a byproduct of hardboard manufacture. Mushrooms are raised on wood substrates to a limited degree in the United States. Only now has the shiitake mushroom industry established a foothold, but there is a good opportunity for this industry to benefit from new technology, grow, and displace shiitake imports.

Special sugars and related chemicals from wood have advantages over more conventional products. Xylitol and sorbitol can displace sucrose and help in preventing tooth decay. Glucose also has special dietetic applications.

Other Chemical Products. Among other potential growth chemicals from wood are glycerol for explosives, tannins for curing leather, ammonia and urea for fertilizer, and high-quality wax for special applications. Organic acids such as formic, acetic, propionic, saccharinic, succinic, and many others are likely to be derived from wood and to substitute for organic acids from other sources. These acids may be used in the manufacture of many other products. As an example, acetic acid may be processed to such consumer commodities as vinyl and cellulose acetate.

Biotechnology Applications.

Many other biotechnology applications can add to the quality of life in the future. Trees of the future will be superior to those of today, partly because biotechnology promises to decrease the time required for identifying and propagating selected better trees, and plant tissue culture will provide alternative means to clone superior trees. Traits such as growth efficiency, photosynthetic efficiency, stress tolerance, and resistance to diseases, frost, drought, salinity, herbicides, and heavy metals and other chemicals may be screened in tissue culture.

Biological fixation of atmospheric nitrogen has the potential to offset the need for commercial nitrogen fertilizers. It should be possible to develop nitrogen-fixing clones of the best tree species that already absorb nitrogen from the air and fix it in the ground. It may be possible to create hybrids between species that fix nitrogen and other trees that are desirable for different purposes. Better strains of bacteria that fix nitrogen can be developed.

Growth of forest trees may be improved in the future by inoculating the soil with mycorrhizae, or root–fungus structures formed by special types of fungi. Experiments on inoculation of southern pines with selected strains of the fungus *Pitholithus tinctorius* have dramatically increased survival and growth on adverse sites.

Spraying chemicals on forests to control insects or disease has met with only limited success, is environmentally questionable, and is often not cost-effective. Biotechnology can play an important role in developing pest-resistant varieties of trees and biological control agents, particularly for insect pests and, possibly, for forest diseases. Italian researchers have demonstrated that a virus can kill the fungus that causes chestnut blight.

In the processing of wood, biotechnology will affect how pulp and paper are made. For instance, pines engineered to overproduce turpentine or pulpwood with a lowered lignin content will have to be pulped differently from the way today's wood is pulped. Because certain micro-organisms can partially break down the cell walls of wood, biological (nonchemical) pulping may be possible in the future.

Pulp and paper mills also produce much more waste than the lignin mentioned previously. Based on the sizes of U.S. industries and the characteristics of the waste streams, 1.2 million metric tons of sugar could be available annually from sulfite pulp mills in North America, and about 1.5 million metric tons of cellulosic material could be recovered from primary sludges in kraft pulp mills. Hardboard and insulation board plants produce about 150,000 metric tons of nonutilized sugar annually. Each of these byproduct streams could be used for the production of numerous fermentation chemicals or microbial protein with the application of biotechnological processing. Because lignins do not serve as growth substrates for microbes, their use as substrates for conversion to protein or other fermentation products is apparently not possible without extensive pretreatment.

The pulp and paper industry already depends on microbial technology to treat its manufacturing wastes, and microbes are being improved to degrade specific industrial wastes or recalcitrant products. The Forest Products Laboratory, in cooperation with North Carolina State University, has recently investigated the use of white-rot fungi, which degrade lignin, to decolorize the highly colored first extraction-stage effluent of pulp mills. This process holds much promise for successful commercial use in the future.

Assessing Forest Resources and Demands

David Darr, *group leader, Demand, Price, and Trade Analysis, Forest Resources Economics Research Staff, Forest Service*

Reasons for Assessing Forest Resources and Demands

Simply put, the Forest Service assesses supplies and demands for United States' forest resources because we have to. The Secretary of Agriculture is directed by law to prepare "an analysis of present and anticipated uses, demand for, and supply of the renewable resources, with consideration of the international resource situation, and an emphasis of pertinent supply and demand and price relationship trends." And the Forest Service acts as his agent in this assessment.

But more importantly, we see our Agency as custodians of the Nation's renewable resources: outdoor recreation, wildlife and fish, range, timber, and water. Since the mining of mineral resources often has significant effects on renewable natural resources, our analyses also include minerals. Results of periodic assessments are used in developing programs to deal with projected resource situations.

Lead times can be long for programs to have much influence in a resource area such as timber, so projections are made 50 years into the future. The Forest and Rangeland Renewable Resources Planning Act calls for an assessment of the supply-demand situation every 10 years. Plans are now under way for the third assessment due in 1989. The last assessment was done in 1979, with an update in 1984, and contained projections to 2030.

Assessments Analysis

Assessments are done by specialists who concentrate on an assigned renewable resource. The analysis of each specialist is organized around the following points: 1) Analysis of long-term trends, demands, and supplies; 2) social, economic, and environmental implications of trends in demands and supplies; 3) description of the resource base; 4) opportunities to manage and use the resource base to meet the goals of society; and 5) quantification of the major implications of the analysis for the Forest Service's Renewable Resources Planning Act (RPA) Program.

The future is uncertain; projections into the future must rest on assumptions about the effects of selected variables and their interactions on forest resource supplies and demands. Projection methodologies vary among the renewable-resource areas and depend on adequacy of the data available. Especially in the areas of economics and sociology, relationships among variables can change rapidly over time. By contrast, measures of physical relationships such as tree growth change relatively slowly over time.

Various types of research are needed to develop the information required for an assessment of each of the resource areas. There are several ways to classify this research, but it all deals in one way or another with demand and supply.

Demand for Resources

Resource demand can be measured in general ways and in ways specific to a resource area. General measures of demand are population, gross national product, and personal income. Current expectations are that the U.S. economy will continue to grow, with more people with more money to spend, leading to increased demands for all resources.

Historical data can be used to develop long-term trends in the relationship between consumption and the measures of resource demand. For example, trends in variables such as prices and consumption measure the outcomes of market interactions. They implicitly include the influences of government policies and many other variables and policies. Analysts not only define and describe these trends but also decide whether or not historical relationships will continue into the future.

They can make long-term projections in some renewable-resource areas better than in others, and technical issues also vary from one resource to another. But the overall approach to making these projections is similar for all resource areas. The timber area has the most advanced projection models and data bases.

The RPA assessment calls for an analysis of long-run demands and supplies. Our approach is to use statistics to estimate supply and demand schedules for timber products such as softwood lumber and plywood. For some timber products, analysts evaluate trends in historical consumption and make projections on a judgmental basis. For timber demands, they tie all projections to a few key variables: housing starts, gross national product, population, and personal income. These variables are primary measures of activity in the U.S. economy.

Demands for housing and other end uses of timber products all influence the demand for standing trees. Supplies of standing timber interact with demand to determine prices and output levels. The latter are key indicators of the resource situation. Our analysts must tie together demands and supplies to gain a consistent view of the resource situation. They do this with a mathematical model called the timber assessment market model.

Supply of Timber

The standing timber resource has many characteristics that make it difficult to simulate for long-run projections. Standing timber is a resource in inventory: it can be harvested or left standing from one day to the next.

While the timber is in inventory, it grows, but it may be damaged or killed by fire, insects, and disease. Analysts try to account for the changes to the resource inventory in various ways, the latest being what we call the timber resource inventory model. Data for projecting growth and other measures of the timber inventory are generally based on historical data from periodic surveys done by Forest Service forest inventory and analysis units around the country.

In addition to data on physical attributes, such as growth and mortality, analysts try to account for changes in the area of timber land over time. Timber-growing areas on public lands may be taken out of production for other uses such as wilderness. Private owners of timber land may convert it into cropland or some other use.

Timber sales on public lands are generally set in a prespecified way and are generally predictable. Timber sales from private lands are less predictable, and generally analysts project sales from these lands using relationships derived from historical data.

Characteristics of the timber inventory vary around the country, as do the technical issues of trying to model this inventory. For example, public lands are relatively more important than private lands in determining timber supplies on the West Coast, but the reverse is true in the South.

In the timber assessment market model, there is an attempt to account for interactions among the various supplying and consuming regions in the U.S. timber sector. Our timber situation is heavily influenced by imports from Canada and to a lesser extent by U.S. exports to offshore markets. Analysts also attempt to assess the influence of international markets on the U.S. resource situation.

The first attempt at a comprehensive mathematical simulation model of the U.S. timber sector was completed in the late 1970's. Although a continuing program of trying to improve the various parts of the model has gone on, our experience of the last few years has shown that there is probably no way to develop a definitive model of the U.S. timber sector. Data and insights change over time and influence how we view the workings of the timber economy.

Significant Future Issues

There is no way to tell either whether the model of the future of the forest sector is realistic. The following examples highlight issues that appear to be especially significant in the future for the timber sector.

Housing. The number and size of housing units is especially important in trying to assess future use of softwood lumber, plywood, and other timber products. Reasons for optimism include expectations of a growing population with rising incomes. Reasons cited for pessimism include the potential for high interest rates and high housing costs. Both arguments rest on assumptions about an uncertain future and are therefore not testable.

Technology. People tend to be either optimists or pessimists about technology. If they believe in technology, a future with economic scarcity of timber products is unlikely. Economic scarcity is defined as a situation with rising prices for timber products compared with other products. If they doubt the virtues of technology, the future becomes more uncertain, with economic scarcity a plausible outcome of the current resource situation. An example in the timber sector is the amount of lumber that can be recovered from roundwood logs. As technology has improved over time, more wood in the form of lumber per unit of roundwood processed has been recovered.

State-of-the-art sawmills are efficient in terms of lumber recovery, but most of the industry's capacity consists of mills built over the past 30 years, with wide variation in efficiency. In making projections, analysts must account for the potential effects of technology on the future resource situation.

Forest Management. Especially in the South, the age of harvest for trees is generally less than 50 years—the length of our projection period. Assumptions must be made about what will happen to the land after the trees are harvested. For example, should it be assumed that the timber land will be converted to cropland, should it be assumed that the land will be replanted, or what? In addition, the land may be managed intensively or not at all. What should be assumed? Some historical data on how land is managed exist, but there are both optimists and pessimists about the future who claim that it will be different from the past.

Futures Analysis. Many other examples could be cited as issues in trying to make long-term projections in the forestry sector. Most of these issues cannot be resolved because they deal with uncertainty. The Forest Service has tried to address this uncertainty through what we call futures analysis, which means we ask a lot of "what if" questions. For example, what if timber management is more intensive in the future than assumed in our projections? What if housing demand is lower in the future than assumed? What if land area available for timber production is less than assumed for the future?

This futures analysis has proven useful in trying to assess the implications of the uncertainties in long-term projections. For example, it has shown that over a wide range of possible futures, the United States faces the prospects of growing economic scarcity of softwood lumber, with continuing increases in prices.

The uncertainties discussed for projections of demands and supplies also are involved in trying to assess the social, economic, and environmental implications of trends in demands and supplies. For example, what will society consider important 50 years from now?

Research Opportunities to Improve Projected Resource Situation

Previous assessments provide indications of the present and prospective supply-demand situations for the various renewable resources. They also provide indications of opportunities to change the expected resource situation. A review of these situations and opportunities to change them is useful in pointing out the directions needed for data bases and analysis methods in the future.

Timber. Comparing available projections of future timber supplies with timber demands makes it clear that a physical shortage of timber in the United States in the decades immediately ahead is not likely. Demands are rising faster than supplies, however, so that the outlook is one of increasing economic scarcity with rising timber and timber-product prices.

Higher prices for timber products have many implications for the U.S. economy. Higher prices for softwood lumber and plywood would raise the cost of housing and reduce both the number and size of houses. Relatively higher prices for timber products would lead to increased use of substitutes such as concrete, steel, aluminum, and plastic. The mining, industrial processing, and power generation associated with increased use of timber substitutes would result in more air and water pollution. Rising prices would also affect the timber resource. Owners of the resource would increase harvests as prices go up; and as harvests rise, net annual growth and inventories would be changed.

Three major ways to respond to rising demands for timber are: (1) Extending supplies through improved utilization, (2) increasing harvests from the existing timber resource, and (3) increasing net annual growth.

Timber supplies can be extended by:

- Increasing the useful life of wood products by preservative treatments; improving designs of new structures, and fixing existing structures rather than replacing them.
- Improving efficiency in harvesting, construction, and manufacturing.
- Utilizing unused wood materials such as logging residues.

Harvests from the existing timber resource can be increased by:

- Accelerating harvests on National Forests in Washington, Oregon, northern California, northern Idaho, and western Montana that have large inventories of old-growth softwood timber.
- Increasing softwood and hardwood timber harvests on forests in the East.

Sustaining increased harvests on the National Forests in the West and on the forest lands in the East beyond a few decades will require large investments in more intensive management programs to increase net annual timber growth.

Net annual timber growth can be increased by:

- Regenerating nonstocked and poorly stocked commercial timberlands, harvesting and regenerating mature stands, and converting existing stands to more desired species.
- Applying intensive timber management practices such as species and spacing regulation, fertilization, and use of genetically improved trees.
- Using management and harvesting practices to prevent or reduce losses caused by natural mortality, undesirable vegetation, wildfire, insects, diseases, and poor logging practices.

Water. Precipitation provides enough surface and ground water to meet prospective demands for water in the United States; however, serious imbalances are caused by geographic, seasonal, and annual variation in supplies. The location of agriculture is especially sensitive to the availability of water for irrigation. In some places (e.g., the areas on the High Plains of Texas and adjoining States where ground-water mining for irrigation is severe), as water production costs go up and the water for crop and pasture land irrigation becomes uneconomic, there will be a shift to dryland farming or range grazing. Food and fiber production will be reduced in the affected areas; eventually production will move to regions where water supplies are adequate and the land is suitable for crop and pasture use.

Most of the prime farmland that is not now in crops or pastures is in forest and range. If production is shifted from irrigated areas in water-short regions, these lands are most likely to be converted to crop and pasture use. The conversion of these highly productive lands will reduce timber and forage production.

Flooding and water pollution are other significant costs associated with the prospective supply-demand situation for water.

Many opportunities exist on forest and range lands to increase and extend water supplies, ameliorate the effects of flooding, and improve water quality. All these things can be achieved by:

- Improving vegetation management to increase the natural recharge of surface and ground water, to reduce evaporation losses, and to change the timing of waterflows.
- Improving protection of watersheds from wildfire.
- Maintaining wetlands.

Water supplies can be increased or extended by:

- Expanding and improving reservoirs to increase storage, regulate flows, and reduce evaporation.
- Improving snow management.
- Improving conservation, including more re-use.

Flood damage can be reduced by:

- Controlling floatable debris such as logging residues.
- Increasing use of structures to control waterflows.
- Improving management of flood plain use.
- Expanding land treatment programs.

Water quality can be improved by:

- Improving use of pesticides and fertilizers.
- Increasing reclamation of mine sites to reduce erosion and acid flows from abandoned mines.
- Improving poor watershed conditions.

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Tree shearers clip off even large trees like this pine at ground level.

Range Forage. The demand for range forage depends primarily on the demand for red meat and the availability of substitute feed sources such as grain. There is some uncertainty about future per-capita consumption of red meat; however, even if per-capita consumption does not increase, total demand will grow because population will grow. Available data indicate that the amount of range forage used by domestic livestock annually has remained unchanged at 200 million animal unit months per year for the past several decades. Increases in demands for red meat would place increased demands on rangeland.

The opportunities to increase forage production and to improve the condition of forest and range land for grazing include:

- Improving rangelands by seeding better grasses and legumes and controlling noxious weeds and other undesirable plants and shrubs.
- Increasing the use of forage on forest and range lands by the use of improved grazing systems and livestock management practices.
- Constructing needed livestock control and handling facilities such as fences, and developing adequate water supplies.
- Reducing forage losses by controlling wildfires, range insects and diseases, and pests.

Outdoor Recreation and Wilderness. In the last two decades participation in most kinds of outdoor recreation has been growing, and this growth is expected to continue. The supplies of outdoor recreation facilities now available will have to be expanded if the projected growth in demand is to be met and quality maintained. New trails and campgrounds will have to be built, and meeting the prospective growth in demand for some activities, such as winter sports facilities, will require special efforts.

Most of the projected increases in demands for outdoor recreation on forest and range lands and inland waters can be met. The major opportunities include:

- Rehabilitating deteriorating sites and adequately maintaining existing facilities.
- Constructing additional facilities such as trails, campgrounds picnic areas, and boat ramps.
- Designating additional areas as wilderness, where appropriate potential exists.
- Improving access to forest and range land and inland water suitable for outdoor recreation.
- Expanding programs concerned with visitor information services including educational services and back-country safety patrols.
- Improving management and information techniques for shifting more recreation demands to underutilized areas and facilities.
- Improving the coordination and integration of outdoor uses with other uses.
- Improving management and protection practices to minimize the adverse impacts on wilderness resources.

Wildlife and Fish. Although there are indications that the populations of some wildlife and fish species have been increasing, there also are indications that they have not been rising as rapidly as demands. For example, the number of big-game animals per hunter has been dropping rapidly in most regions. Demands on the wildlife and fish resource are likely to continue to grow in the future.

Opportunities to respond to the diverse demands on the wildlife and fish resource include:

- Expanding programs to improve wildlife and fish habitats by increasing food supplies and suitable habitat cover, improving water quality, and increasing the size, diversity, and distribution of habitat areas.

- Integrating more fully wildlife and fish needs in the management of forest and range lands for other renewable resources, and especially timber and forage.
- Providing better access by constructing trails, boat landings, and rights-of-way where the wildlife and fish resources are underutilized.
- Controlling land and water pollution, and especially the use of pesticides that adversely affect wildlife and fish species.
- Expanding wetlands nesting habitats through fee purchase of key tracts and easements in the United States and Canada, and preserving and enhancing migration and wintering habitats.
- Increasing the reintroduction of species that have been displaced in areas where suitable habitats exist or can be developed.

