Part I

The Emerging Technologies

Chapter 2

Emerging Technologies for Agriculture

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Chapter 2

Emerging Technologies for Agriculture

American agriculture is on the threshold of the biotechnology and information technology era. Like the eras that preceded it—the mechanical era of 1930-50 and the chemical era of 1950-70—this era will bring technologies that can significantly increase agricultural yields.

The immediate impacts of the biotechnologies will be felt first in animal production. Through embryo transfers, gene insertion, growth hormones, and other genetic engineering techniques, dairy cows will produce more milk per cow; cattle, swine, sheep, and poultry will produce more meat per pound of feed. Impacts in plant production will take longer to occur, almost the remainder of the century. By that time, however, technical advances will allow major crops to be altered genetically for disease and insect resistance, higher production of protein, and self-production of fertilizer and herbicide. Until then, crop yields will increase through the use of traditional technologies, but at less than past rates.

Both plant production and animal production will benefit from advances in information technology. Computers, telecommunications, monitoring and control technology, and information management will be widely used on farms to increase management efficiency.

Some of these new technologies will emerge unexpectedly; however, most will undergo a long process of development, from initiation of ideas to commercial introduction. Since the development of a new technology takes years, often decades, it is often possible to forecast future technologies while they are still in the laboratory. One method is to obtain collective judgments from experts who have direct access to the latest available information, a method OTA chose. OTA collected information from three rounds of a mailed survey to about 300 leading public and private scientists and research administrators who had broad, cross-cutting perspectives about future technologies (Lu, 1983). Based on these surveys and on subsequent interviews with scientists in various disciplines around the country, OTA thus identified the 28 areas of emerging technologies that are likely (with at least a 50-50 chance) to emerge before 2000 and to have major impacts on the agricultural sector. Many of the technologies examined for this study, such as growth hormones, monoclonal antibodies, superovulation, and embryo transfers, are already in the marketplace, while others are still in the laboratory and will not become available for commercial introduction until 2000.

This chapter presents an overview of the major advances in biotechnology and information technology and then describes in more detail the 28 areas of technologies that were assessed for this study. It should be noted that some of the emerging technologies assessed will be in neither the biotechnology nor information technology categories.

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Biotechnology, broadly defined, includes any technique that uses living organisms to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses. It focuses on two powerful molecular genetic techniques, recombinant deoxyribonucleic acid (rDNA) and cell fusion technologies. With these techniques scientists can visualize the gene—to isolate, clone, and study the structure of the gene and the gene's relationships to the processes of living things. Such knowledge and skills will give scientists much greater control over biological systems, leading to significant improvements in the production of plants and animals.

Animal Agriculture

One of the major thrusts of biotechnology in animal agriculture is the mass production in micro-organisms of proteinaceous pharmaceuticals,[1] including a number of hormones, enzymes, activating factors, amino acids, and feed supplements (Bachrach, 1985). Previously obtained only from animal and human organs, these biological either were unavailable in practical amounts or were in short supply and costly. Some of these biological can be used for the detection, prevention, and treatment of infectious and genetic diseases; some can be used to increase production efficiency.

Another technique, embryo transfer in cows, involves artificially inseminating a superovulated donor animal[2] and removing the resulting embryos nonsurgically for implantation in and carrying to term by surrogate mothers. Prior to implantation, the embryos can be treated in a number of ways. They can be sexed, split (generally to make twins), fused with embryos of other animal species (to make chimeric animals or to permit the heterologous species to carry the embryo to term), or frozen in liquid nitrogen.

‘Pharmaceuticals that are proteins.

‘An animal that has been injected with a hormone to stimulate the production of more than the normal number of eggs per ovulation,

These and other genetic engineering techniques are explained more fully under “Animal Genetic Engineering,” later in this chapter.

Plant Agriculture

The application of biotechnologies in plant agriculture could modify crops so that they would make more nutritious protein, resist insects and disease, grow in harsh environments, and provide their own nitrogen fertilizer. While the immediate impacts of biotechnology will be greater for animal agriculture, the long-term impacts may be substantially greater for plant agriculture. The potential applications of biotechnology on plant agriculture include microbial inocula, plant propagation, and genetic modification (Fraley, 1985). All are explained later in this chapter under “Plant Genetic Engineering. ”

INFORMATION TECHNOLOGY

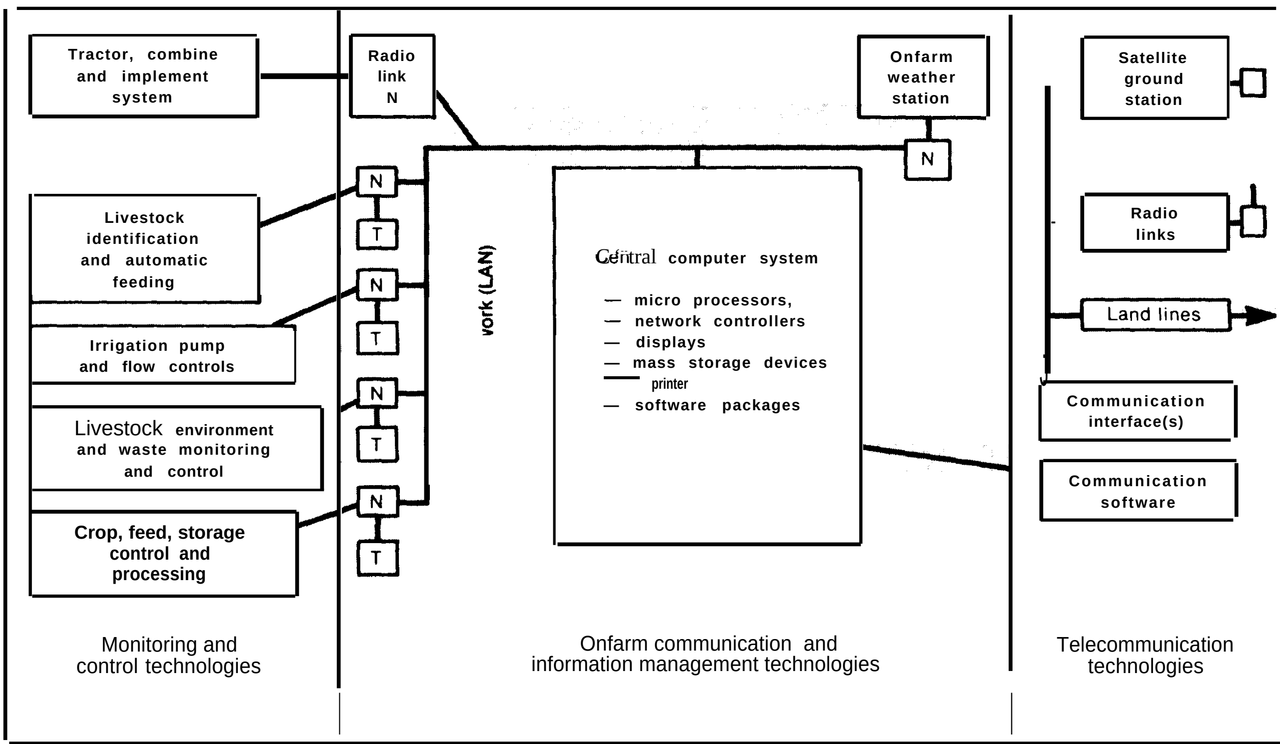
Agricultural information technologies can be classified as: 1) communication and information management, 2) monitoring and control technologies, or 3) telecommunications. The relationships of these classifications are shown in figure 2-1.

Communication and information management consists of onfarm digital communication systems, known generically as local area networks (LANs), combined with the microcomputer-based information processing technologies used by the farm operator as the central information processing and management system. This central computer system may include remote terminals with keyboards, display screens, and printers used for onsite data entry and readout by the farm operator. The computer terminals are indicated on figure 2-1 by the small boxes labeled “T.”

Monitoring and control technologies automatically monitor and control certain aspects of a wide variety of production processes. These technologies, generally considered to be subsystems, are located at the site of production activities, such as livestock confinement systems, storage facilities, and irrigation pumping and control stations, and on mobile equipment such as tractors and combines. Monitoring and control systems can function autonomously, although they are increasingly being connected to the central onfarm information processing system through fixed links and low-power radio links to the onfarm LAN. The LAN connections between the central information management system and the onsite monitoring and control technologies are indicated by the boxes on figure 2-1 labeled “N,” for network node. Several different kinds of local configurations of the LAN and the components of the onfarm computer system are possible. The arrangement shown here is just one of many possibilities.

Telecommunication technologies comprise the hardware and software that connect the onfarm systems with the rest of the world so that the farmer can communicate with people and with computer systems in other firms and institutions. Telecommunication systems may combine both voice and data communications. Three types of telecommunication technologies are shown on figure 2-1: satellite ground stations, low-power radio links, and telephone lines.

Figure 2-1.—General Configuration of Information Technologies in Production Agriculture



N - network node T - Computer terminal
SOURCE Off Ice of Technology Assessment

SURVEY OF EMERGING TECHNOLOGIES

The 28 areas of technologies are shown in table 2-1. OTA commissioned papers by leading scientists in each of these technological areas. A summary of each paper is presented in this section.[3]

[3]The papers prepared by those scientists are referenced at the end of this chapter and are available in ***Technology, Public Policy, and the Changing Structure of American Agriculture, Volume II—Background Papers*** through the National Technical Information Service, U.S. Department of Commerce.

Animal Genetic Engineering

Genetic engineering includes a number of procedures by which genes can be manipulated for improving the health and productivity of plants, animals, and humans (Bachrach, 1985). Three important genetic engineering procedures are: 1) recombinant DNA (rDNA) techniques, also called gene splicing; 2) monoclinal antibody production; and 3) embryo transfer.

Recombinant DNA Techniques

Because of its power to alter life forms, rDNA technology is considered to be one of the great-

Table 2-1.—Emerging Agricultural Production Technology Areas

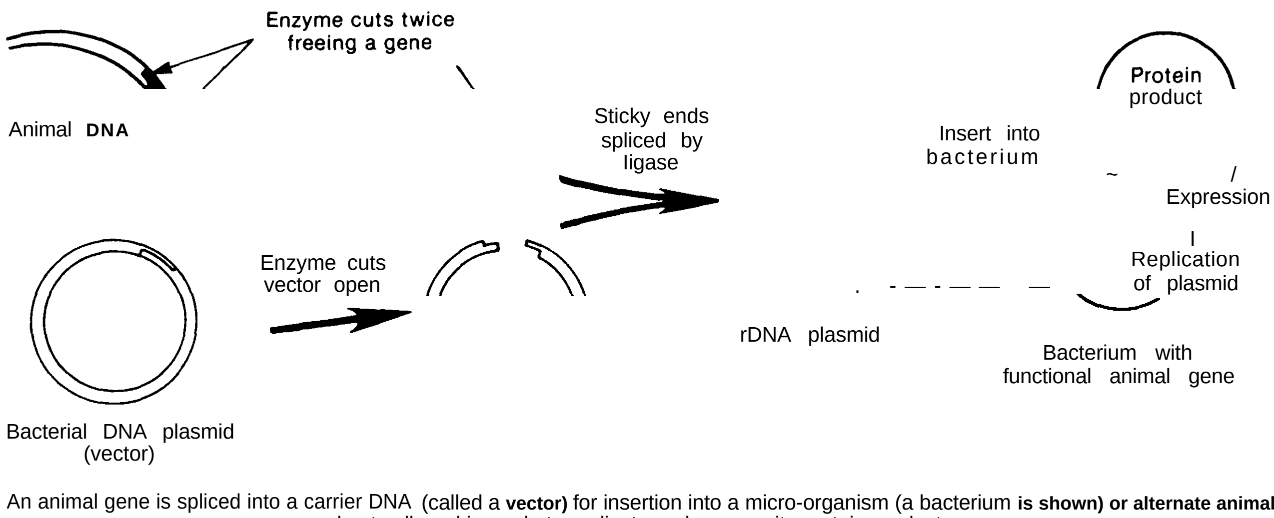
Animal	Plant, soil, and water
Animal genetic engineering	Plant genetic engineering
Animal reproduction	Enhancement of photosynthetic efficiency
Regulation of growth and development	Plant growth regulators
Animal nutrition	Plant disease and nematode control
Disease control	Management of insects and mites
Pest control	Weed control
Environment of animal behavior	Biological nitrogen fixation
Crop residues and animal wastes use	Chemical fertilizers
Monitoring and control in animals	Water and soil-water-plant relations
Communication and information management	Soil erosion, productivity, and tillage
Telecommunications[a]	Multiple cropping
Labor saving[a]	Organic farming
	Monitoring and control in plants
	Engine and fuels
	Land management
	Crop separation, cleaning, and processing

[a]These technologies also apply to plant, Soil, and water

SOURCE: Office of Technology Assessment.

est achievements of biological science. Through this technology DNA fragments from two different species can be fused together to form new units called recombinant plasmids (figure z-2). Such rDNA molecules might contain, for example, a gene from human insulin fused with DNA that regulates the reproduction of bacteria. When such molecules are inserted into bacteria, they instruct that bacteria to manufacture human insulin. Molecules of rDNA can now be inserted into a variety of bacteria, yeasts, and animal cells, where they replicate and produce many useful proteins, such as insulin, growth hormones, prolactin, prolaxin, enzymes, toxins, blood proteins, subunit protein vaccines, immunity enhancers (such as interferon and interleukins), and nutrients like amino acids and single-cell protein feed supplements. Recombinant DNA technology also produces DNA sequences for use as probes in detecting bacterial poisoning of foods and for diagnosing and treating infectious and genetic diseases.

Figure 2=2.—Recombinant DNA Procedure



An animal gene is spliced into a carrier DNA (called a **vector)** for insertion into a micro-organism (a bacterium **is shown) or alternate animal** host cell, and is made to replicate and express its protein product.

SOURCE: Off Ice of Technology Assessment

One of the applications of the new pharmaceuticals is the manufacture of growth hormones that can be injected into animals to increase production efficiency. Monsanto, Eli Lilly, and other firms are developing genetically engineered bovine growth hormone (bGH) to stimulate lactation in cows. This hormone, produced naturally by a cow's pituitary gland, was synthesized by Genentech for Monsanto. It has been reported that daily injections of bGH into dairy cows at the rate of 44 milligrams per cow per day have resulted in an increase of 10 to 40 percent in milk yield. The response to injections is rapid (2 to 3 days) and persists as long as treatment is continued (Kalter, et al., 1984). More recently, it was reported that the bGH treatments have increased milk yield 25 to 30 percent in the laboratory and could increase milk yield 20 percent on the farm (Kalter, 1985). The new hormone now awaits approval by the U.S. Food and Drug Administration and is expected to be introduced commercially in 1988 (Bachrach, 1985; Hansel, 1985; *Chem. and Eng. News,* 1984).

Another new technique arising from the convergence of gene and embryo manipulations promises to permit genes for new traits to be inserted into the reproductive cells of livestock and poultry, opening a new world of improvement in animal health and production efficiency. Unlike the genetically engineered growth hormone, which increases an animal's milk production or body weight but does not affect future generations, this technique will allow future animals to be permanently endowed with traits of other animals and humans, and probably also of plants. In this technique, genes for a desired trait, such as disease resistance and growth, are injected directly into either of the two pronuclei of a fertilized ovum (egg). Upon fusion of the pronuclei, the guest genes become a part of all of the cells of the developing animal, and the traits they determine are transmitted to succeeding generations.

In 1983, scientists at the University of Pennsylvania and University of Washington successfully inserted a human growth hormone gene, a gene that produces growth hormone in human beings, into the embryo of a mouse to produce a supermouse that was more than twice the size of a normal mouse (Palmiter, et al., 1983). In another experiment, scientists at Ohio University inserted rabbit genes into the embryos of mice. The genetically engineered mice were 2.5 times larger than normal mice (Wagner, 1985).

Encouraged by the success of the supermouse experiments, U.S. Department of Agriculture (USDA) scientists at the Beltsville Agricultural Research Center and the University of Pennsylvania are conducting experiments to produce better sheep and pigs by injecting the human growth hormone gene into the reproductive cells of sheep and pigs (Hammer, 1985). USDA scientists provide scientists at the University of Pennsylvania with fertilized embryos from sheep and pigs at their Beltsville farms. After being injected with the human growth hormone genes, the embryos are returned to Beltsville for insertion into surrogate mothers.

The experiments of crossing the genetic materials of different species in general and of using the human growth hormone in particular have prompted lawsuits from two scientific watchdog groups: the Foundation of Economic Trends and the Humane Society of the United States. Both groups charge that such experiments are a violation of "the moral and ethical canons of civilization, " and have sought to halt the experiments. The researchers argued that they are continuing the experiments cautiously and countered that the potential scientific and practical benefits far outweigh the theoretical problems raised by the critics. While the lawsuit is pending, the experiments are continuing.

Monoclonal Antibody Techniques

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. Each antibody can bind to and inactivate a cell of the foreign substance but will not harm other kinds of cells. Until recently, the primary source of antibodies used for immunization and other purposes was blood serum from many animal species. However, such serum also contains antibodies to hundreds of other substances, and each antibody type was limited in quantity.