In addition, there are some opportunities that relate to specific demands on the wildlife and fish resource. These include:

- Increasing efforts to define, protect, improve, and increase critical habitats of endangered and threatened species and the important habitat of other species being adversely affected by changes in management or use.
- Removing barriers to fish migration.
- Promoting the nonconsumptive use of fishery resources in some select areas through special management techniques such as catch and release fishing.

Minerals. The growing U.S. economy will lead to more demands for all kinds of minerals in the future. Some of this increase in demand will be met with imports, but a large proportion will be met from domestic sources. This is especially the case for coal, where there may be as much as a tenfold increase in production by 2030. A tenfold increase in coal production would involve mining large areas of rangelands in Wyoming, North Dakota, and Montana, as well as in other Midwestern and Eastern States. Nearly all of the land disturbed by mining will undoubtedly be reclaimed, but the effects of the disturbance on such activities as production of timber and wildlife habitat can extend over decades.

The impacts of the projected growth in mining on the environment and renewable resources can be managed by:

- Increasing research to develop more efficient and economical ways of reclaiming disturbed land.
- Expanding programs to control mine-related pollution and to reclaim disturbed areas.
- Using appropriate lease and operating stipulations to control environmental impacts.

Future Research Needs

The management opportunities already described can be carried out with existing technology—the knowledge base that has been developed through past research work. Further research can, however, develop new ways to increase and extend supplies of renewable resources and reduce the cost of implementing these opportunities for all resources—timber, water, forage, outdoor recreation, wildlife and fish, and minerals.

For example, research to develop genetically improved plant and animal species, more economical ways of regenerating or propagating desired species, and methods for controlling unwanted species, insects, diseases, and wildfires can contribute to the effectiveness of management practices. Research on better ways of restoring and protecting watersheds and of reducing the adverse effects of activities such as timber harvesting and mining can increase waterflows, reduce flooding, and improve water quality and wildlife and fish habitat. Because of the environmental and biological effects of chemicals, there is a special urgency for research to develop management practices based on natural control measures for reducing the impacts of undesirable vegetation, insects, diseases, and pests.

These are the classic kinds of research opportunities and undoubtedly the ones that can contribute most to meeting future demands on renewable resources. However, there are other research needs. For example, inventories of forest, range, and water resources are basic to almost any decision concerning the management or use of these resources. Presently, inventory information is fragmentary and limited for most resources—and especially so for range, wildlife and fish, outdoor recreation, and minerals.

In many respects, information on the production from, and the uses of, forest and range lands and waters is more fragmentary and limited than that for inventories. National and regional data on the amount of range grazing, many end uses of timber products, recreational activities by kinds, and wildlife harvests are largely nonexistent. Further, lack of comparability and timing severely constrain the usefulness of part of the data that are collected.

Systematic, continuing surveys with national standards and specifications on the data to be collected could greatly help analyses of investment opportunities, the effectiveness of existing policies and programs, and new or additional management and program needs.

More information is needed on the physical responses of forest and range lands and waters to changes in management practices in terms of changes in timber and forage growth, water yields, and wildlife populations. There is an equal need for information on the costs of management practices and on the prices and values of renewable resource products and uses. Such information is essential for evaluating investment programs, analyzing supply situations, and determining harvest and use levels. It also is essential for the management of lands and waters for multiple purposes and for minimizing adverse impacts on the natural environment.

Finally, research is needed to explore further the social, economic, and environmental implications of a future in which the demands for renewable-resource products are rising more rapidly than supplies. Such research is concerned with the societal basis for changing policies and programs. The results are likely to have profound impacts on management and use of forest, range, and water resources.

IX
Sharing New Knowledge

Future Role of Electronic Technology in Agricultural Research and Extension

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Agriculture in the United States is at a major turning point as it enters the information communication age. In fact, some agricultural scientists indicate that the computer is possibly the most significant technological invention in U.S. agriculture today.

The Information Revolution

The information revolution is just in its infancy; many new electronic technologies are appearing daily that go well beyond the computer. These new electronic information and communication technologies are beginning to assume a more important role in our society. This is particularly true in nonformal educational programs such as the Cooperative Extension Service. They use researched knowledge in achieving three main functions: information delivery, educational program delivery, and problem solving.

Whether the focus is on production agriculture, human nutrition, community issues, including water quality, land use or leadership, or working with youth and adult volunteers, electronic technologies are in the forefront of the forthcoming changes in educational delivery and teaching and learning systems.

The information age is relatively new, but agriculture has moved through a succession of changes. In early 1800, agriculture relied on handpower, followed by horsepower in the later part of the century. In 1920 and beyond, mechanical power boosted productivity. By 1945 agricultural production and the allied industries were showing spectacular production gains through the use of science power. Now, a new influence has come to the point of changing research and extension programs radically. This new force is information power.

Electronic technologies are swiftly becoming pervasive. The United States is only 3 or 4 years away from having the major social and economic forces shift from mass society and the industrial age to the information age. It is through this major social and economic transformation that research and extension will fashion new methodologies to extend and translate new knowledge.

New information technologies have the potential to radically change the way individuals live, work, are educated, and use their leisure time. These technologies, along with convergent social changes, will induce significant transformations in the educational programs and activities of the entire research and extension community of the land-grant system, including the national, state, regional, and county levels.

A Changing Society

As the Extension Service continues to fulfill its mission of disseminating research for today and research for tomorrow, trends need to be recognized. The following trends—and these are just a few—indicate tremendous opportunities and change in conducting research. The growth in media usage and electronic innovation also spells out major differences in the ways of disseminating research results.

Worldwide trends follow:

Population Growth. World population will increase from 5 billion in 1980 to 6.3 billion in 2000.

Political and Economic Instability. Increasing populations and instability in economic and political life could reduce or cut off sources of raw materials. Vulnerability to loss of mineral and energy sources may lead to greater domestic emphasis on the production of these materials from lands in the United States.

Electronics. World population will be linked by TV networks and computers. This will lead to instant communications, greater cultural interdependence, and potential for unity and mutual understanding.

Science. Likely breakthroughs in cancer and health care, gene technology, solar and alternative energy generation, agriculture, and high technology applications will provide means to solve many foreseeable problems.

Rise of Pacific Basin. The rise of China as a manufacturing and high technology production center will shift world economic balance to the Pacific Basin.

Third World Industrialization. Rapid increase in Third World heavy industry and manufacturing and increased use of petroleum worldwide could lead to further energy crises.

Global Economy. All nations will be interdependent economically. Short-term business cycles will be felt worldwide, and moves to adjust and control these cycles through international action will increase.

Soil and Agriculture. Shifting demands of agriculture, industry, recreation and residential uses will create changes in land and water uses. Supply and demand pressures will increase on the natural resource base, prime farm land, on waterways, and forest lands by a wide range of users.

Deforestation. Continued destruction of forests in the tropics is likely as land is cleared for fuel and agriculture. Demand for wood from U.S. forest lands will increase, both to supply foreign requirements and to help balance foreign trade payments.

Pollution. Acid rain, oil spills, chemical pollution, ocean dumping of waste, and accumulation of hydrocarbons in the atmosphere may eventually lead to major extensive deterioration in forests, fisheries, water quality, and air quality. Effects on the atmosphere may cause a warming trend, increased melting of ice caps, rise in ocean levels, and climatic changes that could profoundly affect food production.

Extinction of Species. Expanding development and increasing world population will reduce areas of forest, range, and wetlands leading to further extinction of species and elimination of wildlife habitat.

U.S. trends follow:

Population Growth. U.S. population will increase from 220 million in 1980 to 260 million in 2000.

Aging. The average age of U.S. population will increase, implying greater emphasis on health care. Cultural changes will favor mature population over youth cultures. Shifts in types of recreation and levels of consumption will occur. Possible crisis in providing retirement, health care, and other benefits may lead to increases in retirement age and reduction in benefits. There will be a likely increase in immigration to provide work force.

Demographic Changes. Increase in diversity of ethnic, language, and cultural groups presages a trend to pluralism or all-minorities society from a majority-minorities society, with possible effect of greater social and political fragmentation. In California and the Southwest, Hispanic population will rise to majority status by the year 2000. Great shift of U.S. population from north central and eastern States to south, west and southwest will place pressures on resources of the land and local governments.

Rising Value of Resources. All natural resources, renewable and nonrenewable, market and nonmarket, will rise in value as demand intensifies.

Women in the Work Force. Percentage of women in the work force increased from 25 percent in 1970 to 43 percent in 1980. More than 53 percent of married women are now working full time.

Electronic Culture. There will be a cultural shift from physical space joined by the motor car to conceptual space connected by electronics. Instant communication through cable TV, televideo phones and conferencing could change paper-based newspapers, catalogs, books, offices, and shopping.

Future Shock. Today's society is future-oriented and rapidly changing. Most jobs today did not exist 50 years ago. Most jobs today won't exist 50 years from now. The rate of obsolescence in education, technology, and culture will accelerate.

Changing Values. More emphasis is being placed on personal fulfillment rather than single-minded material success. Balance between family, personal, spiritual, and occupational values and less emphasis on job as sole measure of success. "Voluntary simplicity" movement against consumerism.

Suspicion of Experts and Government. The public no longer trusts experts and demands the right to decide matters formerly left to experts, such as in defense, foreign policy, nuclear energy, and chemicals. Major shift from federal solutions to state and local initiatives. The public is demanding a role in land-use decisions that affect them.

Single Issue and Single Resource Politics. Fragmentation of political life as single issues and single-resource advocacy dominate public controversy.

Changing Consumer and End-User Needs

The consumers and end-users of agricultural research and extension information are a continuously changing clientele. Farm financial stress is being felt by many small and mid-sized agricultural operations. While the end result and production have not changed that dramatically, the makeup of producers and their agricultural activities has changed.

As a result of various trends mentioned, needs have changed as well. The demand is high for instant information. The end-user can no longer afford to wait for at least 1 year to read about current agricultural research in a printed journal. The producer needs immediate access and answers to questions on crop reports, crop prices, crop supply, pesticide application, conservation tillage, and Federal programs and regulations.

Research Results Data Base. In cooperation with the Agricultural Research Service (ARS), Extension Service program leaders have developed, designed, and implemented the Research Results Data Base (RRDB). ARS staff in Beltsville, Maryland review ARS research reports and assess their value for use by Extension education programs at the land-grant universities. Those reports judged to be practical and applicable to Extension information are placed into the Extension Service Electronic Information Network for electronic retrieval.

The Extension network is a computerized system of electronic mail and full-text-searchable data bases with users at the land-grant universities, the county Extension Services, and many of the U.S. territories Extension offices. "With the computer, we were able to speed access to research discoveries and cut through several layers of normal infrastructure," says Tom Tate, Extension Program Analyst Officer and Systems Manager of the RRDB project.

Additional data sources for providing recent research results to the data base will be included in 1986. Results are being explored from the Economic Research Service, Forest Service, Agricultural Marketing Service, National Institutes of Health, Department of Housing and Urban Development, Department of Energy, Department of Interior, Food and Drug Administration, and Environmental Protection Agency.

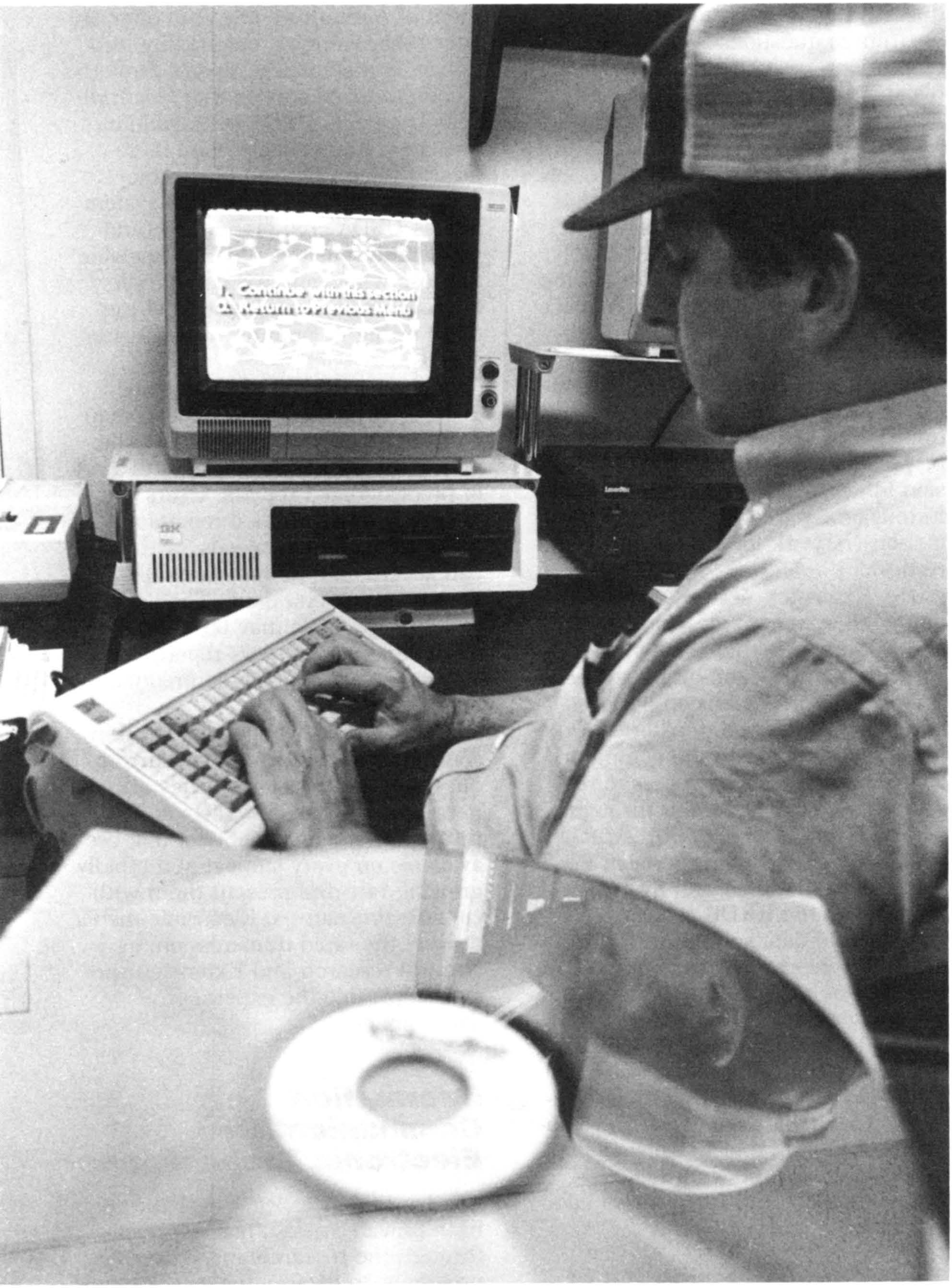
Electronic Dissemination of Information. To speed and integrate information and knowledge on tomorrow's research, the U.S. Department of Agriculture began to offer, in July 1985, its news, commodity, economic, and statistical reports through a computerized service that electronically transmits USDA perishable information immediately upon its release. Called EDI, the Electronic Dissemination of Information system makes USDA crop production (and other time sensitive reports) available to those who want and can handle large volumes of information at medium or high computer transmission speeds.

Realizing that no two users are alike, EDI has structured the system so that the user can preset a profile, giving the user instant access to a set of predesignated reports. Users can take only those profiled reports at lower transmission speeds, or they can accept data in bulk form at high speeds up to 9600 baud. The data which is available may be as brief as a five-line market news report, or as lengthy as a 40-page crop production report.

Producers and consumers need instant answers to instantly occurring questions and problems. They also need agricultural specialists to sift through the volumes of data that are available on every subject at a rapidly growing rate and present them with concise alternatives. Electronic media provide the rapid transmission; agricultural research and Extension specialists provide the expert dissemination.

Information Communication Electronic Technologies

The land-grant colleges over the years have provided assistance, especially through the research and Extension programs, to decisionmakers in many walks of life. To meet these diverse needs, many delivery methods have evolved since the early 1900's. Today,



Federal Extension Service and University of Nebraska's Cooperative Extension Service computer disc set-ups will enable farmers to create a self-help program on cash-flow planning.

in the multirevolutionary environment of technological, social, and economic changes, good supporting information is essential to good decisionmaking and learning new skills. The Cooperative Extension educational role of the future will require access to data about research findings and the efficient delivery of information. More importantly though, will be the task of teaching clientele to use and interpret data in light of the existing problems to be solved or decisions to be made.

These new information wonders, electronic communication devices, provide Extension educators with the capability of multiplication, amplification, and duplication of data. These new electronic technologies also eliminate two important access constraints—time and distance.

Most recently many electronic technologies have converged to make the sum of the parts greater than the whole. Examples of these convergent technologies are the telephone and the computer, the laser disc and the computer. Each of these new hybrid technologies advances the capability of research and extension to meet the ever growing demand for current information to enhance agriculture's management power.

Some of the new electronic technologies that will increasingly gain importance in research and Extension and are on the verge of having wider application include: 1) videocassettes; 2) artificial intelligence and expert systems; 3) interactive videodisc; 4) encoded cards; 5) compact disks; and 6) electronic networks.

Why are these technologies important? A brief examination of the changing social and consumer needs of society should make that evident.

Working at "the margin" is nothing new for researchers and extension educators. The integration of new technologies with traditional methods of program delivery has always been of high priority. What has changed in the last half decade is the rapidity of the development of informational technologies. These advances have tended to be additive rather than singular isolated cases. The need to have access to information will continue beyond the rate predicted by most experts.