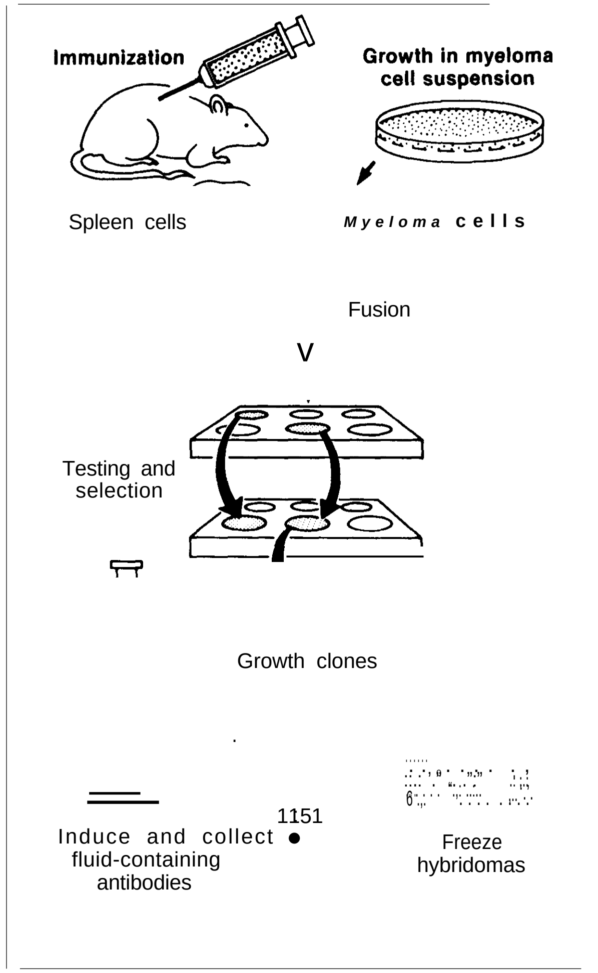
To produce large quantities of a single antibody, scientists now use a technique called monoclonal antibody production (figure 2-3). By fusing a myeloma cell[4] with a cell that produces an antibody, scientists create a hybridoma, which produces (theoretically in perpetuity) large quantities of identical (i.e., monoclinal) antibodies in a pure, highly concentrated form. An array of monoclinal antibodies can now be produced to fight major virus, bacteria, fungi, and parasites and to diagnose the presence of a specific agent in body fluid. The many important uses of monoclinal antibodies in agriculture include: the purification of proteins made by rDNA; the passive immunization of calves against scours; the detection of food poisoning; substitutions for vaccines, antitoxins, and antivenoms; sexing of livestock embryos; post-coital contraception and pregnancy testing; the imaging, targeting, and killing of cancer cells; the monitoring of levels of hormones and drugs; and the prevention of rejection of organ transplants.

Embryo Transfer

Embryo transfer is used for the rapid upgrading of the quality and productive efficiency of livestock, particularly cattle, In the process a superovulated donor animal is artificially inseminated, and the resulting embryos are removed nonsurgically for implantation in and carrying to term by surrogate mothers (figure 2-4). Before implantation, the embryos can be sexed with monoclinal antibody, split to make twins, fused with embryos of other animal species, or frozen in liquid nitrogen for storage until the estrus of the surrogate mother is in synchrony with that of the donor.

For gene insertions, the embryo must be in the single-cell stage, having pronuclei that can be injected with cloned foreign genes. The genes likely to be inserted into cattle maybe those for growth hormones, prolactins (lactation stimulator), digestive enzymes, and interferon, collectively providing both growth and enhanced resistance to disease.

Figure 2-3.—Monocionai Antibody Production



To produce monoclinal antibodies, spleen **cells from** a **mouse immunized against a specific disease are fused with mouse tumor (myeloma) cells to create hybrid cells (hybridoma) that grow in culture. The hybridoma cells are then screened for the production of antibodies. Hybridomas that test positive are injected into a mouse, and the mouse becomes a living factory for the production of antibodies against the same disease. Other positive hybridomas are frozen for future use.**

SOURCE: U.S. Department of Agriculture, Agricultural Research Service.

While less than 1 percent of U.S. cattle are involved in embryo transfers, the obvious benefits will cause this percentage to increase rapidly, particularly as the costs of the procedure decrease (Brotman, 1983). One company, Genetic Engineering Inc., already markets frozen cattle embryos domestically and abroad and provides an embryo sexing service for cattle breeders *(Genetic Engineering News,* ***1983).***

[4]Myelomas are cancerous, antibody-producing cells.

Figure 2-4.—Schematic Presentation of Cow Embryo Transfer Procedures

SOURCE: AdarXed from G.E. Seidel, Jr., "Suoer Ovulation and Embryo Transfer in Cattle, " Sc/errce, vol. 211, Jan: 23, 1981, p. 353.

Because of intense competition between hundreds of firms in the United States and abroad, a great many useful genetically engineered products and processes will be introduced during the 1980s.

Animal Reproduction

The field of animal reproduction is undergoing a scientific revolution that could scarcely have been visualized a decade ago (Hansel, 1985). Indeed, if all of the technology now available were used, a new kind of animal breeding system could be put into operation within 10 years.

By year 2000, artificial insemination maybe replaced by a system best characterized as "artificial embryonation." In this system highly trained technicians will place embryos into the uteri of groups of outstanding female animals whose estrous cycles have been regulated by artificial means, such as hormone injections, ear implants, or intravaginal devices. The ova from this "superovulation" will be culled surgically or nonsurgically (by flushing) and then fertilized in the laboratory by spermatozoa from outstanding males. The fertilized ova can then be cultured, frozen, and stored until needed. Finally, the embryos will be placed in foster mothers nonsurgically.

Ultimately, it maybe possible to sex the embryos by separating the X- and Y-bearing spermatozoa or by identifying the male embryos by immunological techniques so that recipient beef cows will receive primarily male embryos and dairy cows will receive primarily female embryos. Techniques for reducing early embryonic deaths, the major cause of infertility in all farm animals, are also likely to be developed within this time frame.

Achieving these goals will entail the funding of research in three major areas: 1) the development of improved estrous cycle regulation techniques; 2) the development of improved techniques for superovulation and embryo collection, storage, sexing, and transfer; and 3) the development of methods for reducing embryo mortality and improving fertility in all classes of farm animals.

Vigorous pursuit of research in these areas could result, by year 2000, in the marketing of large numbers of genetically engineered embryos containing genes that will improve fertility and fecundity and will result in improved rates of gain, improved carcass characteristics, increased milk production, and increased resistance to diseases in offspring. Despite recent spectacular breakthroughs in introducing human genes into laboratory animals, a great deal remains to be learned about the factors that control chromosomal integration of foreign DNA, the retention of that DNA during embryonic development, and ultimately the expression of DNA, without disruption of the formation and development of the embryo. These developments will affect the major drug companies, genetic engineering companies, equipment manufacturers, veterinarians, inseminators, and extension workers, as well as the Nation's farmers.

The ultimate goal of this research is to increase the efficiency of production so that fewer animals, and less input of labor will be needed to produce the needed animal products.

Regulation Of Livestock Growth and Development

The rate and composition of growth is a critical factor in determining the cost of producing livestock products (Allen, 1985). While much is known about genetic and nutritional variables that influence animal growth, much less is known about the hormonal, cellular, and metabolic mechanisms that determine how and at what rate nutrients are partitioned into the growth of muscle, fat, bone, and the tissues of major concern. An understanding of these fundamental mechanisms is needed to provide a foundation for applying new technologies to the development of products to improve the rate, efficiency, and composition of animal growth.

The potential applications of genetic engineering, cloning, and immunology for the improvement of growth in food-producing animals are many. For example, recombinant DNA technology is responsible for providing sufficient quantities of bovine and porcine growth hormone so that scientists can now determine their role, mode of action, and potential use when administered to animals used for producing meat and milk. In the future, this kind of research may also lower the cost of beef production by permitting small cows, which have lower maintenance costs, to produce large market cattle of desirable composition. It also seems likely

red

U a e q e mea re ba ma m da d da a a g a d mp m d g a g g w that biotechnology will give rise to new products that can alter the inherent mechanisms of muscle protein and adipose (fat) tissue accretion so that the efficiency of meat production will be improved by the conversion of more nutrients into lean meat and less nutrients into fat. Such a development would be in keeping with the consumer demand for lean, but highly palatable, meat at a reasonable cost, and with the medical recommendations that the U.S. consumer reduce the intake of calories from dietary fat.

Other opportunities for advances involve the physical sciences. These include the need for more rapid, accurate, and economical ways of maintaining the identity of animals through the time of slaughter, and for determining the composition of the living animal and its carcass. Improved methods of identifying mammalian meat animals would be a basis for a national record system. This system would benefit producers, packers, regulatory agencies, and consumers, since it could provide information concerned with marketing, carcass merit, disease, and residue-monitoring programs.

A quick and accurate assessment of body composition not only would improve livestock production data and marketing procedures, but would be an example of new technology that could also be used to address human concerns about body weight and obesity. Current procedures used for determining body composition in livestock are too slow, inaccurate, or expensive for adoption by the industry. As a result, the real value differences between animals of low and high carcass merit, as affected by fat content, are normally not fully realized in the market when animals are sold alive.

The implications of applying these kinds of technologies for improving the production efficiency, composition, and consumer cost of animal products are numerous. They include the more efficient use of livestock feeds, possible changes in crop production priorities, improved composition of animal food products, improved production practices from more complete animal records, and implications related to human health. The application of these technologies will depend on understanding the fundamental principles or mechanisms involved in each major research area.