Many technologies will continue to have a growing influence on research and extension. A closer examination of these will provide greater insight into the why and how of this transformation.

Estimated Household Penetration

By Product (As of Year-End 1984)

All Television	98%
Color TV	91%
Monochrome TV	70%
Projection TV	2%
VCR	20%
VDP	1%
Programmable Video Games	25%
Home Computers	13%
Audio Systems	87%
• Compact	51%
• Component	38%
• Console	23%
Telephone Answering Devices	5%
Cordless Telephones	10%
Home Radios	98%

Videocassettes. No video product since the introduction of television has had such rapid and widespread acceptance as the videocassette recorder (VCR). VCR's were selling at a pace equal to 1 million a month during 1985. What does the videocassette have to do with research and extension? If the demonstration method remains the cornerstone of the extension delivery system, then the videocassette plays an ever more important role. This technology provides a mechanism to provide demonstrations without regard to the constraints of weather, distance, time, or season.

These advantages include time and space flexibility, self-paced learning, relative lack of expense, and user friendliness.

The videocassette remains one of the prime ways of reducing program delivery costs. It also is a quality method to extend researched knowledge to an audience increasingly in need of information.

Artificial Intelligence. Artificial intelligence is being heralded as one of the breakthroughs in computer uses that will drastically change education and research, and the nature of work. Artificial intelligence defined in electronic terms is called "behavior by a machine which, if performed by a human being, would be called intelligent." A special project sponsored by Science and Education at USDA set Purdue University scientists to the task of determining the potential applications of expert systems for agriculture and the costs and benefits of widespread usage in agriculture production.

Three subsystems have been identified as having specific potential for agriculture: knowledge systems (especially expert systems), robotics, and natural language processing.

Knowledge systems. The most practical application of artificial intelligence is an expert system. An expert system is a computer program designed to reason like a human expert in some defined area of expertise which is identified as the domain of the system. Within that domain, the expert system can solve problems in a way similar to human experts. Three areas are likely to have high priority here: marketing support, pest management, and troubleshooting and diagnosis. Expert systems have particular application in financial management, personnel management, resource management, and program evaluation within the science and education system itself.

Many positive considerations must be taken into account in the development of expert systems. Expert systems transfer knowledge into computerized form, provide reasons for decisions, or conclusions, communicate with blinding speed, provide alternative decisions, improve worker safety and work flow. In the future, a growing number of expert systems will increase the reasoning power of professionals working to increase agricultural productivity and profitability.

Robotics. Robots are becoming so prevalent in industry that manufacturers are beginning to take a census of robots each year. They are tireless workers that have potential application for research and agriculture. Practical applications for robots in agriculture are replacing human labor in labor intensive tasks, improving the quality of task performance, and improving safety.

It is unlikely that agriculture will take the lead in robotic research. Most of the practical application will derive from examples in manufacturing and military uses.

Natural language processing. One of the major barriers to computer use is the amount of time and effort required to input data. Computer operating systems or programs have not always been user friendly and have had limitations in research and extension programs. The development of systems that use some characteristics of natural language processing is well under way. Natural language processing is being used in other industries and has significant potential for agriculture. A panel of experts assembled at Purdue University to explore some of the potential uses of computer natural language understanding along with voice recognition. Valuable applications included:

- Voice control of machinery, a capability which incorporates elements of robotics and has the potential for vastly increasing worker safety, particularly if the system allows the operators to shut off machines by voice commands.
- Increased ease of computer use, a facility which could indirectly improve the management of farm businesses.
- Increased ease of recordkeeping or data collection, made possible by speaking needed information directly to the computer.

General applications of artificial intelligence will become widespread in agriculture before the year 2000.

One interesting project at Purdue was the development of an expert system that will evaluate research programs. An administrator, with the aid of an expert system, can evaluate proposed research projects for scientific, economic, and institutional acceptability. The concepts in this program can be further expanded to assess research accomplishments, allocate resources, and analyze the effects of governmental policy and other agricultural decision needs. The gains made in agriculture production in the future will be tied to the wise application of information and decisionmaking.

Artificial intelligence will play an increasingly important role in research and extension programs and on farm applications.

Interactive Videodisc. Seldom does a single medium provide the potential for information delivery, educational delivery, and problem solving all in one. This is the case, though, with interactive video. An interactive video system is composed of a computer and a laser disc. The optical laser disc is used to store visual images, sounds and text just as a video tape. A laser disc 12 inches in diameter can hold as many as 54,000 images per side, and material can be found in a matter of seconds with the aid of a computer. Interactive video combines the power and design techniques of the well-known Computer Based Instruction system with the visual and audio capabilities of video recording media.

Interactive videodisc technology has multiple applications for both research and extension activities. Training by interactive video has been extremely cost effective. The use of this medium in agriculture has many practical applications. Presently a new application of the technology is helping farmers plot their own financial paths. The program under study by the Extension Service provides self-help in financial planning to assist farmers in making sound financial management decisions. It is like having a financial planner in your own office. It walks farmers through the lending process and cash flow planning while experiencing a simulated session with a loan officer. Simulation is another important aspect of interactive video.

As an information delivery device, interactive video is being valued at "point of purchase" locations. Several large lawn and garden stores have found the technology useful in providing personal service to customers. Buyers and potential buyers can learn about weed control, pest control, lawn care and management, and information about plant varieties. Latest researched knowledge can be at the fingertips of users in a manner of seconds.

Some educational experts have indicated that interactive video is the single most powerful tool in the edu-

A computer printout containing specific data about his dairy helps a Maryland dairy operator.

cational marketplace today. Wider applications of this medium will be online in research and extension programs in the near future. It is a practical way to distribute information and educational programs and deal with many of the problem-solving issues facing rural communities today. The uses of the technology will only be limited by the researcher's and extension professional's imaginations.

Encoded Cards. Many other technological developments on the horizon will affect agriculture and the integration of new knowledge in agricultural systems. Encoded cards, for example, are now being developed that can store as many as 800 pages of information. One can imagine a card, the size of a credit card, providing all the latest research on a specific subject. With the aid of an encoder (a machine that reads the card), those in need of new information on an ongoing basis will have it readily available at low cost.

Compact Disks. Another technology that is on the horizon for client use is the compact disk. Already popular in audio sound, the compact disk can be used to sort data just as effectively. A compact disk, 5¼ inches in size, can store 225,000 pages of information.

Applications of Future Electronic Information Technology

Don A. Dillman, Professor of Rural Sociology at Washington State University, suggests how some of the applications of this technology might look on a dairy farm in the year 2000 based on the multiple changes in the information age. "These changes could mean making up to the minute assessments of individual production, feed consumption and cost records for herds of genetically manufactured cows, each of which is too large to be allowed out of the milking shed. It could mean sending and receiving production records to or from anywhere on earth by instant electronic command rather than mail or personal visit. It could also mean the capability for video communication with European dairy farmers more easily, more quickly, and at no more cost than once was required to take a vehicle to a neighboring farm home, facilitated by instantaneous computer translation of languages.

It could mean receiving national and worldwide narrowcast TV programs tailored to the needs of dairy farms complete with feedback potential for instant referenda. It could mean easily locating, sorting, and identifying from massive data files the information needed to make a decision using voice rather than keyboard commands. It could even mean, through use of artificial intelligence, the designing of an entirely new way to house, feed, milk and care for cows that takes into account everything from micro farm climate to farmer temperament with the best solution being unique to each locale and farmer."

What Professor Dillman suggests for the dairy farmer can be translated to almost every aspect of agriculture production. Is Professor Dillman correct? Jim McGrann, Professor of Agricultural Economics at Texas A&M already is directing a project "Year 2000 Computerized Farm." McGrann suggests that by the year 2000 "we will be laughing at what we are using today."

The changes in information technologies are unprecedented. The information processing activities and skills of agriculture will be transformed markedly and as profoundly as any industry.

In the past, many new technologies helped to leverage the Extension professional's information, educational and problem-solving roles. These included films, slides, audio tapes, telephone, automobile, newsletters, books, and demonstrations. Today the issues are more complex and require additional information based on the research being conducted at the land-grant universities and State Experiment Stations.

Now there are new technologies to meet the needs of the times. The Extension educator of the future will leverage expertise with satellite transmission, interactive video, data bases, computers, videocassettes, audio and videoconferencing, electronic mail, video text and more. The researcher and Extension educator of tomorrow will be far different from today. As those individuals remain the fulcrum between needs and educational systems, electronic technology will be at the forefront driving the change.

Agricultural Agent of the Future

David W. Dik, *assistant director, Cooperative Extension Service, Cornell University, Ithaca, NY, and* Charlotte B. Travieso, *supervisory computer systems analyst, Extension Service*

"Could a computer replace your county agent?" *The Farm Computer News* (October, 1985) asks.

"Computers are a tool, a good one, of the county agent's trade" says Vivan Jennings, Extension Deputy Administrator for Agricultural Programs. "We're going to need good minds in people to interpret data and to provide additional analysis of information transmitted by computers," adds Kenneth Bolen, Director of Extension at Colorado State University.

Following is a future scenario, a look at the Agricultural Extension agent's office of the future:

It is 8:30 a.m. on Monday, May 10, 1990. Extension Agent Terry arrives at the office. Terry remembers how the office looked when it was filled with the cabinets and piles of paperwork. Now there is room for a conference table, some chairs, teleconferencing phone setup, and, of course, the office computer, its communications equipment, and a large screen television. The worktable is neater than the old desk used to be. Terry rarely uses a typewriter. The telephone and associated electronic media are used to communicate with clientele.

Portable Computers, Electronic Mail, Stored Voice Messages. The first thing Terry does is to connect a portable microcomputer to the county computer and retrieve the voice and text electronic messages which were received overnight. Since the telephone company converted to digitized voice signals, the office computer now stores voice messages.

Terry uses the office computer to check the day's appointment calendar and scan voice messages. Harold has a question on planting seed varieties whose germination will not be inhibited by the herbicide applied last spring. Because the voice message is digitized and stored in the office computer's memory, Terry is able to readdress the voice message to the university subject matter specialist along with a priority request for a quick response. Terry adds a note describing the land area and supplying the chronological data that the specialist needs to answer Harold's question accurately.

National Computer Network. Terry also sets an acknowledgment-requested clock which will return a notice if the specialist has not retrieved the message within a specified time. If the specialist at the land-grant school is unavailable or cannot answer the question quickly, the problem can be forwarded, via the national Extension network, to other scientists and specialists who are knowledgeable about herbicide use.

Terry is impressed with the capability of the technology and communications equipment in the county office. It can forward a farmer's question instantaneously to people with experience and expertise in all of the U.S. land-grant schools. Some questions raised by clientele also are answered by researchers working with private companies, since the network extends beyond the public sector to researchers at private corporations.

After handling the overnight voice messages left by clientele, Terry checks the electronic text messages. Terry types responses to some and adds voice annotation to others. Terry addresses the responses, including spoken comments, to the appropriate clients. Next, Terry teleconferences with agents in six other counties to discuss a report due at the state office at the end of the week. The other agents agree that Terry will summarize their suggestions and send them, by voice message, to the committee chair. The chair will listen to the suggestions and decide how to incorporate them.

Teleconferencing. Terry and the other agents like being directly involved in the decisionmaking process for the report. They are confident the comittee chair will forward their ideas, along with the full text of the report, to the state specialist, who will be able to complete this report in a few days. Previously, reports were exchanged through the mail to be revised and retyped before being submitted for final approval. This process took 2 to 3 weeks instead of 2 to 3 days using this technology.

Terry next checks the day's current and forecasted weather maps. They were sent from the land-grant school the previous night and were stored in the county computer. Terry downloads the weather information to a portable computer that can be carried throughout the county.

Expert Systems. Terry notices that the county computer is busy polling the remote weather stations in this area of the State. The computer automatically collects, stores, and forwards the data to the university computer. Weather research information is continually updated and transmitted to the main computer, to be used by the climatologist to update forecasting models for local weather. This practical agricultural application is one result of research in artificial intelligence and expert systems.

A freeze alert is forecast for certain areas of the county the next morning from 2 to 5 a.m. Terry selects from the county computer a list of fruit growers in the area of the freeze alert, along with their phone numbers. Then Terry dictates a warning message and instructs the computer to call each grower and deliver the message. The computer dials each number, waits for an acknowledgement code, and repeats the message alerting each grower to monitor for freezing conditions tomorrow morning. The county fruit growers subscribe to the service. Extension pioneered this service, which combines research improvements in weather forecasting with timely information delivery to county fruit growers.

Mobile Phones. Terry drives to a master food preserver volunteer training site. The trip takes about twenty minutes. During the drive, Terry uses the portable car phone to call the four county Food and Nutrition aides to discuss their game plans for the day. Conference call capability makes it possible for all of them to be on the line simultaneously. At the farmers' market, Terry coordinates the master food preserver volunteer trainers and leaves the special software that was developed to help the volunteers analyze the nutritional value and cost effectiveness of home processed foods.

On the road again, Terry uses the portable car phone to call clients who have left messages on the office computer. The first reply is quick: "Yes, the 4-H meeting is Tuesday, and thanks again for your volunteer support." The second is to a more complicated question from a farmer who has an insect outbreak. Terry pushes a button to capture this message and indexes it so it can be passed to the electronic mail system for later reference.

In-Field Problem Solving. The third call is an appointment confirmation to visit a farm to see a newly seeded alfalfa field. The farmer wants to know why the seed failed to germinate. Terry arrives and finds the farmer's problem is unexpectedly complex. Using the portable computer and the mobile radio-phone, Terry accesses the university's computer, retrieves valuable alfalfa seed data, and immediately shares the data with the farmer.

The university also provides a decision-aid program to help the farmer decide whether to participate in a government program to reduce the production of soybeans in the region. After seeing the financial figures, the farmer chooses the program. Terry then transmits the farmer's name, address, and decision to the university. This information will be used later when the specialist sends a questionnaire to the farmer. Was the recommendation provided by the Extension Service beneficial? What benefits were received? What economic impact did the decision have on the farmer's business? Data collected by this method will go into a research data base for agricultural economists to use in tracking historical impacts of government policies and programs on farm income.

Interactive Videodisc. At 1:00 p.m. Terry drives back to the office. At 1:30 p.m. the 4-H crop and livestock judging teams come into the office to practice livestock and crop judging for the state contests in July. Terry instructs the 4-H members on the use of two new computer-controlled videodisc players. To acquire judging skills, the members use judging lessons prepared by Terry and the livestock specialist. The videodisc lessons save time because farmers no longer have to host the livestock judging teams for practice on their farms. Terry no longer has to transport the teams from farm to farm to make sure that they get the experience needed for state competition.

The computer-controlled videodisc players are programmed so an individual can view three or four classes of animals, select a placement of those animals, and key the selection into the computer for each class. If the judging candidate has made the right selections, the computer plays back segments of the videodisc with instructions on the quality points of one animal over the other. If the candidate has made the wrong choices, the computer points out the animal's quality characteristics that may have been overlooked. This program also displays the production records for each of the animals so that style and quality points can be related to actual production capacity of the animal. The learning experience is valuable for these future members of the agricultural production segment of society.

Terry checks the list of people who have stopped at the office technology center to use the programmable videodisc players to find information and to solve problems. Many questions relate to personal finance and financial management alternatives. Terry forwards to the family living specialist at the university a message indicating increased use of programs on family resource and financial planning.

It is now 3:30 p.m. Terry puts a message on the dial-access system and in the computer mail system to announce the countywide farm field days scheduled for the next month. The message is automatically sent to the commercial videotext companies that supply information, market, and banking services to farmers in the county. Using commercial videotext companies and the county computer makes it easy for Extension to inform clientele about upcoming events in the county and target information to people who might be interested.

Terry finishes the workday by reviewing the secretary's progress and by looking at appointments and projects for tomorrow. Terry then accesses the national Extension plan-of-work data base to see if other States are working in priority areas similar to those in Terry's county.

While closing up the office, Terry notices the worn briefcase behind the door. Smiling, Terry thinks, "I used to take that thing home loaded with papers many a night. All I need now is my computer at home and here at the office. I'm able to perform at a professional level with new tools and feel proud to be a part of the Extension system."

Information Centers: From Irradiation to Biotechnology and Beyond

Maria G. Pisa, *leader, Special Services and Communications, Education and Information Staff, National Agricultural Library, Beltsville, MD*

Modern agricultural research is a dynamic enterprise requiring the digestion of large amounts of information to help give it focus, direction, and justification. As the Nation's storehouse for that information, the National Agricultural Library (NAL) answers a steady flow of inquiries. From scientists and technicians across the country, come inquiries like these:

- A scientist in Texas conducting research on polyculture of channel catfish and freshwater prawns in a 10-acre pond is in need of the latest studies on the subject. Her continuing research may lead to increased production of farm-produced fish to help satisfy international food needs and increase farmer income.
- A U.S. Department of Agriculture (USDA) research administrator attempting to determine risk factors in the potential release of genetically engineered organisms into the environment requires an exhaustive search of the literature. This information will help guide the Agricultural Research Service in formulating policy for future biotechnological research.
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- In Oregon, a university faculty member serving on a national task force focusing on emerging industrial crops requests data on levels

of investment in new crops research. The data supplied reveals a minimal national investment of resources. This information is supporting the development of industrial crops vital to the economy.

- A team of USDA scientists petitioning the Food and Drug Administration to allow the irradiation of poultry meat at medium doses questions the potential of Clostridium Botulinum growth in the irradiated product. A comprehensive bibliography of published research findings substantiates their concern and offers a solution to the

Subject-oriented information centers at the National Agricultural Library in Beltsville, Maryland, support research conducted at adjoining USDA research facilities and throughout the country.

problem: controlled refrigerated storage.