Animal Nutrition

The U.S. food animal industry is immense. Food animals provide 70 percent of the protein, 35 percent of the energy, 80 percent of the calcium, 60 percent of the phosphorus, and significant proportions of the vitamins and mineral elements in the average human diet in the United States (Pond, 1985).

The future of this industry will depend not only on profitability, but also on the industry's adoption of new technology and on the industry's response to consumer concerns about cost, esthetics, convenience, and health. Areas of nutrition research that may result in major advances in animal food production and use in the next 20 years include: 1) the relation of animal product consumption to human health, 2) alimentary tract microbiology and digestive physiology, 3) voluntary feed intake control, 4) maternal nutrition and progeny development, and 5) aquiculture.

Many consumers are concerned about the effect on human health of consuming animal food products because of the amount and composition of fat in those products as well as the amount of sodium, nitrates, and potentially harmful bacteria or chemical residues. Studies have suggested strong links between some of these factors and human cancer, osteoporosis, and cardiovascular disease. Research on-line is addressing these concerns by applying nutritional and genetic principles to the improvement of animal food products. For example, changes in animal fatty acid composition will be possible by using "protective" feed additives in specific animal diets. Changes in total animal fat content will probably occur through energy restriction, nutrient partitioning, and genetic selection. Sodium content of animal products can be reduced at the processing stage.

The direct impact of advances in this area will be animal food products that are safer for human health. The indirect impacts may be greater, however: to produce such products, producers may have to switch to more pasture, forage, and nonconventional feed resources. Such adjustments could change the total profile of agriculture.

Research into factors controlling voluntary feed intake and nutrient partitioning will result in the diversion of the use of nutrients from body maintenance to lean tissue growth and other productive functions. Such methods will save feed and provide opportunities for alternative uses of feed resources.

More complete knowledge of maternal nutrition in relation to fetal survival and prenatal and postnatal development may lead to significant increases in the amount of edible product per breeding unit. This outcome will be translated into savings in labor and resource use.

Finally, aquiculture has emerged as an important new field of animal agriculture in the United States. Research into specific nutrient requirements for different species of fish during all phases of the life cycle, and interactions between nutritional requirements and water environment, will provide new technology that will make the industry more competitive in animal agriculture. Future growth of private aquaculture will provide an additional supply of edible fish and shellfish for consumption by the U.S. population, whose per capita appetite for animal products may be saturated.

Animal Disease Control

Diseases of livestock are the greatest single deterrent to the efficiency of animal production (Osburn, 1985). Together, animal health-related problems and the resulting inefficiencies in reproduction limit the productive capacity of livestock enterprises to 65 to 70 percent of their potential. Although major epidemic diseases such as foot-and-mouth disease and tuberculosis have been eradicated or controlled, an estimated $17 billion or more annually is lost in production because of a variety of infectious diseases, parasites, toxins, and metabolic disorders.

Some of these losses result from a lack of understanding of animal health problems, such as reproductive inefficiency, neonatal death losses, or mastitis. Other losses relate to the change in structure of livestock enterprises to a system that has both fewer farms and a greater concentration of animals per farm. For example, dairy operations of up to 5,000 milking cows, and poultry operations of 100,000 or more birds, are now relatively common. In these large production units the introduction of an infectious disease can have devastating consequences.

The technologies that show the greatest promise for improving management schemes and controlling disease are: 1) data management and systems analysis, 2) rapid diagnostic tests, 3) selection for disease-resistant strains of livestock, 4) genetic engineering of micro-organisms and embryos, and 5) immunobiology.

Computers and computer programs already allow the farm manager to assess the well-being of each animal in large production units. Data on feed consumption, vaccination records, and conception dates, for instance, can be stored in the computer and retrieved quickly by the manager or veterinarian. Such systems can be coordinated with radiotransmitters used to identify each animal. Within 5 to 10 years such systems will be widely used by progressive animal producers.

Advances in biotechnology will include further development of animal-side test kits for rapid assessment of animal health. One of these tests, the enzyme-linked immunosorbent assay, can test for hormones (to determine pregnancy), detect drug residues in milk or feed, and diagnose disease (through antibody detection). If economical tests can be developed, their use will be widespread and immediate (5 to 10 years).

For certain intractable health problems, like parasites and mastitis, efforts are being made to breed disease-resistant strains of livestock. Advances in embryo transfer, gene insertion into embryos, and amplification of gene products will increase the number of more desirable offspring by year 2000.

Recombinant DNA technology is already being used to alter vaccines genetically so that pathogens in the vaccines cannot replicate in the inoculant and cause a mild infection that could spread to other animals. The development of vaccines for several viral diseases, such as bluetongue, should be possible in the next 15 years.

Finally, knowledge gained in the past two decades is being used to improve that system's efficiency. Ingredients (adjuvants) in vaccines are being used to pace the release of antigens into the body or to manipulate or favor certain immune responses. In addition, monoclinal antibodies are being used to detect and prevent disease. The major constraints to the use of these technologies include: 1) funding of field studies, 2) commercialization of products by the biological and pharmaceutical industries, and 3) cumbersome and expensive processes for assuring quality. The benefits of controlling disease will be a decrease in the cost of production for the farm operator and a decrease in food cost for the consumer.

Livestock Pest Control

Major insect pests cause losses to livestock and poultry of more than $2.5 billion (Campbell, 1985). Some insects, primarily the blood feeders, are pests of all warm-blooded animals. Others are host-specific, although related species may prey on several classes of livestock. Losses maybe direct, in terms of decreased livestock products; or indirect, in the form of insect-transmitted disease, secondary infections, predisposition to other diseases, irritation that causes unthriftiness, and costs of insect control.

New technology, particularly for livestock insects that are difficult to control, will be more expensive and will have a lower cost-benefit ratio than that of current technology. Progress in new technology in the science of veterinary entomology is relatively slow for the same reason that adaptation of existing technology is slow—there are few scientists (60) doing research. Several technologies show promise for controlling insect pests of livestock, however.

Although animal producers will continue to use insecticides for the immediate future, progress is being made in such areas as habitat management (pasture rotation and brush control for ticks); integrated pest management (biocontrol, sanitation, and waste management for fly control at feedlots and dairies); and use of pest-resistant breeds in cross-breeding programs (Indian crossed with European cattle).

For blood-feeding insects research is directed at developing slow-release technology, whereby a chemical ingredient is formulated into a matrix that slowly erodes or vaporizes to release insecticide. For example, insecticide boluses are used in the stomach of animals, where they slowly release insecticide that destroys manure-developing fly larvae. Insecticide can also be implanted in an animal's body. Eartags impregnated with a slow-release insecticide have been very effective for horn fly control and have improved face fly control in cattle. As the insecticide vaporizes, it spreads over the haircoat of the animal, destroying insects that rest or feed on the animal. (However, horn fly resistance to the pyrethroid insecticides used in eartags has become widespread.) The newest of these technologies are implants that directly release insecticide into the bloodstream, destroying blood-feeding insects. However, implants and boluses will have a limited effect for migratory, blood-feeding insects unless many producers join the control effort.

Recombinant DNA technologies will be used for the molecular cloning of desired antigens, toxins, enzymes, or other biologically important molecules for use as research tools or in the development of vaccines for bluetongue, anaplasmosis, and other diseases for which insects are vectors. In addition, this technology will enhance the study of molecular genetics and metabolic control in Bacillus *thuringiensis,* a bacterium pathogenic to some insects.

Advances in genetics will allow scientists to manipulate the reproductive capabilities of pest species. These advances include the sterile insect release method and chromosomal translocation, among others.

If technology already available were used on a wider scale, livestock losses from insects could be reduced by one-third ($700 million). This outcome would entail at least a doubling of current extension efforts in livestock entomology. The new methodology discussed might reduce losses by another 15 to 25 percent, but at a lower cost-benefit ratio.

Environment and Animal Behavior

The effects of environment on animal well-being have become ever more important because of the trend toward production systems that confine a large number of animals together in a more artificial environment (Curtis, 1985). Confinement simplifies the environment, reducing an animal's opportunities to alter its surroundings to advantage. While such intensive systems increase production per unit of labor input or space, they can be detrimental to animal function and performance.

The advent of intensive production systems changed the relative importance of various environmental factors as well as the strategies for improving animal production through the application of technology. New technologies likely to emerge by 2000 as a result of current research lie in the areas of energy conservation, optimization of total stress, stress-altered disease resistance, and photoregulation of physiological phenomena.

Feed and fuel—sources of energy—account for much of the cost of animal production. Although the trade-offs between feed and fuel have been quantified for most species, the integration of additional research will result in further energy savings. For example, environmental temperature management schemes developed in an era of cheaper fuel are too luxurious today. Animal producers tend to maintain constant environmental temperatures for their stock, even though the animals evolved in the cyclical thermal environment of nature. In one experiment, when young pigs were allowed to regulate their own environmental temperatures, they inserted a daily 200 F fluctuation of warm afternoons and cool nights, resulting in unchanged pig performance but a 50-percent reduction in fuel use during cold weather. Lowering thermostat settings to parallel age-dependent changes in thermal requirements has also been found to save fuel. In some cases cooler surroundings spur appetites, so performance actually increases. Cost-effective, low-maintenance designs of heat exchangers and solar heating systems will affect further energy savings.

Either too much or too little environmental stimulation can have deleterious effects on the performance, health, and well-being of agricultural animals. To optimize total stress, more must be learned about how stress acts on and is perceived by animals. Devices that animals can use to regulate certain environmental factors are already being recommended to farmers. Computerized sensing devices and control equipment will make biofeedback-linked automation of environmental regulation a reality in animal agriculture.

Researchers are also investigating how the environment influences specific mechanisms of immunity to disease. A variety of common environmental stressors-temperature, crowding, mixing, weaning, limit-feeding, noise, and movement restraint—are known to alter animals' defenses against infectious agents. New techniques in basic science, coupled with more traditional neurobiological, endocrinological, and immunological approaches, can yield abetter understanding of how stressors influence regulatory signals among lymphoid cell subpopulations.

The regulation of light is of particular interest in animal production. The advent of photoperiod management revolutionized the poultry industry 40 years ago. Light is managed in poultry confinement operations so that it stimulates poultry growth. In the last two decades the effects of photoperiod management have also been characterized for sheep reproduction. Although the results of similar studies on cattle and swine have been less definitive, some results have been encouraging: under controlled lighting, sows weaned heavier piglets, cows yielded more milk, and lambs grew faster. Experiments now in progress will produce information immediately applicable to animal production.

Crop Residues and Animal Wastes

Improved use of crop residues and animal wastes represents a tremendous potential for more efficient use of resources (Fischer, 1985).

Livestock on U.S. farms produce about 55 million tons of recoverable manure. Approximately 363 million tons of crop residues are produced annually in the United States. Several technologies and major lines of research and development exist in this area: 1) energy from manure, 2) animal feed from manure, 3) chemicals from crop residues, and 4) animal feeds from crop residues.

The high volume of manure production that occurs at many large feedlots and dairies is an opportunity in disguise. Manure has value both as a soil additive and as a source of energy for heat and electricity. Traditionally, manure has been either applied to the soil surface in an unprocessed form or disposed of in a sewage lagoon. Application of manure to the soil surface creates environmental problems in many areas and results in a loss of up to ***90*** percent of the useful nitrogen value of the manure. Technology is available to inject the manure below the soil surface, resulting in only a 5-percent loss of nitrogen (Suttan, et al., ***1975)***.

Large farms may benefit from installing anaerobic digesters to produce methane from manure, for use as a heating fuel or as a substitute for propane in electric generators. The slurry that remains after digestion contains most of the original nutrient value and may be applied to cropland as fertilizer. Injection of the slurry is preferred, since most of the nitrogen after digestion is in the form of ammonia.

In many farm operations, it is profitable to process manure and use it as a source of nonprotein nitrogen and fiber in cattle and dairy cow rations. Manure is a low-cost source of nutrients, and reusing it as feed reduces the volume of animal wastes that must be processed or disposed of. If used for cattle feed, manure must first be concentrated, then processed by heat treatment or by ensiling.

Using crop residues as a source of chemical feedstocks and animal feed involves some complex trade-offs in most areas because crop residues are becoming widely valued for their ability to reduce soil erosion in combination with conservation tillage practices. Even when crop residues are completely tilled into the soil, they have significant value in maintaining soil structure and nutrient content. However, useful amounts of residues maybe removed from fields in many parts of the United States where cropland slopes are gentle and residue density is high. The cost of transporting bulky crop residues generally constrains the area over which collection is economically feasible.

Several technologies under development have promise in areas where residue collection is economically feasible. Residues may be broken down into their component parts by mechanical, chemical, or biological processing, or a combination of all three. The principal components of crop residues are lignin, hemicellulose, and cellulose. Lignin can be used to produce solvents such as benzene, toluene, and xylene. Hemicellulose is readily converted into furfural, which is, in turn, a feedstock for the production of numerous chemicals. Plastic films and fibers and the simple sugar, glucose, can be produced from cellulose. Production of these chemicals is likely to require moderately large-scale technology based on industrial processes and equipment. Transportation costs reduce the likelihood that crop residues will be used as feedstock for industrial processing. Some farms may adopt direct combustion of crop residues for use as a source of heat for grain drying.

In the near term, the most likely process for conversion of crop residues is biological: ruminant animals. Most crop residues can be fed directly to ruminant animals as a source of roughage. A substantial potential exists for developing technologies to increase the palatability and digestibility of crop residues. Numerous efforts have been made to develop simple mechanical and chemical pretreatments, with some success. The problem is difficult, owing to the degree with which the digestible hemicellulose and cellulose are bound to the nondigestible lignin component in the residues of mature cash grain crops. Additional research and development leading to economic and effective pretreatments would have substantial benefits because the size of this resource is so large.

Plant Genetic Engineering

Biotechnology is not new to plant agriculture (Fraley, 1985). Plant breeding, agrichemicals, and microbial seed inocula have made major contributions to the remarkable development of American agriculture. Within the last decade, major advancements have been made in the understanding of gene function and architecture, and powerful methods have been developed for identifying, isolating, and modifying specific DNA segments.

The further application of biotechnologies in plant agriculture could modify crops so that they would make more nutritious protein, resist insects and disease, grow in harsh environments, and provide their own nitrogen fertilizer. While the immediate impacts of biotechnology will be greater for animal agriculture, the long-term impacts may be substantially greater for plant agriculture. The potential applications of biotechnology on plant agriculture will include microbial inocula, in vitro plant propagation methods, and genetic modification.

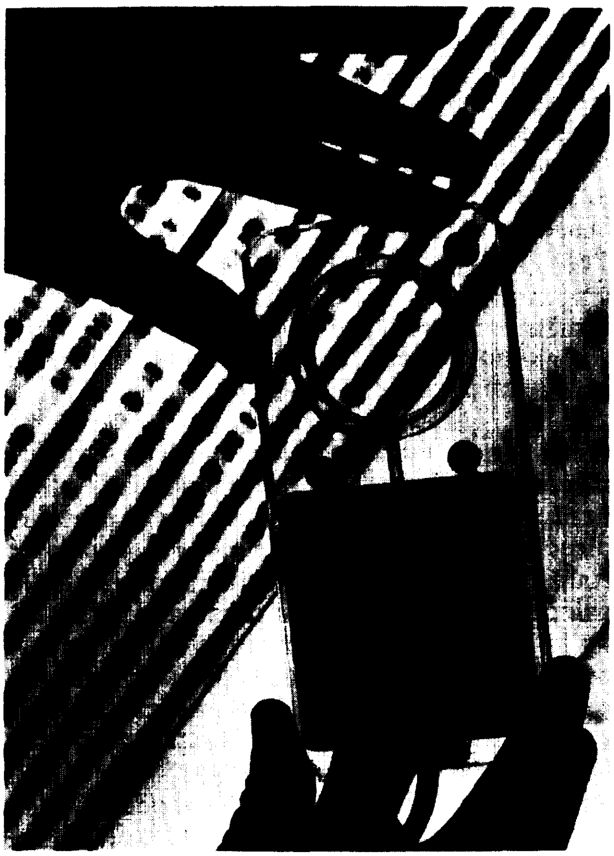


Photo credit: US. Department of Agriculture, Agricultural Research Service

Plant geneticist is determining the structure of a soybean DNA segment that resembles the movable genetic elements first discovered in corn. Each band represents a "letter" or nucleotide, in the genetic code.

Microbial Inocula

Research on plant-colonizing microbes has led to a much clearer understanding of their role in plant nutrition, growth stimulation, and disease prevention, and the possibility exists for their modification and use as seed inocula. Rhizobium seed inocula are already widely used to improve nitrogen fixation by certain plants (legumes). Extensive study of the structure and regulation of the genes involved in bacterial nitrogen fixation will likely lead to the development of more efficient inocula.

Two years ago, scientists at the University of California, Berkeley, genetically engineered ice-nucleation bacteria that inhibit frost formation in potato plants. To form ice, there must be nucleation sites around which the water molecules can form the regular ice structure. In the ecosphere, this role is performed by specialized bacteria called *Pseudomonas syringae,* which contain specific proteins that act as the nucleation centers for the growth of ice crystals. B y colonizing plants in the manner of epiphytes,[5] these bacteria induce ice formation and thus cause frost damage to plants as the temperature drops below freezing (Feldberg, 1985).

Scientists constructed a new strain of bacteria in which the nucleation protein is absent or altered so that the bacteria can no longer play the role of nucleation centers. Having successfully constructed a new strain of bacterium, these researchers were ready to field test this new organism to see if it would outcompete the normal strains. If so, the new bacterium would protect crops from frost damage, and millions of dollars in lost crops would be saved. As the

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Plants that derive their moisture and nutrients from the air and rain and that usually grow on another plant. Spanish moss is an epiphyte.

novel bacteria were scheduled for release to the field, a coalition of public interest groups filed a lawsuit to postpone the field trials (see chapter 10 for more detailed discussion about this controversy).