Information centers at NAL are supporting researchers daily by supplying information that will lead to answers to these and other questions. Inquiries in subject areas such as biotechnology, aquaculture, critical materials, food irradiation, and food and nutrition are referred to information center coordinators who stand ready to use the world's information base to deliver the documentation vital to a scientist's research.

Life Cycle of a Question

NAL each year responds to more than 30,000 requests for information exclusive of the more than 150,000 requests received solely for documents. A portion of these questions will be reference research requests and will be directed to an appropriate subject-related center. Once there, they will be carefully analyzed and the most effective response determined.

Within a given center a wealth of information is available, and, literally, at the fingertips of a librarian or technical information specialist. Through the course of answering a complex research request, for instance, an array of computerized databases will be tapped to track the world's published literature on a given topic, locate research in progress, and cull statistical data. Sophisticated search strategies will be designed to retrieve precisely the information needed, in the format in which it is needed.

Relevant documents will be selected and photocopied from NAL's expansive collections or borrowed through interlibrary loan. A carefully constructed support network of subject area experts and organizations will be activated for referrals. Private files compiled ad hoc will be scoured. Finally, a detailed information package reflecting a potpourri of inputs will be assembled and readied for delivery.

Once a reference inquiry is completed to the satisfaction of the user, it will take on a new dimension within an information center. For the center's coordinator, the question itself as well as the answer becomes information—information which will likely serve as the building blocks for expanding the resources of the center and NAL. The inquiry may be used as the basis for evaluating the strength of NAL collections in a particular subject area. How effectively was the question answered through on-site collections? Are core journal titles missing? Have important texts or directories been published recently that the Library should acquire? Is the best information contained in the private library of a noted expert or housed at another library, and should the center seek to duplicate it on microfiche, laser disc, or some other technology?

The question's interest to a wider audience also will be considered. If the inquiry is on a timely topic likely to generate numerous requests for the same information, a *Quick Bibliography, Special Reference Brief,* or *Pathfinder* may be developed.

These information products direct users to the available literature and other resources with instructions for how to obtain the information. Other, more extensive bibliographies also may emanate from the original request.

Information Centers—Back to the Future

Information centers are a relatively new concept at NAL. Why information centers? What is the impetus behind their creation? And more importantly, how will their services differ from those the Library has traditionally provided? To answer these questions, let us digress a moment to the past.

Bill Carnahan, USDA

Outreach activities such as attendance at professional meetings and trade shows heighten awareness of information center products and services.

When Isaac Newton, the first Commissioner of Agriculture, outlined the program for a new Department in 1862, he placed near the top of his list the establishment of an agricultural library. He believed that a rich mine of knowledge would be accumulated through exchange, gift, and purchase. With the blessing of Commissioner Newton and an appropriation of $4,000, 1,000 books were transferred from the Agricultural Division of the U.S. Patent Office. These volumes formed the nucleus of what was to become one of the most extensive collections of agricultural literature in the world.

The Library, from its inception, has been the principal agency in USDA for the acquisition, storage, and dissemination of scientific and technical information. A primary objective of the early library was to develop collections and provide services to support the Department's programs. Since research has always been a key program, the Library grew into a major research library supporting not only all USDA agencies, but other related government activities as well.

As the Library's collection and services steadily expanded, so did its reach. The Department's agricultural library rapidly became the Nation's agricultural library with a collection of 1.8 million volumes including 25,000 journal titles. Today, NAL is one of the largest agricultural libraries in the world. Nationally, it is the coordinator and primary resource for a network of State land-grant and field libraries that work together to deliver information to all sectors of the population—from the researcher to Extension workers, farmers, lawmakers, industrialists, students, private citizens, and others with an interest in agriculture.

Internationally, it is the designated U.S. center for the worldwide agricultural information system sponsored by the United Nations Food and Agriculture Organization (FAO). Roughly 60 percent of its collection is of foreign origin. Most of these materials are obtained through an international exchange program that brings some 100,000 items into NAL each year. A tradition of special donations and gifts by individuals and private organizations complements this process.

Over the years, NAL has become many different things to many people: an internationally recognized research library; AGRICOLA, a computerized database offering worldwide access to more than 2 million references to books and journal articles in the NAL collection; Special Collections, housing rare books, manuscripts, oral histories, photographs, and the donated private libraries of eminent scientists and administrators; CALS, an automated system which keeps USDA researchers alerted to the latest literature in their field of interest; the site of investigations into the use of laser technology and experts systems that are changing the means by which information is stored, distributed and used, and much more.

But for all of this, NAL remains a dynamic organization continually searching for ways to enhance its responsiveness to its current clientele and in the process reach new user groups. To help accomplish this goal, the Library decided to create information centers on various subjects and in doing so work with support groups in industry, Federal and State agencies, and the scientific community to establish these centers as national focal points for information dissemination activities. The Library's unparalleled collections would provide the bibliographic and informational foundation from which these centers would grow.

Structure of an Information Center

Recognizing that agriculture is a broad-based discipline, several factors have determined what subjects will initially be covered by information centers. These include: 1) Congressional mandate; 2) priorities within USDA; 3) availability of subject expertise on NAL staff; and 4) financial support and interest by agricultural trade and professional organizations.

While information centers are not physically isolated units—materials are housed at NAL within the regular collection—the designation of a topic as an information center will effect increased activity on several fronts including:

Collection Development. Strengthen the identification and acquisition of new books, journals, audiovisual materials, and computer software. Locate and acquire outstanding historical collections and oral histories that will help enrich the national collection. Enter these acquisitions into AGRICOLA and other computer data base systems, making materials available nationally and internationally through interlibrary loan.

Information Products. Develop researcher and consumer finding aids such as directories of experts, institutions, associations, and current research as well as guides to the literature such as subject bibliographies and pathfinders.

Outreach. Increase the awareness of information center products and services through presentations to interested organizations, attendance at professional meetings and trade shows, specialized brochures and pamphlets, and traveling exhibits.

Public Services. Provide expanded information services for responding to consumer and scientific inquiries through appointment of one or more NAL staff to coordinate a center's response network.

Information Centers at a Glance

Since the introduction of the information centers' concept, several centers have been established and are operational. Some of their varied activities are:

Food Irradiation. Interest in the uses of food irradiation to control insect and microbial contamination, prevent disease, and keep food fresher longer is growing among consumers, the food industry, and government. This interest has been stimulated by public concerns over potential health hazards associated with the application of postharvest chemical treatments to food commodities. Public and private demand for information about food irradiation has spurred Library efforts to centralize and enhance access to the large body of food irradiation materials.

A direct result of these efforts has been the acquisition of several collections from the USDA Eastern Regional Research Center in Wyndmoor, Pennsylvania. These include the Raltech studies on the nutritional and toxicological properties of irradiated poultry meat and the findings from the Natick Laboratory and U.S. Army Test and Evaluation sponsored research on the effects of meat irradiation.

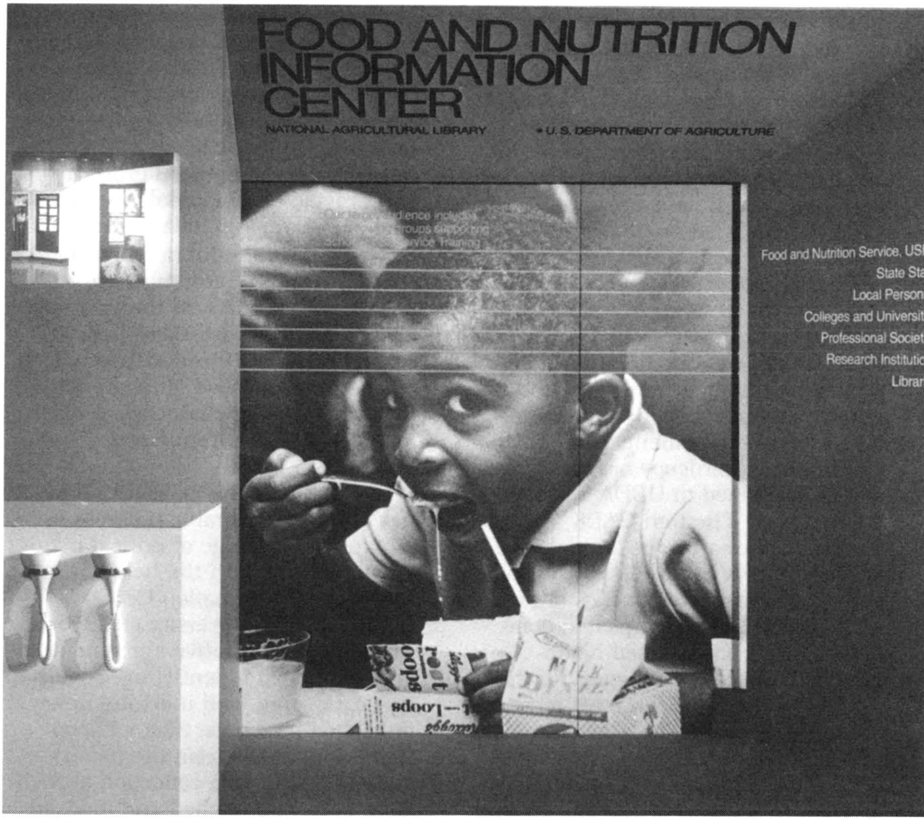
Together these collections represent research conducted by leading authorities in government, industry, and academia since 1945. These collections are particularly valuable for their inclusion of unpublished reports, supporting documents, and brochures. The acquisition of other toxicological studies is being pursued nationally and internationally through exchange agreements with foreign countries. The Center is working with the Agricultural Research Institute's Special Committee on Irradiation Processes for Agricultural Products, the Coalition for Food Irradiation, and other organizations to help direct future expansion and to identify additional sources of support.

Aquaculture. Based on the National Aquaculture Act of 1980 calling for the establishment and maintenance of an information service for aquaculture, this Aquaculture Center has steadily increased its resources.

In collection development, the Center has acquired microfiche copies of the Virginia Institute of Marine Sciences' (VIMS) sizable aquaculture collection. This document collection includes journals, books, reports, theses, proceedings, newsletters, and English translations of foreign papers. It provides coverage on the cultivation of marine, brackish, and freshwater organisms including disease, economics, engineering, food and nutrition, and legal aspects. The collection is particularly useful for its short, "how-to" articles and news items. And, perhaps most importantly, the VIMS acquisition places NAL in the position of being able to act more adequately as a document delivery backup for some of the more fugitive materials in this field.

The Center also has made inroads into streamlining worldwide aquaculture information collection and dissemination responsibilities. In an arrangement with the National Oceanic and Atmospheric Administration (NOAA) and the FAO's Aquatic Science and Fisheries Information System (ASFIS)—an international bibliographic service covering the world's literature on aquatic sciences and fisheries—ASFIS is supervising all indexing of aquaculture information. NAL supports ASFIS by ensuring a flow of aquaculture-related documents from its own acquisitions to be abstracted, indexed, and entered into the ASFIS database. This arrangement will permit a more thorough coverage of the literature of aquaculture than was previously available in AGRICOLA. It also will free NAL staff to provide better coverage in other areas.

As interest in aquaculture continues to accelerate, so does the demand for information. To help cope with the daily barrage of inquiries, Center staff are in the preliminary stages of developing an expert system that may someday perform some of the activities which now lie within the domain of the reference librarian. In the not-too-distant future, a would-be aquaculturist eager to start a catfish farm in Mississippi may be able to sit down



Food and Nutrition Service

The Food and Nutrition Information Center serves as a model for new information centers.

at a computer work station and, through a series of menu-driven questions and linkages with other systems, receive much the same in-depth service that has come to be expected from a reference specialist. Not as warm and congenial perhaps, but hopefully equally effective.

For the immediate future, however, the Center has several bibliographies and short guides to the literature available to assist users. Titles include general aquaculture, shellfish and milkfish culture, and salmon ranching.

Biotechnology. The Biotechnology Information Center was formed as part of a continuing effort to complement and support research priorities in U.S. agriculture. Biotechnology is creating new opportunities throughout the agricultural sciences—finding solutions to problems that were previously unapproachable. As the results of promising new research are reported, it becomes imperative that documentation is captured immediately and available for use by the scientific establishment.

The staff of the Biotechnology Information Center are working to ensure that all relevant biotechnology literature is indexed and accessible worldwide through appropriate bibliographic services. With the cooperation of USDA scientists and other biotechnology experts, Center staff have launched an intensive evaluation of NAL's present collections and future acquisitions policy to meet the challenges of this still-emerging field.

For USDA personnel, keeping posted on recently published biotechnology literature is possible through a CALS (Current Awareness Literature Service) system search of Telegen—a database of scientific, technical, and socioeconomic information related to genetic engineering and biotechnology. Full-text documents from Telegen in either hardcopy or microfiche can be furnished to USDA and non-USDA users. Through CALS, a scientist establishes a profile consisting of keyword terms to express a particular subject interest. The profiles are regularly compared with updated computer tapes from selected bibliographic databases producing for the scientist a listing of the most recent literature published on a given topic.

Related efforts of the Center have been the production of a list of NAL journal holdings in biotechnology and the preparation of subject bibliographies on the biotechnological aspects of plants, animals, soils, risk assessment, molecular techniques, food production and application, and biomass applications.

Critical Agricultural Materials. The Critical Agricultural Materials Information Center was created in response to agriculture's new and emerging role as a supplier to the Nation's industrial base. This Center's information collection, dissemination, and preservation activities focus on the use of domestically produced agricultural products that have the potential for providing industrial materials of vital importance to the economy, the defense, and the general well-being of the Nation. Where the United States has a high degree of reliance on foreign suppliers for certain key products, research into the production of crops that can substitute for these commodities has taken on a new urgency. Some of the products from these nonfood crops that can provide raw materials for industrial application include natural rubber from guayule; lubricating oil from jojoba; nylon from crambe; paper from kenaf; lauric acid from cuphea for the soap and detergent industry; surfactants from meadowfoam; plasticizers from rapeseed; and chemicals, industrial carbon char, carbon black and alcohol fuels from forest products.

In support of this research, NAL has made considerable progress in enhancing coverage of critical materials literature with the help of the Arid Lands Information Center (ALIC) at the University of Arizona. Through a cooperative agreement, area experts are identifying, acquiring, cataloging, and indexing newly published materials. Also, noncopyrighted materials from the extensive guayule and jojoba collection at ALIC have been microfiched and indexed with the support of the USDA Office of Critical Materials.

The Center operates in consultation with the Office of Critical Materials to develop bibliographic products and provide services to advance the research and development of these emerging crops. *Quick Bibliographies* are available from the Center on a range of farm and forest crops with industrial potential including Chinese tallow tree, crambe, cuphea, kenaf, lesquerella, lunaria, stokesia, and vernonia.

Food and Nutrition (FNIC). This highly successful Information Center serves as a model for new ones. The Food and Nutrition Service and NAL in 1971 founded FNIC as a national repository of educational and training materials for use by persons in USDA's Child Nutrition Program (school lunch, child care, etc.). The 1977 Farm Bill established FNIC as a resource for State education agencies and other interested persons.

FNIC serves many types of users including researchers, educators, school food service personnel, cooperative extension agents, and consumers. It can help a school administrator implementing a program of nutrition education or a food service manager interested in effective techniques for supervising personnel. The Center maintains an extensive collection of audiovisual materials (e.g., films, videocassettes, posters, games) that deal with human nutrition, food service management, and food science.

Reference services are provided by a staff of registered dietitians and nutritionists. FNIC also is a national demonstration center for food and nutrition microcomputer software with over 100 programs on topics such as diet analysis and nutrition education available for review.

FNIC, in addition, contributes the food and human nutrition portion of the NAL's AGRICOLA database which includes asbtracts. *Pathfinders* developed cooperatively with the Pennsylvania State University list appropriate information resources for consumers, educators, professionals, and others on a wide variety of topics.

Over the years, several selected bibliographies have been published. As a result of two of the publications, FNIC has become the national depository of all training and education materials developed by USDA's Supplemental Food Program for Women, Infants, and Children (WIC) and the Nutrition Education and Training Program.

FNIC works closely with the Food and Nutrition Service, Human Nutrition Information Service, and Extension Service of USDA, as well as with various agencies of the U.S. Department of Health and Human Services, the March of Dimes, the Society for Nutrition Education, and the American Dietetic Association.

The Center has established a dissemination network with State representatives of the American School Food Service Association and the State nutrition educators for WIC.

Information Centers . . . Preparing for the Future

The identification of high priority topics for inclusion in the Information Centers Program is an ongoing process. Suggestions and recommendations are considered from all sources. Centers soon to be established include Alternative Farming Systems, Fibers, Horticulture, and the Family.

Much of the work so far has been done with existing NAL staff and funds. Additional resources will enable NAL to expand its activities even further.

As NAL plots a future course for its information centers, the needs of research remain a prime consideration just as they were more than a century ago. But unlike the previous century, the Library has moved beyond its traditional role as primarily the keeper of the Nation's agricultural knowledge. The information explosion and the advent of new techologies to cope with it has challenged us to mobilize the knowledge collected, and to integrate and repackage it to make it more meaningful to the people that use it.

In preparing to meet the information needs of research in the next century, specialized information centers will offer a forum for librarians and scientists to explore the complexities of information and to cooperate in the search for advanced methods of communicating the wealth of new agricultural information issuing from research centers around the world.

New Technologies: Computerizing the Future

Robert W. Butler, *leader, Training and Education, National Agricultural Library, Beltsville, MD*

The National Agricultural Library (NAL) is both the library of the U.S. Department of Agriculture and the Nation's ultimate research library for agriculture. With its collection of 1.8 million volumes of books, journals, and reports, and with specialized information centers on a variety of subjects such as aquaculture, biotechnology, food irradiation, and critical agricultural materials, NAL provides both broad and selective, indepth service to researchers, educators, and practitioners.