Recently, Monsanto announced plans to field test genetically engineered soil bacteria that produce naturally occurring insecticide capable of protecting plant roots against soil-dwelling insects (House Committee on Science and Technology, 1985). The company developed a genetic engineering technique that inserts into soil bacteria a gene from a micro-organism known as *Bacillus thuringiensis,* which has been registered as an insecticide for more than two decades. Plant seeds can be coated with these bacteria before planting. As the plants from these buds grow, the bacteria remain in the soil near the plant roots, generating insecticide that protects the plants.

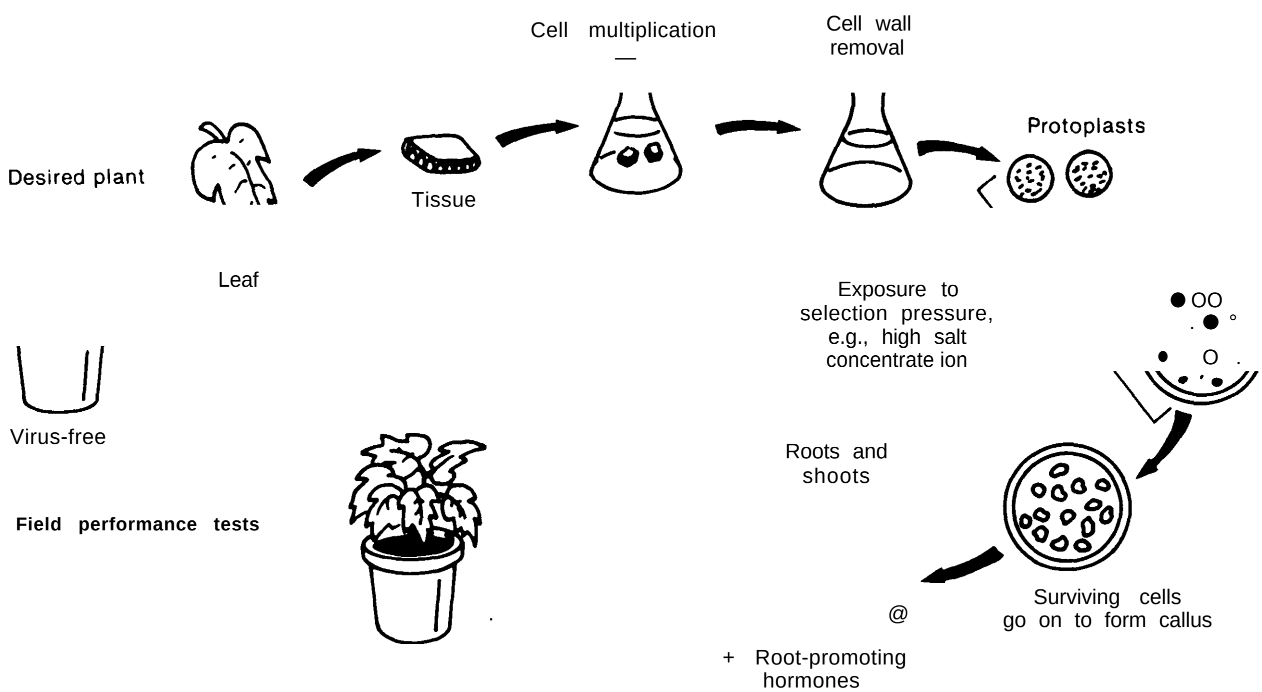
Plant Propagation

Cell culture methods for regenerating intact plants from single cells or tissue explants are being used routinely for the propagation of several vegetable, ornamental, and tree species (Murashige, 1974; Vasil, et al., 1979). These methods have been used to provide large numbers of genetically identical, disease-free plants that often exhibit superior growth and more uniformity over plants conventionally seed-grown (figure 2-5). Such technology holds promise for important forest species whose long sexual cycles reduce the impact of traditional breeding approaches. Somatic embryos[6] produced in large quantities by cell culture methods can be encapsulated to create artificial seeds that may enhance propagation of certain crop species.

‘Embryos reproduced asexually from body cells.

Figure 2-5.-Plant Propagation— From Single Cells to Whole Plants

The process of plant regeneration from single cells in culture



SOURCE: Off Ice of Technology Assessment.

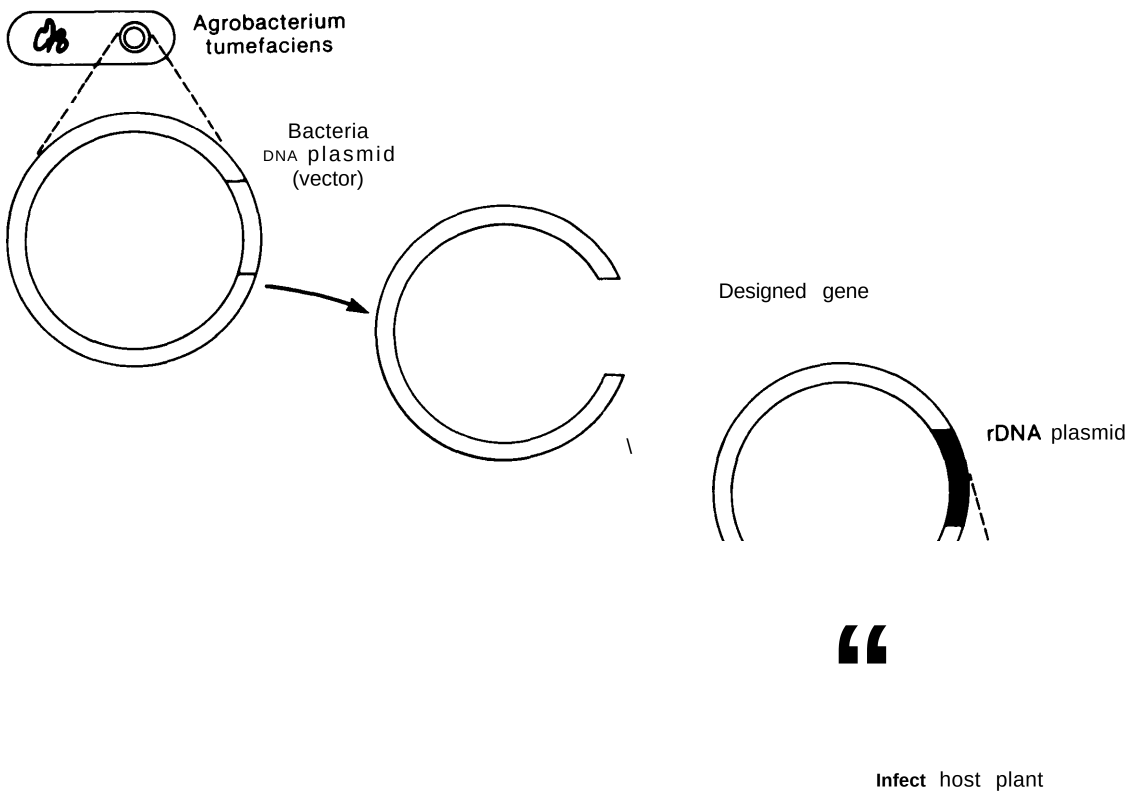
Genetic Modification

Three major biotechnological approaches—cell culture selection, plant breeding, and genetic engineering—are likely to have a major impact on the production of new plant varieties. The targets of crop improvement via biotechnology manipulations are essentially the same as those of traditional breeding approaches: increased yield, improved qualitative traits, and reduced labor and production costs. However, the newer technology offers the potential to accelerate the rate and type of improvements beyond that possible by traditional breeding.

Of the various biotechnological methods that are being used in crop improvement, plant genetic engineering is the least established but the most likely to have a major impact. Using gene transfer techniques, it is possible to introduce DNA from one living organism into another, regardless of normal species and sexual barriers (figure 2-6). For example, it has been possible to introduce storage protein genes from French bean plants into tobacco plants (Murai, et al., 1983) and to introduce genes encoding photosynthetic proteins from pea plants into petunia plants (Broglie, et al., 1984).

Transformation technology also allows the introduction of DNA coding sequences from virtually any source into plants, providing those sequences are engineered with the appropriate plant gene regulatory signals. Several bacterial genes have now been modified and shown to function in plants (Fraley, et al., ***1983;*** Herrera-Estrella, et al., ***1983).*** By eliminating sexual barriers to gene transfer, genetic engineering will greatly increase the genetic diversity of plants. This technology will have a major impact on the seed and plant production industries as well

Figure 2-6.—Gene Modification-insertion of a Desired Gene into the Host Plant Through Vectors (or gene taxis)



SOURCE: Office of Technology Assessment

as on the chemical, food processing, and pharmaceutical industries.