The Library has intensified its efforts to enhance and expand its information-providing capabilities by testing the exciting possibilities of the new technology, including computer-based and video technology, both often coupled with recently developed and developing laser technology, and artificial intelligence software.

Electronic Database

Computer technology has been in use for some years at NAL. Computer terminals are in frequent daily use, particularly in the reference area of the Library, for searching computerized, online databases, usually the AGRICOLA database, prepared by NAL in computer-readable form since 1970. AGRICOLA consists of citations to books, periodicals, and technical reports and of articles in journals, proceedings, and books in the field of agriculture and related subjects. Over 2 million citations are in the database, with about 100,000 citations added each year.

Two commercial systems acquire the AGRICOLA database and make it available to their online customers. One is the DIALOG Information Retrieval Service, Inc., in Palo Alto, California, now providing access to more than 220 databases in all subjects, and the other is BRS Information Technologies, Latham, New York, with more than 90 databases. These databases can be searched using a computer or terminal communicating through telephone lines from anywhere in the country and, indeed, the world.

Besides AGRICOLA, two other major agricultural databases available online are the CAB database, prepared by the Commonwealth Agriculture Bureaux, United Kingdom; and the AGRIS database of the Food and Agriculture Organization of the United Nations, Rome, which contains records prepared in various countries throughout the world. NAL provides the largest portion of the AGRIS database.

Computer Technology

Microcomputers or terminals and associated monitors and printers are used by the Library's reference staff to perform searches as requested through mail delivered not only by the post office but also over electronic mail systems, such as DIALCOM, to these same computers. Interlibrary loan requests are sometimes received in the same manner. The computers are used by both the librarians and technical-clerical staff to prepare letters or reports with word processing software, such as Wordstar; to prepare budget cost statements using spreadsheet software, such as Lotus; or to prepare listings such as that of the Library's exchange partners with database management software, such

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An instructional videodisc system helps orient users to the National Agricultural Library.

as dBase III.

To support and expand effective use of computers, NAL's Food and Nutrition Information Center recently established a demonstration center for food and nutrition microcomputer software. Over 120 microcomputer programs offered include packages on diet analysis, food service management, and nutrition education. Patrons are provided the opportunity to spend "hands-on" time with the programs on the Center's microcomputers in its subject area.

Building on its initial success in the nutrition field, the Library plans to broaden this concept to create a national demonstration center for agricultural microcomputer software. There, its many users—scientists, researchers, farmers, Extension Service personnel, teachers, economists, administrators, and others interested in agriculture—can evaluate software for application to their work and be aided in making purchasing decisions.

Laser Technology

NAL has been evaluating and is expanding its use of the recent and rapidly developing laser optical disc technology. Two systems on hand illustrate two different applications of laser disc technology, using Pioneer LDV-1000 laser optical disc players and the IBM-PC microcomputers.

Laser Optical Discs. One system is the NAL orientation laser disc used to view an NAL orientation course, prepared in a relatively early phase of this technology. It includes a floppy disc with menus, text, videodisc frame numbers, and programming; and a laser videodisc with about 200 still pictures of NAL, as well as motion video taken from an earlier NAL orientation videotape.

An experimental course prepared by NAL staff uses this same NAL orientation disc to instruct in the makeup and use of the AGRICOLA database. The course adds questions and scores the student.

A videodisc contains about 54,000 frames, each of which can contain one still picture or graphic; one-half hour of motion will occupy the entire disc. The images (or text, as described later) are recorded on a thin, metallic surface as pits burned in by a laser beam. A thick plastic coating covers the foil-like recording surface, making the disc very durable. The player reads light reflected from the pits as the disc spins at 1,800 revolutions a minute. The contents of the videodisc must be indexed and recorded so you know what is on the disc and where it is (i.e. frame number for a still and beginning and end frames for motion).

The NAL collecting policy is extending to commercial videodisc materials such as Control Data Corporation's *Feeder Pig Production and Management Course* with nine videodiscs. As an example of the material on the discs, one titled "Baby Pig Management" shows farmers giving shots, docking tails, notching ears, and so forth of pigs within 7 days of birth. The discs support textual materials, primarily the *Pork Industry Handbook (PIH)*. Three floppy discs provide games and questions to assure that the material has been learned. A guidebook leads users through the course.

NAL Full Text Laser Discs. The second computer-laser disc system deals with text, in digitized form. The system includes a microcomputer with PCIX operating system, a 20 megabyte hard disc, a laser disc player, a black box serving as the interconnecting device, a computer monitor, and a video monitor. The 12-inch laser disc contains approximately 2 million characters of text plus pictures, drawings, and graphs from the *Pork Industry Handbook (PIH)*. It contains 200,000 AGRICOLA records. This type of disc is capable of holding 800 million characters (around 150,000 single-spaced typed pages, or 500 books of 300 pages each on one side of a disc). The user is guided by menus in using the system. Search software stored on the hard disc makes possible retrieval of all the paragraphs containing any word, or combination of words, in the text.

When a search is done, the first occurrence of the text matching the search words appears on the computer monitor and may be printed out on an attached printer, or the next occurrence may be requested. Pictures or graphs accompanying the text appear on the attached video monitor.

Because of the large capacity of the 12-inch laser disc, NAL is continuing its investigation and use of these systems for storing and accessing full text of publications. NAL is preparing a second disc that will contain the full text and pictures or graphics of 13 USDA and State Extension Service publications. Land-grant university libraries and State Extension Service directors have been asked to participate in the project, providing feedback on the use and effectiveness of laser discs for disseminating agricultural information. Hardware required for this full text disc system and software for system operation and for searching the text are: a microcomputer with 512 kbytes of memory with monitor and mono-adapter card; a laser videodisc player; a controller with interface card; monochrome display monitor; parallel printer; and search software.

The system will work like the earlier system described, providing menus to guide users through the process of searching for any word or combination of words in the entire text of any publication on the disc to find information in the form of text or pictures, drawings, or graphs contained there.

Effects of the Technology

The use of these technologies is changing the ways information is provided in the Library. Computerized databases are replacing printed indexing and abstracting tools and data compilations as sources for finding information. The use of computers for electronic mail, word processing, database management, and spreadsheets is making faster and more flexible receipt, processing, and delivery of information requests, services, and products. The laser disc technology offers unique advantages in education and training and for storage and access of text and other data.

NAL continues to lead in the development and applications of the technology with more projects under way and planned.

AGRICOLA Instruction System

The education disc system described is an early and straightforward application. NAL has begun working with the University of Maryland (University College, Center for Instructional Development and Evaluation) to design, produce, and evaluate an interactive course for instruction in the searching of the AGRICOLA database online or with reference to a version of the database being placed on CD-ROM (described later).

This course will contain many tracks for the user to follow and choices for the user to make; text for the course will be on computer floppy disc, with motion videos, still pictures, graphics or animation and sound residing on a laser video disc for access by the course as needed. The system is intended primarily for one-on-one use, but also may assist an instructor. The advantages of these computer-laser disc courses are the direct user interaction with and control of the system and the motivation and interest created in the user by the use of motion and still pictures and graphics.

The student using this system might be an information specialist, an extension worker, or a research scientist, and might want only an understanding of what AGRICOLA is and what an online database is, or understanding sufficient to do an indepth search. The course might begin with an invitation to learn about AGRICOLA, offering the following options: (1) Explanation of the AGRICOLA database, (2) brief instructions on searching the online AGRICOLA database, (3) detailed instructions for in-depth subject searching in the online AGRICOLA database.

If you key in (2), the system then might ask whether you need to go through the protocols to access either the DIALOG or BRS system, whether you want instructions and samples of searching by author, or by title, or by subject. Should you now choose the DIALOG protocols, the system might show in detail the words to use to get into the system, responses from DIALOG, and dealing with problems that might come up. It may run through a video of someone actually using a terminal and getting into the DIALOG system and accessing the AGRICOLA database (among the 200 or more in the system). Should you wish at any time to go to the next or any other part of the course, you would key in the appropriate instruction to the system, even in the middle of a lesson. You can tell the system to end at any point.

In this way, the system guides the student through a lesson on whatever aspect of searching the AGRICOLA database the student chooses. One of the great benefits of this system is the ability of the student to look at only those parts of the courses of interest, even limiting the search, if desired, to specifics such as what AGRI-

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This picture of woodcutters at a turn-of-the-century lumber camp in Montana is part of the Forest Service historical photo collection stored on a laser videodisc for preservation and retrieval at the National Agricultural Library.

COLA category codes are, what BRS is, and how to search by date of publication. The student may, on the other hand, go through extensive lessons such as how to search in the DIALOG online system or how to find all there is on a subject.

CD-ROM

Another high technology application that interests NAL is CD-ROM (Compact Disc, Read Only Memory), using 4¾ inch discs, the same kind as audio compact discs, increasingly popular as media for music. The full text of the AGRICOLA database in digitized form will be mastered on a number of CD-ROMS. The disc player will be connected to a computer, using software enabling retrieval by any word in the records.

The CD-ROM has a capacity of about 540,000,000 characters. Players are now being produced that are small enough to fit in the space occupied by a full-size, floppy disc drive, so the CD-ROM player may be well situated right in the computer itself. Some applications might require several players (for accessing large database occupying several discs) or a juke-box-type mechanism whereby one of several discs is automatically put in the player and then automatically removed and replaced with another.

Searching the AGRICOLA database on an online system, such as

DIALOG, you may find the system down or slow, and you have to pay for line use, for use of the database, and for each citation brought up, whereas with the laser disc system you have immediate and sure access with no costs other than for subscribing to the database.

Computerizing Text

Another technology that interests NAL concerns the manner of getting information into a format the computer can read. A national standard is now being developed that would establish a standard format for keystroked data to be used throughout the country. The Library had to rekey the *Pork Industry Handbook* from the printed version—an expensive process. In creating a second full text disc, the Library will, at least in several cases, save rekeying by using titles that have already been digitized and where photocomposition tapes are available.

The Smithsonian's National Air and Space Museum also is developing a system using similar technology with impressive results. This system scans the page of printed text with a camera, digitizing the image of the page. From the image, the words in the text itself are then digitized. The digitized text stores the images and indexes on an optical disc. A software system provides access to each word of the text, which can be printed out as wanted.

NAL is investigating this system for possible storage of publications of State Experiment Stations and Extension Services, now being microfilmed, or for preservation of publications in the NAL collection. The advantage is rapid and inexpensive capture of the text in digitized form, together with the usual optical disc characteristics of storage of large numbers of publications on one disc and retrieval by any word or words in the text.

Photo Collection on Laser Disc

NAL has acquired the Forest Service historical photo collection, the largest in the world on the subject of forestry. NAL is working with the National Archives and the library of the University of Maryland on a pilot project for putting 54,000 of the 500,000 or more photos on one side of a laser videodisc, its capacity. The disc will be indexed so that the photos can be accessed by subjects.

To use this system to view photos on lumber camps in the 1890's, you would sit at the computer, look up a topic such as "lumber camps," get a list of photos under that topic, and then automatically view them on the screen. Each photo on the disc is nearly as clear as the original print. You avoid going through files of photos and handling the originals. When you identify a photo you really need to see in the original print, you tell the attendant who retrieves it for you.

Expert Systems

Artificial intelligence is another area of high interest and activity. It includes robotics, pattern recognition, games, computer vision, speech recognition and, the one NAL is developing, expert systems.

Expert systems are a class of computer programs that mimic the advisory work of human experts. NAL is working on an expert system that will support and complement the work of a reference librarian, answering questions, or guiding a user in finding information on a subject, either specific data or citations.

The system will guide you with menus and questions, as follows: from an initial menu listing different subjects, you might choose "drip irrigation." When the system asks whether you want specific data, citations of books and journals, lists of people, or lists of manufacturers or of vendors, you choose vendors. When it asks "vendors of what?" again providing a menu, you pick suppliers of equipment. Then "what type of equipment?" you choose supplies for home gardens; "in what geographic area?" you pick the whole United States. The system then might provide a list of 10 suppliers in different parts of the country with name, address, product name, and telephone number for each.

A system is being planned on the subject of aquaculture to connect an expert system to a full text system. The expert system will lead the user to sources of data or information on aspects of aquaculture. Then the sources themselves—reference books, articles, or reports—will automatically be accessed on the laser disc, and the data or text containing the answer to the specific questions will be displayed and, if desired, printed out.

Future Integrated Systems

With systems made possible by new and continously developing technologies such as computers and lasers and intelligent software, NAL intends to increase its ability to provide information services and products. With an integrated system, the user will be able to search the AGRICOLA database through an interactive computer-laser disc system, then, at the same location, perform searches on a CD-ROM system, and turn to an expert system to diagnose and resolve problems.

A researcher, wishing to see what techniques are being used to culture shrimp and the diseases involved, may begin with an expert system that will lead to articles on shrimp culture. The text of the articles could be found on a connected CD-ROM automatically by the expert system, and displayed on a monitor or printed out. The expert system also might lead the researcher through video sequences from a laser videodisc to which it is connected, showing shrimp culture facilities and detailed photos of diseased shrimp and shrimp tissue.

The technology now in use and being developed is exciting because it enables us to provide services in ways not even thought of a few years ago. With the support and assistance of users in USDA and the rest of the agricultural community, NAL will continue to develop the most effective means to present information as clearly, completely, and immediately as is possible.

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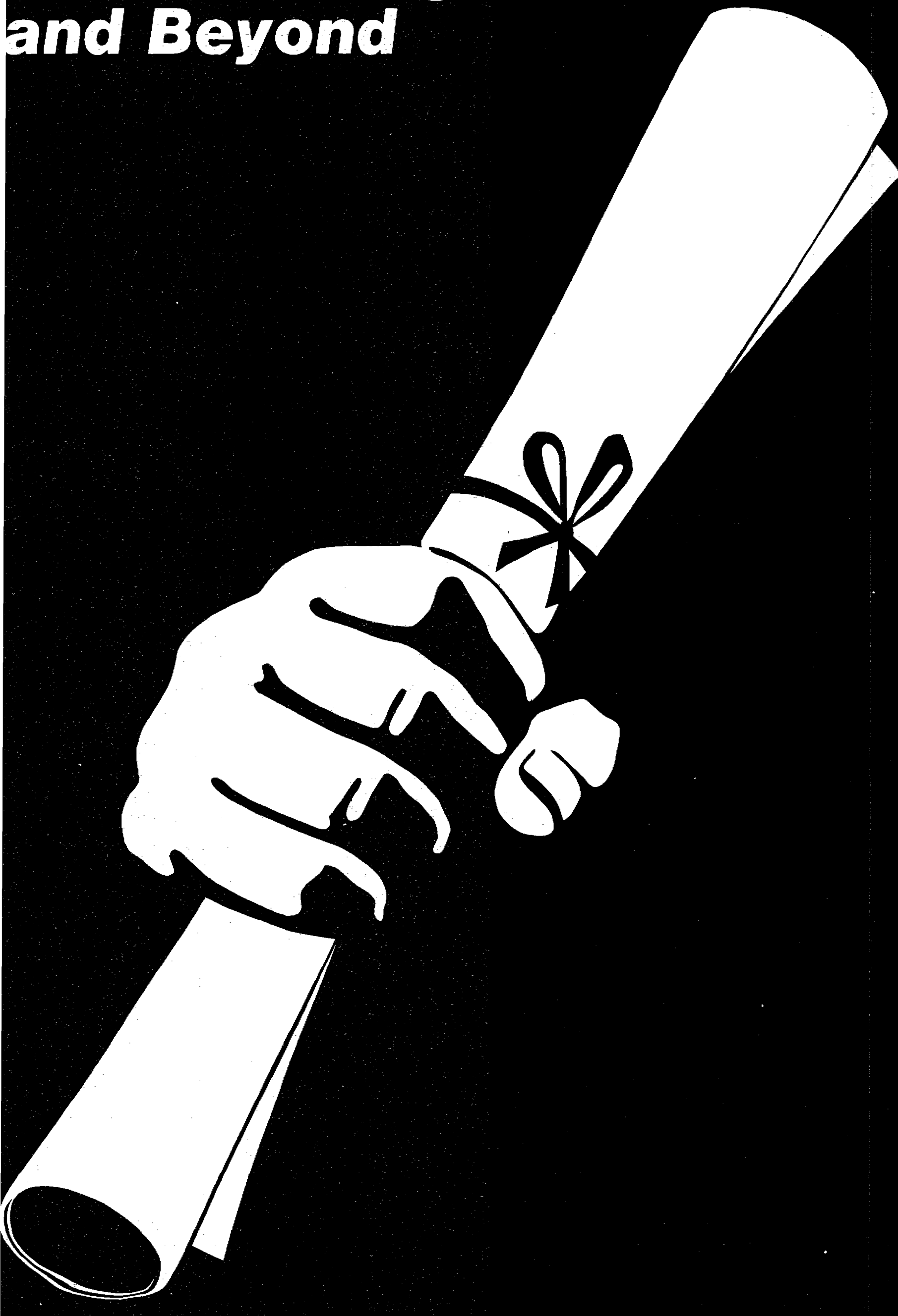
Careers in Agriculture and Beyond



Agriculture: A World of Scientific and Professional Opportunities

Dale Stansbury, *director, Agriculture and National Resources Programs, National Association of State Universities and Land-Grant Colleges, and* Kyle Jane Coulter, *director, Higher Education Programs, USDA*

In the face of the current dilemma confronting U.S. agriculture, how could anyone dare describe careers in agriculture as a "world of opportunity?" In fact, however, the problems confronting U.S. agriculture increase the need for high quality professionals with vision to find solutions.

Further, opportunities abound because agriculture is the most critical sector of our roughly $4 trillion economy. The challenge to produce food and fiber needed by earth's 6 billion citizens is staggering. The challenge of getting the food from producers to consumers, who frequently are thousands of miles apart, also is awesome.

Few people, however, fully understand the breadth and complexity of the U.S. food and agricultural system, nor are they aware of the human capital base underlying this phenomenally successful system.