The commercialization of plant biotechnology will require breakthroughs in several technical areas, including increased understanding of plant cell culture, plant transformation systems, plant gene structure and function, the identification of agronomically useful genes, and plant breeding. Increased research funding is needed in these specific areas and generally in the basic plant sciences and in molecularbiology to accelerate technical development. Commercialization of plant biotechnology will also depend on other factors, including environmental regulation, university-industry relations, economic incentives, and consumer acceptance.

Improved plants produced by gene transfer methods should be commercially available in 7 to 10 years. The introduction of plants produced and selected using cell culture manipulations and certain biotechnology-derived microbial seed inocula or products could occur earlier.

Plant genetic engineering methods will initially emphasize the same targets for crop improvement (increased yield, improved qualitative traits, and reduced labor and production costs) as traditional breeding programs do. Ultimately, the technology will lead to improvements not even imagined in American agriculture.

Enhancement of Photosynthetic Efficiency

Photosynthesis is the fundamental basis for plant growth (Berry, 1985). Through photosynthesis, energy from sunlight is absorbed by chlorophyll-containing tissues of the plant and used to assimilate carbon dioxide into organic molecules. The photochemical reactions in the process are intrinsically very efficient. However, several factors inhibit photosynthetic efficiency in plants: 1) certain mechanisms of photosynthesis itself, 2) the efficiency of water and nutrient use, and 3) environmental stress. Research is ongoing in each of these areas.

Plants vary in their efficiency of photosynthesis. Higher plants have an enzyme (RuBP carboxylase) that causes oxygen to react in a side reaction during photosynthesis, diverting energy that would otherwise be used to fixate carbon dioxide. This oxygenase reaction, which appears to result from a metabolic defect in plants, is encouraged by the high-oxygen, low-carbon dioxide concentration of normal air. Artificially increasing the content of carbon dioxide in the air partially suppresses this mechanism and generally results in increased crop yields. This suggests that improvements in the mechanism of photosynthesis could result in increased yields, all else being equal.

Plants known as C_4 plants have developed a biological and morphological modification that reduces the impact of the oxygenase reaction. As a result, they waste less energy during photosynthesis. C_4 plants include corn, sorghum, sugarcane, and millet. Plants that cannot suppress the oxygenase reaction are called C_3 plants. They include wheat, soybeans, cotton, and rice.

C_4 plants have an advantage over C_3 plants when leaf temperatures are high and a disadvantage when they are low. Moreover, C_4 plants use nitrogen and water more efficiently in photosynthesis. Thus water use efficiency could be increased in warm, arid regions if more C_4 plants could be used.

Along-term prospect for improving photosynthetic efficiency lies in research to understand the basis for the oxygenase reaction and efforts to inhibit the reaction chemically or to modify the enzyme by using rDNA technology. Success will depend on many breakthroughs in understanding the chemistry and molecular biology of chloroplasts and in manipulating chloroplast genes.

Molecular biology has already yielded the ability to modify the sequence of amino acids in RuBP carboxylase to produce modified versions of the protein. This provides experimental tools of unimagined power for investigating the mechanisms of enzyme-catalyzed reactions.

Other research is being directed at improving the efficiency of use of water and nutrients through: 1) better management techniques that use microcomputer-based plant growth models, and 2) new instrumentation to monitor cropperformance. Improved weather forecasting will also be important. Breeding plants for efficient water and nutrient use and for stress resistance is possible and has already had some impact. These technologies have the greatest immediate prospect for improving the efficiency of photosynthesis in the next decade, although a strong research effort is needed to realize these potentials.

Plant Growth Regulators

Plant growth regulators are natural or synthetic compounds that are applied (usually directly) to a plant to alter its life processes or structure in order to improve quality, increase yields, facilitate harvesting, or any combination of these (Nickell, 1985). Used commercially since the 1920s, plant growth regulators have had a variety of impacts. One of their earliest was in rooting powders and solutions for the propagation of cuttings. Another was the use of maleic hydrazide to prevent sprouting in potatoes and onions during storage.

The biggest boost to plant growth regulation came with the discovery that phenoxyacetic acids kill broadleaved plants (such as weeds) but not grasses, Using such chemicals in herbicides has out distanced economically all other uses of plant regulators and, until recently, dwarfed their general importance.

Overall research on plant growth regulation is currently multipronged. Industrial research is particularly directed at two major U.S. crops—corn and soybeans.

An increasingly important research effort is that for antidotes to herbicides. Called protectants, or safeners, such compounds can be applied to the crop, usually to the seed, to make it resistant to an herbicide. When the herbicide is applied to the crop row, it kills only the weeds.

USDA has used plant growth regulators so successfully in the guayule bush that it maybe theoretically possible to have a rubber industry within the boundaries of the United States.

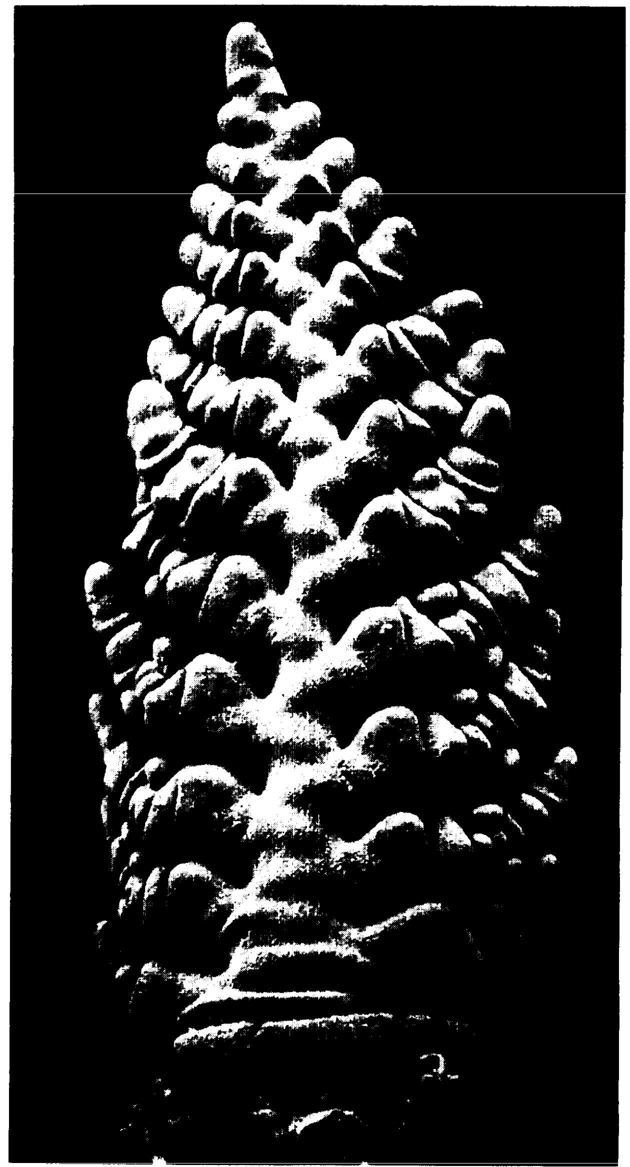


Photo credit: John Gardner, Brigham Young University

Scanning electromicrograph of a developing wheat head reveals vertebrae-like spikelets branching from its axis. By unlocking the hormonal secrets locked in the tissue of the spikelets, researchers hope to increase the number of spikelets per head, and the number of kernel-producing florets on each spikelet—thus increasing yield.

Ethephon, which is used to prevent coagulation of latex flow in rubber trees, eliminates the need to tap the tree daily. Plant growth regulators of the triethylamine type are used to increase the total rubber content of the guayule bush. A similar use of growth regulators is the use of paraquat on pine trees. The result is a significant increase in oleoresin content and the possibility that the naval store industry may take on new life in the Southeast United States.

The success in the sugarcane industry in the control of flowering, in the use of gibberellic acid to increase the tonnage of both cane fiber and sugar, and in the use of ripeners to enhance sugar yields allows industry to turn its attention to developing dessicants for use as harvest aids.

In the grape industry the successful use of gibberellins on grapes is stimulating studies on the control of abscission (the shredding or separating of plant organs such as fruit or leaves) and the use of ripeners to increase sugar content. Abscission agents have been used successfully on cotton, oranges, cherries, and olives, where it reduces the tenacity of the fruit sufficiently to allow easy harvest by hand-picking, mechanical harvest, or shaking. Abscission agents have also been used to thin apple blossoms, changing the yield pattern from alternating light-fruiting and heavy-fruiting years to annual, successfully bearing years.

Plant growth regulators can reduce harvesting costs by changing the shape of the whole plant or just its fruit to allow easier mechanical harvesting. Apples, grapes, and wheat are examples. Gibberellic acid is used with grapes, for instance, to lengthen the pedicel to each berry. This reduces the rotting that normally occurs because grapes grow too close together. The size and shape of both apples and grapes can be changed by cytokinins and gibberellic acid.