Miracles Achieved

U.S. agriculture has achieved miracles, producing the widest variety of wholesome food at the lowest relative cost for more than 230 million Americans. Furthermore, it supplies $30 to $40 billion of farm commodities for shipment abroad as commercial exports and humanitarian aid.

The greatest compliment to the success of the U.S. agricultural system is that nearly every citizen takes for granted the quantity and quality of food produced by U.S. farmers. This is not the case for much of the world, nor has it been the historic norm. There has been a serious famine somewhere in the world every year throughout recorded history. This dismal history led British economist Thomas R. Malthus to hypothesize that the world's population growth ultimately would outstrip our ability to feed ourselves.

Not only have our farmers refuted Malthus' famous predictions, rather they seem to have reversed his theory—our Nation is awash with surplus food. But this abundance must be put into proper context. World food stocks represent only a few months' supply if production were ended. The ominous consequences of the alternative—shortages—make these surplus stocks less burdensome.

While U.S. agricultural producers are outstanding, they, in fact, are only a pivotal component of a remarkable food and agricultural system—a system that affords a multiplicity of career opportunities for college and university graduates.

Farming and ranching are often the most visible parts of the system, but ultimately account for only about one-sixth of employment in the food and agricultural system which accounts for one-fifth of national employment. The system is a team effort, its diverse players ranging from United Auto Workers in farm machinery plants to research scientists in biotechnology. If any fail, the effectiveness of all will slip.

Archlike Nature of Agriculture

The U.S. food and agricultural system can be depicted as an arch. The key-stone of the arch is the producer. The arch rests on two vital bases—natural resources (including climate, soil, and water) and science and technology. Other critical components include the agricultural supply sector (including fertilizer, chemicals, and equipment manufacturing), service institutions (such as financial, insurance, and communications entities), marketing activities (transportation, processing, wholesaling, and retail units), and public service activities (market reporting, grades and standards, and weather information), all of which support the food and agriculture system.

Multiplicity of Careers

While this depiction of our food and agricultural system is not comprehensive, it shows that agriculture careers extend far beyond farming. Two important factors add to the excitement of agricultural careers.

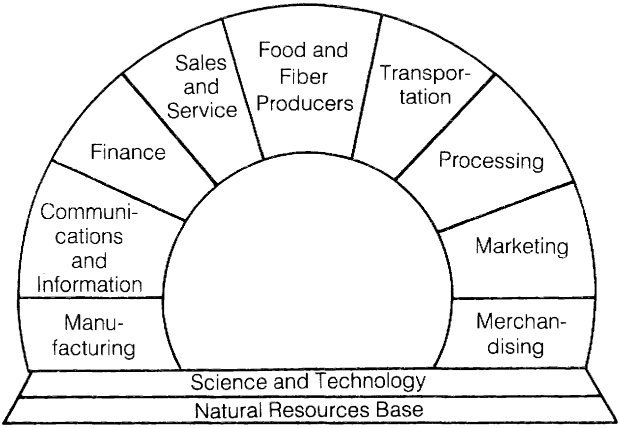
First, agriculture is a biologically based endeavor. Climate, diseases, and pests are unpredictable adversaries that constantly threaten the system. It is an unending struggle to keep ahead of a rather fickle Mother Nature who seems to find ragweeds just as appealing as corn and gypsy moths as important as trees.

Second, U.S. agriculture functions in a global market. The product of one out of every three U.S. acres is shipped abroad. The weather conditions in Siberia or Argentina as well as the trading policies of other nations affect the U.S. system. Furthermore, the reverse is true. Italian pasta manufacturers may well be more concerned about weather reports from North Dakota than from Rome.

Complex, Challenging System

This complex, challenging system affords an almost limitless variety of career opportunities in natural resources management, food and fiber production, science and technology, business, education, and government. Agriculture needs the talents of the best professionals to meet old and new challenges of producing and delivering food and fiber to the world's consumers. It affords dynamic, exciting opportunities with domestic and international dimensions.

American Agriculture—A Global Enterprise



Beyond the Farm Gate: An Abundance of Career Opportunities

Dale E. Wolf, *group vice president, Agricultural Products, Du Pont Company, Wilmington, DE*

The American food and agriculture system stands atop the ranks of global enterprise. It is the world's largest commercial industry with assets exceeding $1 trillion.

It accounts for 20 percent of the United States' gross national product. And more than 23 million Americans are employed in agriculture-related jobs—most of which are beyond the farm gate.

This lofty status places the American food and agriculture system, and the people who make it work, at the center of international business and finance. Agricultural professionals are making their marks in such places as the brokerage houses and investment banks of Wall Street, international trading companies, Madison Avenue advertising agencies, and the board rooms of national and international corporations—as corporate executives, managers, financial and commodity analysts, and sales and marketing representatives.

Many food and agricultural specialists also are at the vanguard of science and technology. They are developing and using new techniques to improve the productivity and cost efficiency of American farmers and to enhance their ability to compete in the world marketplace. Likewise, new and better food products are being developed continously to enhance consumer welfare and satisfaction.

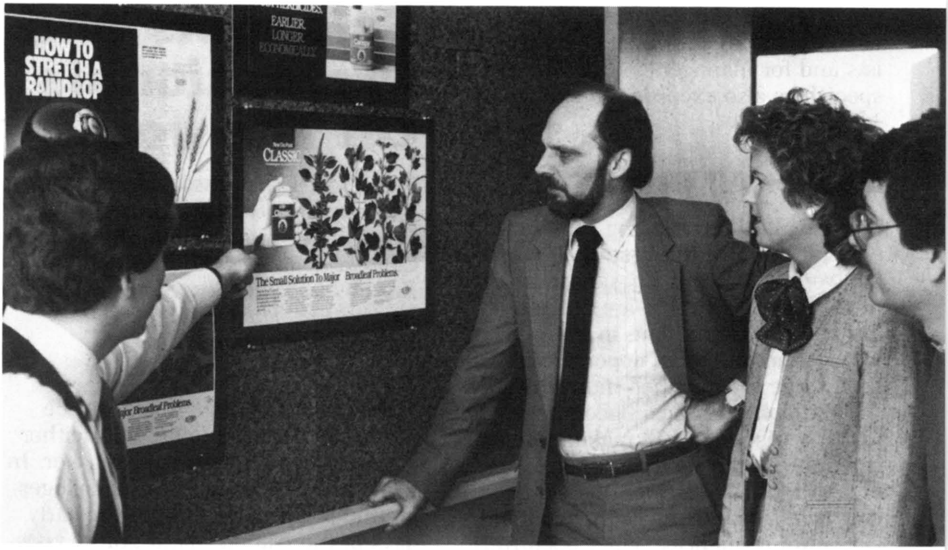
The globalization of American agriculture has important implications for students in the food and agricultural sciences. Few, if any, agriculture-related businesses, whether they are financial, manufacturing, service or processing, can ignore international business issues today. No other industry compares with agriculture in terms of diversity of career opportunities at home or abroad. And no other industry offers a broader, more complex array of challenges to the best and the brightest seeking involvement in key domestic and world issues.

The Ultimate Challenge

Tomorrow's agricultural scientist, in either the private or public sectors, faces the ultimate challenge—helping to feed a world population expected to grow by 80 to 90 million people annually through the end of the century.

Already the pace of scientific innovation is accelerating to meet this challenge. Today, new, highly effective, environmentally safe crop protection products, applied at fractions of an ounce per acre, are replacing those which were applied at pounds per acre. And, as significant as this breakthrough is, it is a mere harbinger of what is to follow. Every major corporation that manufactures or processes agricultural products has a significant research effort that extends from the most basic to the applied.

In decades to come, biotechnology and genetic engineering will be used to develop herbicide-resistant plants. The livestock industry will use embryo transfer techniques to produce more productive animals. Crop physiologists will work with fruit and vegetable growers to improve yields through the use of plant growth regulators. And computer experts will de-



Rumrill-Hoyt, Inc.

Increasingly sophisticated communications techniques have created a demand for advertising and public relations professionals with backgrounds in the food and agricultural sciences.

velop models to predict and monitor yield-limiting soil erosion and reduce production costs.

Diverse Opportunities

Bright career opportunities in agriculture are by no means limited to the laboratory. A study conducted by the U.S. Department of Agriculture in 1986 revealed that of the 49,000 annual employment opportunities for college graduates in the food and agricultural sciences, 32 percent are in the marketing, merchandising, and sales sector. Included in this category are landscape contractors, marketing specialists, and sales representatives. Research and development openings for scientists, engineers and technicians account for 28 percent of the openings, while 14 percent of the projected positions are for managers and financial specialists. Overall, nearly three fourths of the opportunities are expected to be in the agribusiness components of the food and agricultural system. The study also revealed significant career opportunities in farm management, agricultural economics, international trade, agricultural engineering, communications, education, and many more occupations.

More Good People Needed

Despite these excellent employment opportunities, there is a need for more college graduates in the food and agricultural sciences. The 1986 USDA study all too accurately predicted that the annual average demand for college graduates in the food and agricultural sciences will exceed the available supply by 10 percent through 1990. In several areas, the shortfalls are more severe.

For example, the annual demand for marketing, merchandising, and sales representatives exceeds the supply by 17 percent. Demand for scientists, engineers, and related specialists and for managers and financial specialists also exceeds the supply by 16 percent.

Best of All Worlds

As a result, those seeking careers in agriculture have the best of all possible worlds. Not only does agribusiness offer careers that are challenging and rewarding, but, in many areas, there are more opportunities than there are qualified individuals.

Philosopher Francis Bacon once said," A wise man will make more opportunities than he finds." As we approach the 21st century, his words ring true for students of the food and agricultural sciences. Their opportunities are limited only by their ability to create them.

Scientists and Professionals On The Job

Stanley C. Ernst, *associate Extension editor, Agriculture, Office of Information, and Applied Communications, and* Kenneth W. Reisch, *associate dean, College of Agriculture, The Ohio State University, Columbus*

The old gray mare might not be what she used to be, but neither is the college student studying her. In fact, students in agricultural colleges are much different than in the early days of the Nation's land-grant system. Where once colleges of agriculture trained students to be farmers and home economics teachers, today's students are being educated to go new places and do things many people would never think go along with a degree in agriculture. Agriculture programs at the Nation's land-grant universities are graduating food scientists, marketing specialists and economists, as well as providing an excellent foundation for degrees leading to jobs as lawyers, medical doctors, editors, teachers, and a host of other professions.

A recent survey of agricultural colleges in the Midwest showed barely 10 percent of those schools' graduates going into farming or professional farm management. Over 28 percent of the graduates entered some form of agribusiness, 13 percent went into another industry, and nearly 14 percent entered graduate or advanced professional studies.

The advanced scientific training available through agricultural colleges is just one reason those who use agricultural colleges as a springboard into other areas took a nontraditional route to their career. Some of these people ply by 17 percent. Demand for scientists, engineers, and related specialists and for managers and financial specialists also exceeds the supply by 16 percent.

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The advanced scientific training available through agricultural colleges is just one reason those who use agricultural colleges as a springboard into other areas took a nontraditional route to their career. Some of these people

Ron Garrison, Zoological Society of San Diego

Barbara S. Durrant, San Diego Zoo's reproductive physiologist, works to increase populations of endangered species like the South African cheetah.

come from the traditional farm background and want to move into other fields. Other students have no relationship at all to farming but find agriculture is the career they want to pursue. And still more find that an agricultural degree is a great stepping stone into unique careers.

Take Barbara Durrant for instance. While many of her peers at North Carolina State University were content with studying pigs and cattle, she had other plans for her expertise in reproductive physiology.

"I never wanted to spend my life producing domestic animals strictly for slaughter," she says. "I went into animal science to get a good overall basis and physiological training with the thought of applying my skills to endangered species."

Everything from antelopes to zebras are part of Durrant's "herd." As the San Diego Zoo's reproductive physiologist, she is working in a field that is both challenging and sometimes frightening. Unlike traditional livestock studies, zoo researchers may have only one or two individuals of a specie to work with. This requires greater caution in research, she says, and there is little chance to gather results from large groups and often no prior work to base her studies on.

When she left North Carolina State in 1979 with a Ph.D. in Animal Science, Durrant had most of her experience with domestic animals. Today, she may be working with exotic birds, tomorrow it might be peccaries, a relative of the domestic hog. Her traditional training has paid off for the exotic species for which she is now responsible.

"I'm seeing that embryo transfer is not the savior of endangered species that we once thought it could be. Going to my background in animal science I know the primary genetic improvement method hasn't been embryo transfer but artificial insemination. I'm finding that to be the same with the more exotic animals."

Is there room in the zoo business for more Barbara Durrant's? Currently, she says, only three zoos—San Diego, Washington, D.C. and Cincinnati—have full-time reproductive physiologists on their staffs. That should change. More and more zoos are recognizing the need for larger research groups and that should mean more openings for physiologists and other specialists in the field.

"I don't think most agricultural schools or animal science students think much about the exotic animals as a profession," Durrant said. "But it's something more and more of them need to consider. Virology, endocrinology, genetics, nutrition, physiology and animal behavioral sciences are all areas where we need specialists, and animal science is a good background. True, there aren't all that many jobs in zoos right now, but I think that as administrators continue to recognize the need for good research, we're going to see more opportunities opening up."

Sometimes things don't turn out the way they were intended to. Steven Gerdes intended to get his B.S. in agriculture and specialize in finance. Somewhere along the way the Walnut, Illinois farmboy took an entrance exam for law school. Now Gerdes specializes in federal income taxation, particularly as it applies to municipal finance, for Vinson & Elkins—a law firm of more than 400 attorneys in Houston, Texas.

"I hadn't really thought about law, but for some reason, the accounting program at the University of Illinois was full of pre-law students," Gerdes says. "I was taking all these accounting courses to pass a CPA exam and started thinking about law from being surrounded by those people. I finally said, 'OK, I'll take the entrance exams for law school, and if I can get into a good one, I'll do it.' "

After graduating with highest honors from Illinois in May 1977, Gerdes entered Harvard Law School and received his J.D. degree in May 1980. He says he was probably the only student in the Harvard Law School at the time with a degree in agriculture.

Gerdes' roots were still on his mind after law school, but Vinson & Elkins offered a different opportunity from the firms he interviewed that had agricultural specialties. In short, the Houston firm offered what he saw as a once-in-a-lifetime chance.

"This position provided me an opportunity to do something I won't be able to do again. I ended up here because I wanted to try it. This is a very specialized firm, and municipal finance is the specialty they've assigned me here. While it doesn't deal with agriculture all that often, occasionally I have something involving a grain elevator or agribusiness and at least I know what they're talking about."

In some parts of the country, agricultural law is a big interest, and some college students today may take that route, Gerdes says. But lawyers always have options. Legal principles are basically the same whether they concern municipal finance or farm foreclosure, he says.

The key for prospective law students is the education they receive. Gerdes says his degree in agriculture prepared him for law school. But getting locked into a career-oriented mindset, first with accounting and later law, may have kept him from making the most of his opportunities.

"In an agriculture major, you often

have a lot of electives that enable you to diversify. I think I fell victim to the philosophy that if you can't use it on the job, you don't need it. Students should go ahead and broaden their horizons—take a classical literature course or some art history or whatever. Those are the kind of things you won't have time to do later that you have the opportunity to benefit from in college, and who knows when they might come in handy."

Some people with degrees in agriculture or home economics have had diverse educational experiences, many times caused by a change in plans.

Cassie Murphy-Cullen had bachelor's and master's degrees in political science and was teaching the subject at Texas Tech University while preparing for law school in the mid-1970's. A personal tragedy made her think about how families interact with the medical system, and she found a course in Texas Tech's Department of Home and Family Life that appeared helpful. That course's focus on family behavior in crisis times changed her career focus, she says.

Murphy-Cullen completed a Ph.D. program in family relations at Texas Tech in 1979, specializing in family interaction and family intervention with minor work in child development and medical sociology. She is now part of the Department of Family Practice and Community Medicine at the University of Texas Southwestern Medical School in Dallas.

"I feel very secure in my educational background and its relevancy to a post-graduate residency training program," she says. "I go on daily rounds with the residents to see their in-hospital patients and am available the rest of the day to discuss patient care and personal concerns with the residents working in the family practice center. If you help the physician and care about how he or she is reacting, assistance to the patient and family is more effective. I observe not only from the perspective of how they (the physicians) are doing with their patients, but how they are doing, in general, as human beings in terms of taking care of themselves and their families."

William Richards says he graduated in 1953 from Ohio State with a good education in agricultural economics and little practical knowledge of farming. But graduate school could wait. He found a farm, jumped on the then-innovative concept of minimum-tillage cropping and kept going.

Bill Richards is more than a farmer. The 7,000 acres cropped by Richards Farms, Inc. in 1986 are slightly less than past years, but the agricultural economy makes other farm ventures more practical, he says. Marketing, consulting and custom farming for others are just part of the future for the Circleville, Ohio operation.

"The financial management and organization of the family farm is going to be the innovation it's going to take to survive in the near future," Bill Richards says. "We're changing, retrenching our position, farmers will have to operate much differently in the future to stay competitive."

Competitive advantage comes from innovation, and the Premium Ag Commodities cooperative is one way Richards achieves both. Several years ago, he pulled together 10 of his area's larger farmers to form the private co-op. Individually, these farmers had some bargaining power. Collectively, he says, they can do much better when buying or selling products. And, although a few more members have been added, the organization is still small enough that each member serves on the board of directors and the cooperative can cater to individual needs.

Richards also promotes farmers not owning their own land. He rents land from investors from as far away as

England. He sees more and more farmers looking for outside investors for land and machinery in the future.

"Let the long-term investor own the land," he says. "Farmers need control, not ownership. Take inflation out and land is not profitable for the farmer. He cannot afford it. The operating farmer, to obtain the scale of operation he needs, just can't put that farm base together with net income if he tries to own that land."

Thoughts like this are not always well-received in the farm sector but make Richards a popular speaker. He's been on panels at the Harvard Business School, Agri-Business Executive Education Program and American Agricultural Law Association Conference, been part of a special report on CBS-TV's "60 Minutes," spoken at the National Public Policy Education Conference, and in 1976 was the first farmer ever to speak at the USDA Outlook Conference in Washington, D.C. And he regularly returns to Ohio State as a visiting instructor in agricultural economics.

McCall's

A. Elizabeth Sloan, Editor-in-Chief of McCall's, *reviews slides for publication with the magazine's art director.*

"Basically, we take university research and adjust things to work for us," Richards says of his farm's success. All three of his sons have studied agriculture at Midwestern universities and contribute their knowledge to the Richards' enterprises. Staying on top of the markets, looking for the best possible financing and arranging for outside investors are all part of the plan. And keeping up with the latest research and developments made by agricultural colleges is important too, he says.

"Waiting 12 years to go to graduate school made it much more valuable," Richards says. "I knew more about the business and was able to get what I needed for our operation out of it."

"Business"—that's how Bill Richards looks at farming. Instead of riding a tractor or driving to town for machinery parts, the Ohio businessman is more likely to be studying futures markets or talking to a group of financial specialists about the agricultural economy. He says he's always learning. He's teaching, too.

Many people attribute their first job to being in the right place at the right time. But for Elizabeth Sloan, it was more a case of being in the right place in the right era.

Sloan, editor-in-chief of McCall's magazine and vice president of the McCall's Corporation, had the skills to capitalize on the 1970's "consumer revolution." When she earned her Ph.D. in 1976, there was much misunderstanding about the safety of the Nation's food supply, she says. By then, the New Jersey native had decided to do something new—explain to the public the scientific facts of food safety. No one with her background had tried this area before, but it was something she felt needed to be done. It was almost like a social reform, a changing of misconceptions.

"I guess I was really the first one with any training in this area," Sloan says. "Now I'm running around the country trying to get schools to go along with the major companies who are looking for people to bridge the communications and scientific gap. There's a growing need for people with technical knowledge and practical communications skills."

Sloan is a 1973 honors graduate of Rutgers University in New Jersey with a B.S. in food science. She earned a Ph.D. in 1976 from the University of Minnesota in food science with a minor in communications and journalism. With that background she was able to take a product, test it, and let the public know what the results were. Before going to McCall's, Sloan did educational projects in food safety and nutrition for General Mills, edited food magazines, put together special features for all types of media and tested products to receive the Good Housekeeping Seal of Approval.

"The marketplace is becoming more and more technical," Sloan says. "People are demanding more information, and they know more about topics like food safety and nutrition. Let's face it—the agriculture areas are the backbone of everything. They're the life areas.

"The best thing about an education in agriculture is you get into the very logical, scientific way of thinking," she adds. "Once you can think that way, it's a matter of being able to tell others. So, this type work is much more than communications or journalism—it's conveying scientific research."

"Universities must stress that our greatest enemy is inertia—the tendency to keep moving in the same direction we always have," says Rich Feltes. "That may be part of the problem in the farm sector right now. We must look ahead to change and adapt to change. If you can't adapt to change, you're in trouble. If you're an inertia person, you are in trouble.

Richard J. Feltes is vice president, director of commodity research for Refco, Inc., in Chicago. He believes the time is right for young people in agriculture. And production, according to the 1970 University of Illinois graduate, may be the best bet. Someone who is sharp and gets ahead in production agriculture's new emphasis on marketing should do well in an industry currently experiencing a major shakeout. He says success in production agriculture requires knowledge, discipline, courage, money, and the energy to merge them properly. But if farming does not attract agricultural graduates, there are many career opportunities in marketing and processing.

Feltes grew up on a farm that now includes the largest roadside market in DuPage County, Illinois. Rich contracted polio as a child but was quite active in wheelchair sports throughout his college career at Illinois. In fact, he set a world record for the mile as a senior in 1970 that stood for 4 years. Feltes also earned an MBA from Southern Illinois University in December of 1972 before joining Continental Grain Company as a cash grain merchandiser.

Feltes coordinates commodity research and price forecasting in agricultural and financial markets for Refco, Inc., the world's largest futures commission merchant. He also is specifically responsible for the grain and oilseed price forecasting delivered daily and weekly to Refco's domestic and international offices. Continental Grain's crop research department, where Feltes developed monthly crop production forecasts for North and South America, provided an ideal springboard for his leap into the fast-paced commodity futures business.

Feltes thinks his agricultural education prepared him well for a career in commodity market analysis. Students need to pay more attention to specific skills if they want to succeed in agribusiness, he says.

"There's a real demand for people who are articulate and understand marketing," Feltes says. "Graduates need to understand the financial markets—futures, stocks and bonds. Their importance grows every day. Communication skills—the ability to sell yourself and your ideas—are crucially important as one must know how to sort out what works (cash flows) and what doesn't. Above all, however, one must try. It's better to try and fail then not try at all. Failures must be viewed as stepping stones to success."

Every once in a while, someone takes their production agriculture classes literally. For example, a self-proclaimed "city slicker" who had spent more time in ballet class than barnyards became a hog farmer a few years ago.

In fact, Julia Ford Fanjoy went into agriculture "whole hog." The 27-year-old from Hickory, North Carolina now operates her own 310-sow farrow-to-feeder hog operation.

And while hired help handles much of her farm's daily activity, the 1981 graduate of North Carolina State University also works as part of the field staff for Murphy Farms. Murphy's is the Nation's third largest hog processing firm, with nearly 30 farms throughout the Carolinas, including Fanjoy's, under contract. Fanjoy started her career in the swine industry as Murphy Farms' first female manager after graduating from North Carolina State.

"I'm a city slicker," she confesses. "I grew up in the streets of Hickory which is a city of about 65,000. I've always enjoyed animals and known I wanted to work with them since I was very young. I had cats and dogs and rode horses and liked working with the veterinarian. I never thought it would be hogs, though."

"I stayed in school an extra year to get the second degree in poultry science because I was discouraged when I saw most people with animal science degrees getting jobs back on their family farm. I didn't have one (a farm) so I thought I could find something in the poultry industry—marketing or processing. Look where I ended up."

Where Julia Fanjoy ended up was the White House and on NBC-TV's "Today Show." As one of Glamour Magazine's "Outstanding Young Working Women of 1986," she became a bit of a national celebrity. And her secret, the fact that she was a city girl, was revealed to her Murphy Farms co-workers.

Not having a farm background shouldn't discourage young people from studying agriculture, Fanjoy says. It may mean you have to work a little harder to understand the practical side of the classroom instruction, but the important thing is doing what you feel comfortable with.

"Actually, my background, or lack of farm background, was an advantage when I came to Murphy's. A lot of people come from a family farm, then get 4 more years of college training and go out thinking they know how everything is. I really had no preconceived ideas about this end of agriculture. I really have to be humble and just keep learning."

Can a person with no family ties to farming be attracted to an industry where financial failure and little profit seem to be the big news? Obviously Fanjoy was, and she thinks other young people should take another look at agriculture, regardless of their background.

"Young people looking for a career and saying, 'Yuck, look at the farm economy' should look again. Agriculture is still a very possible career and can be a very lucrative one," she says. "It certainly is challenging, and no two days are alike. One day I might be called on to do some veterinary work, and the next it'll be computer analysis. It keeps changing."

Some have found a career in agriculture and others have used their degree as a springboard to other fields. Their titles may be doctor, lawyer, marketer or editor, but they are "today's aggie." Today's education in agriculture is a stepping stone into many fields.

"Aggies"

Stanley C. Ernst, *associate Extension editor, Agriculture, Office of Information and Applied Communications, and* Kenneth W. Reisch, *associate dean, College of Agriculture, The Ohio State University, Columbus*

Agriculture students of the 1980's aren't the stereotypic "aggies" of the past. Farming, for the most part, is not the vocation they are studying. More of these students are using their degrees to enter fields not usually associated with agriculture. And today's students are more often the cream of the crop. Agriculture attracts top high school scholars, leadership award winners, students who aspire to medical degrees, and individuals from many different walks of life.

Amelia and Mark Besola are an answer to any argument that agriculture does not attract the top students. This brother and sister were both among the State of Washington's top high school scholars and consequently named Freshmen of the Year at Washington State University (WSU).

Amy Besola is described by her advisers as "an outstanding intellect and leader who is at ease as a woman in a nontraditional setting and maintains excellent relationships with peers, faculty and staff." She was one of two students in her State to receive a Century Three Leadership Scholarship and holds both a Washington State Merit Scholarship and a Seattle First Merit Scholarship. The WSU junior is simultaneously enrolled in the College of Veterinary Medicine and as a general agriculture major in the College of Agriculture and Home Economics.

Miss Besola's accomplishments as an active student include reaching the highest levels of distinction in Albackground.

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Amelia and Mark Besola, both students of veterinary medicine, aspire to different careers—Amelia's interest is agriculture and Mark's is preservation of endangered species.

pha Zeta. She currently serves on the honorary's national board of directors and was the top National Alpha Zeta Scholar. She is also one of five students currently serving in the Leadership and Academic Development Program of Alpha Zeta. At WSU, Miss Besola has served in the college senate and was one of the students responsible for developing the organization's original charter and constitution. She maintains this high level of involvement while holding a 3.97 grade average (of a 4.0 total).

Some students of this caliber would consider moving away from an industry with the problems agriculture is reported to have. But rather than being discouraged, Amy sees a challenge and notes the demand for well-educated people in agriculture. And while she sees herself in a rural veterinary practice, that one-on-one transfer of research to grass-roots farming is critical to continuing the consumers' food supply, she says.

"Agriculture is still our future," she says. "It's a lot more than the cows-and-plows scenario we see portrayed so often. It's high technology and innovation, and we need intelligent people in the industry to help take advantage of those resources. I'd rather be part of the solution and help us do a better job of feeding the world than sit around and talk about how bad things are."

Younger brother Mark could be accused of following in Amy's footsteps. The sophomore animal science major has been accepted to the WSU College of Veterinary Medicine and plans to carry a major in general agriculture at the same time. He also excels as a student, according to his advisers. Mark also is a Washington State Scholar and a WSU Distinguished Scholar as well as western region winner of a Purina scholarship. Like Amy, he is active as a student senator and as a College Ambassador, recruiting students for the College of Agriculture and Home Economics.

But when it comes to career goals, the similarities cease. True, both are studying veterinary medicine, but graduation from veterinary school is still 4 years away for Mark, and he wants to keep his options open. He considers all areas of veterinary medicine to be both challenging and worthwhile but is leaning toward working in a zoo or wild animal park environment.

"I think the challenge of preserving endangered species is great and there needs to be more done in that area," he says. "After working in a Smithsonian program at The National Zoo last summer, I decided that a career working with exotic species might be for me. We have a lot of research on domestic animals. Now those concepts in such areas as nutrition and reproduction need to be adapted to preserve diversity in the animal kingdom."

The younger Besola agrees with his sister that a degree in agriculture was a good move for them. And he also says the dim picture painted of the industry's economy should not discourage students from studying its individual disciplines. There are so many ways agriculture degrees can be applied, he says, that quality people with expertise in those disciplines will continue to be in demand

Four years as an undergraduate can change goals and redirect careers. When Jerry Boley entered The Ohio State University in 1982, he was very interested in science and interested in agriculture. His plan was to earn a degree in animal science, go on to veterinary school, and go back to western Ohio to establish a rural practice while helping manage and expand his family's swine operation.

Now a senior nutrition major in the Department of Animal Science, the former high school valedictorian has a different plan. Boley excelled in Ohio State's honors program, achieving near perfect grades, and has been accepted to four medical colleges across the country.

What changed Jerry's direction? He says he did not feel stimulated enough by early courses in livestock production to make a career in that area. A nutrition course got him to thinking about medicine for both animals and people. And a summer job in a community hospital back home convinced him which way to go.

But the Ohio State senior doesn't see medicine as a way out of agriculture or rural life. In fact, he believes his upbringing and education will help him achieve the thorough understanding of people that he says doctors must have to be effective. Boley may even end up putting that knowledge to direct use.

"I can't pick what area I'll specialize in right now," he says. "But if I had to, it would probably be family practice in a rural area. I think oftentimes doctors coming into that type of situation don't know how to relate to it, and neither they nor their patients receive the best of the situation. I think my knowledge of that lifestyle would be a real help and I could feel comfortable in that situation also."

Malcolm Emmons

Jerry Boley's agricultural education led to an interest in medicine; after medical school he may go into family practice in a rural area.

Feeling comfortable with where you are is critical. And although you can't overlook the problems in the farm economy, diversity and optimism for the future made Ron Risley finish his degree in agriculture and go on to a graduate program in the same area.

Risley, from Campbell, New York, graduated from high school in 1973 and entered Cornell University to study animal science. He says he was not happy with where he was and what he was doing at Cornell, so he left school and went back to his father's dairy farm. After working at home for 4 years and then taking a position with a farm in western Maryland, Risley entered the University of Maryland in 1983.

"I wanted to get out in the world more and deal with different types of people while still maintaining my ties to agriculture and especially the dairy industry," he said of his return to college. "It just seemed like the time to get off the farm and get back into school."

Risley switched to agricultural economics at Maryland and graduated in 1985 with highest honors—a perfect 4.0 grade point average. That 8-year vacation did him good, he says. He saw other sides of agriculture and was ready for new challenges. The New York native is currently on an assistantship at Virginia Polytechnic Institute and State University in a master's degree program for dairy marketing. The farm economy may be discouraging at times, but Risley believes agriculture students who want a career in the industry can have one by broadening their horizons.

"I don't think you can ignore the economy right now," he says. "There are times when things look pretty bleak. But we have to attempt to broaden our horizons. In my case, that means taking more finance courses to develop some specialty. The bottom line is that I'm doing what I want to do—what I'm happiest doing—and that's being involved in agriculture and the dairy industry in some way."

Ag Graduate—Will Travel

H. O. Kunkel, *dean, College of Agriculture, Texas A&M University, College Station*

The world is the job market for agriculture graduates. For decades now, many graduates of colleges of agriculture have looked toward employment in foreign settings as a beginning for their postcollege careers. The internationalization of agriculture has taken an increasing share of agricultural graduates abroad at some time in their careers.

Graduates of U.S. universities in the agricultural sciences reside in all parts of the world. Many, of course, are citizens of other countries who came to the United States for all or part of their university education. But a substantial number, too, are U.S. citizens. Some are on extended tours and some are but frequent business travelers to foreign sites. The 1,000 or more who apply annually for agricultural assignments in the Peace Corps illustrate the continuing attractiveness of a foreign assignment for a substantial number of agricultural graduates.

For all, the experience is enriching. Consequently, more colleges of agriculture across the United States are positioning themselves to provide an educational base for a global world of work.

Agricultural Colleges in International Arena

Largely in collaboration with U.S. foreign assistance programs, colleges of agriculture began in the 1950's to develop international agricultural programs to complement the traditional functions of academic instruction, research, and extension. These programs extended the contributions of universities to the development of human resources, institutions, and agriculture of developing countries. They represented an effort to address the threat of global malnutrition and hunger, a potential now recognized as chronic poverty as well as a lack of technological development.

Through the years, U.S. land-grant universities have sent hundreds of faculty and staff members to engage in training and institution building. Nine institutions in India, universities in Bangladesh, the Philippines, West, North and East Africa, the Dominican Republic and a host of other countries are the legacies of involvement of U.S. colleges of agriculture. The evolving legacy is also a growing corps of U.S. agricultural graduates who function effectively as world citizens.

Title XII of the 1975 Foreign Assistance Act provided for an expanded and institutionalized long-term commitment of universities in development. Strengthening grants, memoranda of understanding between the U.S. Agency for International Development (AID) and universities, and the development of a joint professional career system to allow faculty members to work for AID and AID professionals to work on a university campus have been means by which universities built continuing interest and capability for international agriculture.

Collaborative Research Support Program (CRSP). CRSP, supported by AID, extends agricultural research and graduate study. CRSP's are long-term research programs for collaboration of U.S. universities, AID, USDA, and other research institutions with institutions in developing countries. The CRSP program is multifaceted and may be aimed at any aspect of the food chain, including production, nutrition, and

Florida Department of Citrus

Florida grapefruit awaits export from Miami.

cultural and economic elements.

International Agricultural Research Centers (IARC's). Developing, too, are informal as well as formal collaborations among university scientists and IARC's and cooperative efforts between U.S. university scientists and scientists in developing countries. Networks among agricultural scientists on global basis and long-term linkages between U.S. universities and foreign institutions are now surfacing. The flow of agricultural science and technology has become increasingly a two-way flow.

With this commitment to international issues, on-campus educational and training programs and courses to prepare international and U.S. students for work in world agriculture have expanded, a trend that was encouraged through the Title XII Strengthening Grants. Some institutions have established graduate and undergraduate majors or collateral emphases in international agriculture.

Colleges of agriculture are increasingly integrating the international dimension into their academic and research programs. So, substantial educational opportunities exist for agricultural students who are willing to travel internationally in their careers.

Multinational Agribusiness and Industry Opportunities

The more than $30 billion agricultural export sales each year require an extraordinary number of highly trained food and agriculture professionals. The U.S. private sector—agribusiness and industry, national and multinational companies—is a dominant factor in agricultural careers abroad.

A major U.S. corporate firm, for example, has built and operates an irrigated mechanized farm in the Sudan. It instigated a joint venture to establish a date processing company to process and export invert dates from Tunisia to North America. Another company has been a catalyst for international food conferences. Major grain firms have established plant breeding programs in South America. Such corporations develop a marketing and supply infrastructure.

Often U.S. professionals are not posted permanently in these countries; they are administrative and technical specialists who help manage a project while training their foreign counterparts.

As developing countries attain certain levels of technological status, a U.S. or multinational company may seek out management and investment opportunities, thereby implementing a transfer of agricultural technology and providing employment for agricultural professionals.

Multinational Organizations. Large grain and cotton handlers, commodity trade firms, and food firms are examples of multinational organizations with activities and holdings in both developed and developing countries. They have research, sales, and management components with representatives posted in recipient countries. Agricultural economists find employment as economic analysts and forecasters in these international settings.

Food Industry. The food industry is a large component of agribusiness with substantial international interests. These interests provide opportunity for both long-term assignments in other countries and periodic tours of duty in other lands, for graduates in food science and technology and related areas such as food economics, marketing, horticulture, and biotechnology.

FAS

International trade fairs, like this one in Paris, open market doors for U.S. produce.

Importers of fruits and vegetables employ graduates as buyers in producing countries. A number of food companies in the United States have strong international groups for marketing their products. These manufacturers employ professionals with technical knowledge as sales representatives in countries in which they wish to develop markets such as Japan and Europe. Nearly all American food manufacturers are active importers of food products. For this effort, they have field representatives and buyers with a broad array of technical and marketing knowledge. U.S. companies that manufacture food processing equipment have markets around the globe. They employ food scientists and food engineers, among other kinds of engineers and technologists, to install food processing units in foreign countries.

Other Business Opportunities. Banks in the United States that finance international trade and multinational agribusiness also employ agricultural economists with specialized knowledge of international business. Export and import businesses also provide opportunities for employment for graduates in agribusiness or agricultural economics. International insurance firms that insure international transport of agricultural products likewise employ agricultural analysts.

Agricultural Development Opportunities

Foreign assistance programs have been under way since 1942, and many of them have been specifically designed to strengthen the food and agricultural capacities of developing countries. These programs are directed toward the improvement of policies, reduction of constraints on agricultural production, development of human resources and institutions, and expansion of roles of the private sector.

A large number of agricultural professionals are employed in carrying out U.S. interests throughout the developing world.

USDA. USDA provides services to AID through a wide range of Participating Agency Service Agreements (PASA) and Resources Support Service Agreements (RSSA). USDA scientists assist AID in special assignments for surveys, project analyses, and related activities in developing countries.

USDA also operates programs designed to prevent entry of foreign pests and diseases and provides assistance to developing countries in controlling disease and pest problems. Entomologists, plant pathologists, and veterinarians are sent on special assignments into other countries. USDA professionals also assist in export market expansion activities.

The place of agricultural attachés warrants special note. These agricultural professionals are assigned to embassies and missions. They play an important role for the U.S. economy as information specialists relative to the agricultural economies of other countries. They are frequently the most highly respected U.S. officials in the countries in which they work.

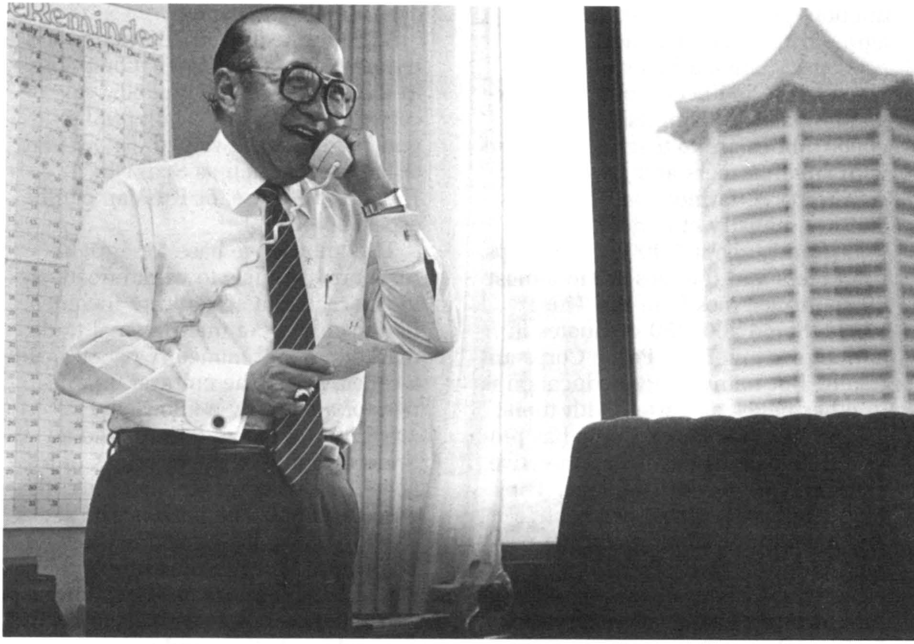
AID. AID personnel—agriculturalists, development officers, nutritionists, and others—work with developing country counterparts in planning, management, and evaluation of a wide variety of agricultural projects. AID makes scientists and advisers available to developing countries through contacts and agreements with U.S. universities, private firms, and other U.S. agencies.

Opportunities With International Organizations

IARC's. Supporting IARC's is the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agricultural Organization of the United Nations, the World Bank, and the United Nations Development Programme. IARC's started with private foundation (mainly Rockefeller and Ford Foundations) support, foster both research and training while providing technical assistance and support of agricultural research and institutions in developing countries.

At their beginning IARC staffs came mainly from the land-grant university system. A substantial number of staff members still do. These centers focus on the development of improved production and marketing technologies, better varieties of crops, and improved methods of disease and pest control. They are regarded as truly exemplary successes in international agricultural research and extension.

World Bank and Inter-American Development Bank (IDB). The World Bank and IDB provide long-term commitments to training,



FAS

A USDA agricultural trade officer helps with agricultural projects in Singapore.

institution building, and infrastructure development. The World Bank is the largest single source of external loans for agriculture in developing countries. It and the IDB are both employers of graduates in the agricultural sciences.

The World Bank and IDB have staffs located in their Washington headquarters as well as in various regions of the world. Their widely dispersed interests insure that nearly all their professionals will travel abroad extensively.

Peace Corps Opportunities

The Peace Corps stands as a highly visible overseas outlet for graduates in the agricultural sciences, both as opportunity for work in other lands and cultures and for expanding one's education. The pay is modest, and working conditions can be frustrating. The living conditions can challenge the ability to adapt. Peace Corps volunteers, however, often see an assignment as an adventure, as a way to serve others, and as an opportunity to learn.

The Peace Corps focuses its efforts on fundamental human needs—health, nutrition, food and water, knowledge and skills, economic development, housing, energy, conservation, and community service. The methods involve interactions on a person-to-person level. The volunteer's work role and lifestyle often merge.

One of each six Peace Corps assignments requires skills in agriculture. Most volunteers are college graduates, although accumulated experience enables some without college degrees to enter the Peace Corps. Assignments include crop production, plant protection, soil science, agricultural education, agricultural economics, animal husbandry, farm mechanics, and beekeeping. One expanding activity is in fisheries. The opportunities are to teach and to work with small farmers and government counterparts, farmer cooperatives, and the ministry of agriculture.

Currently about 5,400 Peace Corps volunteers and trainees are in almost 60 countries, mostly in the Third World. Some 200–250 graduates in agriculture enter the Peace Corps annually. But many, whose education is in other fields, also work with them.

For most, the Peace Corps has provided a means of developing creative skills and fluency of language. They have acquired a global perspective and a certain wisdom regarding peoples, cultures, and agriculture in other lands. About 60 percent of returned Peace Corps volunteers seek further education. A number go on to gain positions of influence and leadership in government and with major multinational firms. The Peace Corps clearly serves the educational growth of many developing professionals.

Educational Preparation

The Peace Corps probably provides the principal opportunity for the baccalaureate graduate. Some of the jobs offered by multinational business and industry, however, also are directed towards B.S. degree graduates if such organizations provide additional training in necessary skills and knowledge.

But, for the most part, positions require an advanced degree that warrants attention and respect of counterparts in other nations. The value of an advanced degree or experience is that work in foreign settings often requires both broad technical knowledge and maturity of judgment. An international career may well demand a more comprehensive education than does a domestic career.

Although technical knowledge is a requisite for many international jobs in the private sector, an ability to communicate and a facility in language are equally valued. Knowledge of languages such as Spanish, French, Japanese, or Russian can be especially useful.

The knowledge base for agricultural professionals to work effectively in international agriculture includes understanding of international trade, marketing, and monetary policies. But a sensitivity to the cultural uniqueness of a country, a knowledge of property rights and tenure, and an understanding of the priorities of a people and their government are likewise essential. The person who seeks work in a developing country should be prepared for multiple interactions between agriculture and social processes, between the methods of farming and marketing, and the culture and livelihood of the people, all of which may be quite different from those in the United States.

Patience is a quality that also is required. The tendency is to underestimate the logistical problems—distribution systems, the natural resource base, the managerial and staffing abilities. The ability to distinguish between what is feasible and what is not may be the most critical skill for the "ag" graduate who wants to travel and work in an international setting.

Unquestionably, there can be something special and satisfying about careers away from home that afford opportunities to influence agricultural policies and economic development of host nations. Degrees in the agricultural sciences, spiced with certain broadening elements of education, can open the way.

Accelerating Into Tomorrow

Henry A. Robitaille, *agricultural manager, The Land, Agriculture Office, Epcot Center, Walt Disney World, Lake Buena Vista, FL*

To maintain U.S. agriculture at a competitive and profitable level, productivity and production efficiency resulting from new knowledge and technology must continue to increase. In only 45 years, 1 farmer has gone from feeding 19 to 116 people by using better fertilizers and feeds, tractors, genetic hybrids, irrigation, and pesticides. Problems like soil erosion, aquifer depletion, and environmental pollution have occurred, but work on these problems is now leading to newer technologies like conservation tillage, learning to grow plants in weeds and stubble to minimize soil exposure; drip, surge, and other new approaches to irrigation; and integrated pest management using an increasing variety of available tools to manage crop and pest interactions.

There are many dramatic examples of increasing productivity in all agricultural areas. To illustrate only one, animal scientists in a recent comparison found that 33-pound pigs fed a 1907 diet gained 7 pounds in 60 days, while those on a 1983 diet gained 63 pounds, a ninefold increase in productivity.

Increasing productivity may mean even fewer farmers in the future. But it also means many exciting new careers in fields like biochemistry, agricultural engineering, plant and animal sciences (genetics, breeding, physiology and pathology), entomology, agricultural economics, and soil sciences.

The potential to increase productivity is, by no means, exhausted. Consider, for example, that the average yield for eight major U.S. crops—corn, wheat, soybeans, sorghum, oats, barley, potatoes, and sugar beets—is estimated to be only 20 percent of the record yield of the same crops. Of the unrealized 80 percent of the potential yield, stressful conditions (drought, salty soils, suboptimal temperatures, etc.) account for about 70 percent, with the remaining 10 percent attributable to insects and diseases. For all crops, record high yields are 3 to 7 times greater than their average yields.

And in the future, record yields too will be increased as plant physiologists understand phenomena such as the efficiency of basic nitrogen fixation, and water and nutrient uptake. A recent *Agricultural Research* article projected increases in yields of corn from an average of 113 bushels an acre today to 275 and 385 bushels an acre by the years 2000 and 2050, respectively. These yields exceed the highest experimental yields ever produced. New methods of growing, processing, and marketing will all be developed.

Future Tools

Computer science and biotechnology are two disciplines that will affect all areas of agriculture in the future.

Computer Science. Computers will be increasingly used to control operations and systems like pest management and irrigation with great precision. High cash crops will be grown in sophisticated greenhouses where computers will control 1) the root and shoot environments, 2) robots that seed, space, irrigate, manage pests of, fertilize, and harvest the plants, and 3) marketing selections for maximum profit. Tomorrow's tractors will be intelligent machines that use computers to plant, prune, selectively harvest, super cool and field

Walt Disney Productions.

Agricultural engineers find numerous and diverse applications for computers at The Land. On tomorrow's farms as well, computers are moving into areas like "expert systems" and robotics controls. Here, background plants grow hydroponically; soilless growing will find limited applications on earth but important applications in space agriculture.

pack crops automatically and with great precision.

Support for these kinds of developments will come from agricultural engineers like Roy Harrel at the University of Florida, who has already developed a prototype robot to harvest citrus.

Biotechnology. Horticulturists and foresters are already using one area of biotechnology called tissue culture to clone huge numbers of disease-free vegetables, ornamentals, and forest trees starting with tiny plant parts and sometimes even single cells.

In doing genetic engineering, molecular biologists who introduce new genes into plant cells also depend on whole plant regeneration to see expression of that gene. In one example, plant genetic engineers succeeded in transferring the structural gene from the major storage protein in bean seeds into tobacco plantlets, where it did produce the bean seed protein at low but constant levels.

Animal scientists are excited by experimental results with bovine growth hormone produced industrially by genetically engineered bacteria. The hormone can increase milk production by 10 to 33 percent without proportionately increasing feed intake, at least on a short-term basis.

Walt Disney Productions

Horticulturist uses tissue culture for rapid propagation and production of disease-free clones.

Genetic Diversity

Today less than 0.1 percent of about 350,000 available plant species are used for agriculture. Agronomists, particularly plant breeders and genecists, are extremely concerned about preserving and, in some cases, cataloging this invaluable future resource. Genes to incorporate traits like disease resistance and salt tolerance into tomorrow's crop plants will come from this vast germplasm pool. Similarly, continued improvement of animal agriculture is dependent on preserving and using world resources of animal germplasm.

Some plants will be selected from this germplasm pool for cropping in the future, for new uses or products, and to meet the need for crops that are adapted to adverse environments. Two examples for potential food use are 1) winged bean for the wet tropics with high protein seeds, leaves and pods for vegetables, and starchy tuberous roots, and 2) buffalo gourd for the deserts with seeds high in vegetable oil and protein, and starchy roots.

Green plants, the best solar-energy-capturing devices known, produced today's gas, oil and coal deposits, and will help meet tomorrow's hydrocar-

Walt Disney Productions

Little-known plants like Euphorbia lathyris *may be important future sources of hydrocarbons, industrial raw materials, and biochemicals for medicine.*

bon needs. Jojoba seeds are 50 percent oil of such high quality that this desert shrub will help save the sperm whale by replacing whale oil for special lubricating applications. You'll also hear about another desert shrub called guayule for domestic natural rubber production, and plants like *Euphorbia lathyris* and *Copaifera multijuga* for mobile fuels. The latter, a Brazilian tree, can be tapped to yield 40 liters of a material like diesel fuel annually.

New Frontiers

Agriculture will move into space on orbiting stations and lunar and planetary bases during the 21st century. Green plants will be required for food, landscaping, and to help recycle carbon dioxide, nitrogen, and water. Although soil scientists may find that extraterrestrial soils support plant growth, much space horticulture will be through hydroponics or soilless growing where 13 normally soil-derived essential plant elements are dissolved in the irrigation water. Horticulturists, entomologists, and plant pathologists are anxious to learn how their particular organisms will behave and interact in the microgravity of space.

Exciting Careers

The past 85 years alone have given us hundreds of new tools like tractors, controlled-atmosphere storages, pest-controlling chemicals, computers, center-pivot irrigation systems, and plant breeding. Our knowledge base in all fields including plant and animal biology has increased exponentially.

Since producing food, fiber, wood, fuel, environmental beauty, and other agricultural products must continue to be the most important technology over the next 85 years as well, the future looks incredibly bright and exciting for all agricultural disciplines. Today's best students will be needed to apply the continually expanding base of science and technology to applications in agricultural engineering, agronomy, animal science, forestry, food technology, and other fields to continue both solving agricultural problems and increasing productivity.

The Land

Future World at Epcot Center is a place where the technologies, tools, and concepts for tomorrow are displayed for the millions of guests visiting the Walt Disney World Vacation Resort annually.

At The Land, sponsored by Kraft, 30 young agricultural professionals grow the most important and potentially important world crops in the environments of a tropics, desert, production greenhouse, and creative farm. Horticulturists and agronomists like Margit Hentschel (University of Florida 1984) produce tons of cucumbers, tomatoes, lettuce, bananas, malabar, peppers, and other crops for Epcot Center restaurants in controlled environments using hydroponics.

They're supported by 4 entomologists like Chris Halliday (Penn State 1981), and 3 plant pathologists like Jean Batzer (University of Minnesota 1982), who are developing a highly effective integrated pest management program emphasizing biological controls. The young scientists work with sophisticated tools in growth chambers, laboratories, and greenhouses, learning to use agricultural pests' natural enemies for their control.

Andrea Grainger (Auburn University 1985) and Tom Ardelt (Illinois State University 1986) are animal scientists producing fish for Epcot Center's restaurants in the densely populated raceways in The Land's aquacell. For conservation, water is recirculated through an elaborate filtration system. In addition to studying this state-of-the-art aquacultural facility, Andrea and Tom are also evaluating new animals, cropping systems, and feeds.

Agricultural engineers provide essential support to all production and research efforts at The Land.

Eldon Muller (University of Idaho 1981) heads up the computer team, working on projects like detailed environmental monitoring of all growing areas, crop scheduling and pest prediction modeling, and precision computer-control of operations like crop irrigation and aquacell flow rate. He writes software as well as evaluates new hardware as it becomes available. On the horizon—robotics!!

Other specialists, like Sandra Gerdes (University of Iowa 1981) who propagates The Land's pineapples, bananas, strawberries and other clones via tissue culture, round out The Land team, a team approaching the Future World of agriculture with excited anticipation.

Credits

The people who made this book possible, besides the authors, include:

- USDA's research information team, which helped outline and produce this yearbook. They are: Ovid Bay, Ben Blankenship, Eugene Farkas, Hubert Kelley, Patricia Lewis, Robert Nelson, Linda Russell, and Johna Pierce, all public affairs officers from agencies of USDA.
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