Regulators can also be used to speed or delay the maturation of fruit. Success has already been notable with navel oranges and with pineapple, peppers, cherries, coffee, tomatoes, and tobacco. In addition, the tremendous losses of food crops following harvest almost guarantees an increase in research to develop preharvest and postharvest preservation through plant growth regulators.

Finally, preliminary indications with Cycocel and other chemicals suggest that overcoming environmental limitations via plant growth regulators should be a fertile field for investigation.

A substantial number of new products or new uses for existing products can be expected in the 1990s. Because of the difficulty in registering new compounds, many of the advances will be extensions of uses of existing products. Since so much of the chemistry, evaluation, and expensive toxicology has already been done on existing products, finding new uses for those products might well have a greater impact than researching new compounds.

Plant Disease and Nematode Control

Plant diseases are caused by viruses, fungi, bacteria, nematodes, and other micro-organisms (Browning, 1985). Collectively, these organisms cause considerable losses before and after harvest, an estimated $18.6 billion annually. Only a few of the thousands of species of pathogens and insects cause concern, however; the rest are controlled by natural immunity. Many organisms that do cause loss may theoretically be controlled by managing more wisely the mechanism of host-plant resistance. This area is a major one for research.

Some beneficial micro-organisms help protect plants from disease. In addition to their nutritional benefits, modulating bacterial and mycorrhizal (root-extending) fungi render some plants more disease resistant. Micro-organisms also provide a vast gene pool for improving plants and other micro-organisms through rDNA technology. "That technology is already available for synthesizing microbes of naturally occurring products for use as pesticides. Such genetic engineering should lead to new biocontrol agents; for example, modified plant viruses that wilI give cross protection. One success story is that of crown gall, a serious bacterial disease of many woody and herbaceous plants. Crown gall is now controlled biologically by the K84 strain of bacterium that is a close relative of the bacterium that causes the disease. Inoculating a seed or transplant with K84 produces a bacteriocin that protects against crown gall.

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D sease es s an u a s an be b ed and es s an e managed Genet a y p an es s an e s ond oned by ma o effe genes and m no -effec genes A though ma o effe genes a e eas e o wo k w h and g e mo ed ama e u he effe ene n he f e d has f e quently been disappointing. Thus researchers have turned to minor-effect genes, which are more difficult to work with but are the most successful way of controlling disease in the homogeneous cultivars demanded by mechanized Western agriculture. Major-effect genes show promise for controlling disease in heterogeneous cultivars, as occurred with multiline oat and wheat cultivars developed in Iowa and Washington, Even highly epidemic foliar pathogens can be controlled in this manner. A major line of research may result in using resistance genes to obtain diversity without sacrificing bona fide needs (as opposed to merely cosmetic needs) for uniformity. This may be one of the fastest ways simultaneously to control certain highly epidemic diseases and to reap the tremendous potential benefits from plant genetic engineering.

Additional work is needed at all levels of pesticide development, but is especially needed for completing the development of systemic pesticides that have two sites of activity on the molecule, thereby extending the pesticide's effective life. Research is also needed on more effective delivery systems for systemic pesticides.

Other research will be directed to developing naturally occurring chemicals that will stimulate the plant's defense mechanisms or enhance activity by biocontrol agents. Ultra-low-volume delivery systems will be needed for these and regular pesticides that are active at very low dosages.

A final important area for research is that of crop loss assessment. Although it is possible to assess plant loss from single pathogens, weeds, and arthropods (and a few combinations of these), such assessments are less precise when made for larger areas, several cultivars, and a wide variety of plant stresses. Research to improve crop loss assessment will help set research priorities and aid in making management decisions.

Management of Insects and Mites

Insects and mites are humankind's greatest competition for food and fiber (Kennedy, 1985).

Although less than 1 percent of all insect and mite species are considered agricultural pests, those pests cause average annual losses to agricultural production of 5 to 15 percent, despite the expenditure of millions of dollars each year for agricultural pest control. Thus, protecting crops from such losses will continue to be an important component of agricultural production.

Research on this problem is being conducted in the broad areas of: 1) chemical controls for insects and mites, 2) genetic manipulation of plants and insects and their natural enemies, and 3) information processing.

Because they are highly effective, economical, and fast acting, chemical insecticides and acaricides (for mites) are widely used for reducing insect and mite populations to subeconomic levels. Advances in insect physiology, toxicology, and analytical chemistry are leading to the discovery of new compounds that disrupt the normal growth and development processes of insects. Compounds with juvenile hormone activity that prevent an insect from molting to the adult stage, those with anti juvenile hormone activity that cause insects to molt prematurely to the adult stage, and those that interfere with the normal synthesis and deposition of exoskeleton all hold promise for the future. Similarly, advances in the chemistry of natural products and the study of plant defenses against insects and mites are leading to the identification of naturally occurring, insecticidal and acaricidal compounds with novel modes of action. Many such compounds are likely to be suitable for large-scale production via fermentation processes with genetically engineered micro-organisms.

With existing application technology only 25 to 50 percent of a pesticide is actually deposited on plant surfaces, and less than 1 percent actually reaches the plant. In addition to being wasteful, this situation greatly exacerbates undesirable effects to the environment. One factor is the incorrect mixing and calibration by pesticide applicators. Efforts are thus being made to design equipment that injects pesticides at the proper rate directly into the lines carrying water to the nozzle, eliminating the need for tank mixing. Other research will ensure more uniform droplet size, will control spray drift, and will improve adherence of the spray to the plant.

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Advances in genetic engineering greatly increase the likelihood of new classes of insecticides and acaricides. Insect pathogens, including bacteria, fungi, protozoa, and viruses, are likely candidates for genetic engineering to enhance their utility as microbial insecticides. The pathogenic bacterium *Bacillus thuringiensis* is already commercially available and widely used to control caterpillars on certain crops. Genetic engineering holds great promise for expanding the spectrum of pests controlled by this bacterium.

Crop varieties resistant to insect pests have been used to manage insects with success in a number of important crops. Use of genetic engineering to transfer genes from resistant wild plants to crop cultivars holds great potential for insect and mite management, but requires very specific knowledge of the biochemical bases of the resistance crop to be transferred. In most cases, the requisite knowledge is not yet available.

Improvements in the design and availability of computer hardware and software will produce tremendous changes in insect and mite management at the research, extension, and farm levels. To contribute to crop profitability, insect and mite management entails the processing of tremendous amounts of information on the condition and the phonological stage of the crop, the status of insects and mites and their enemies in the crop, incidence of plant diseases and weeds and measures used in their control, weather conditions, crop production inputs, and insect and mite management options. Computers at the farm level, with access to centralized databases, will allow farm operators to design and implement pest management strategies for their farms. Some software systems are already in place and are continually being improved. In general, however, improvements in databases are awaiting advances in knowledge about pest dynamics and crop pest interactions.

Biological Nitrogen Fixation

Nitrogen is a critical nutrient for crop production (Alexander, 1985). Although abundantly available-either as atmospheric nitrogen (N_2) or in organic complexes in the soil—nitrogen in these forms cannot be used directly by plants. It must first be changed to ammonia (NH_3) or nitrate (NO_3). Thus the large supply of nitrogen needed to grow crops is most commonly provided by nitrogen fertilizers. However, such fertilizers are expensive, and their production consumes a nonrenewable resource, hydrocarbons.

Nitrogen can also be provided through biological nitrogen fixation, a process by which certain bacteria and blue-green algae use an enzyme, nitrogenase, to convert N_2 to NH_3. The most important of these bacteria agriculturally belong to the genus *Rhizobium*. These bacteria enter the roots of legumes and form nodules in which they "fix," or convert, nitrogen in the air to forms used by plants. A legume may receive all of its nitrogen needs this way, given the right *Rhizobium*. In turn, the rhizobia are somewhat protected from microbial competition and predation and from other detrimental effects in the soil environment.

Photo credit: Howard Berg, University of Florida

A scanning electron micrograph of a root tip from a sorghum *(Sorghum bicolor)* plant with kidney bean shaped bacteria *(Azospirillum brasilense)* on its surface. Such nitrogen-fixing bacteria may live on the root surface or in the surrounding soil. The white, threadlike projections are root hairs.

Other kinds of nitrogen-fixing bacteria live near cereal crops and grasses, possibly providing small, beneficial amounts of nitrogen to the plants and receiving needed organic compounds but no protection from detrimental effects in return. This relationship is known as associative fixation.

If its magnitude can be increased, the process of biological nitrogen fixation offers an attractive way to supply the large nitrogen demand of crops without the extensive use of nitrogen fertilizers. To this end, considerable research has been done in the last decade on the biochemistry and genetics associated with the process, and much useful information has been gleaned from this basic research. Research is also under way to determine the possibility of developing cereal crops that fix their own nitrogen, and recent studies have provided needed approximations of the amount of nitrogen provided by associative fixation.

To provide enough nitrogen biologically to sustain high crop yields, however, the stresses affecting legumes and rhizobia must be better understood, and improved bacterial strains and other ways to overcome these constraints must be found. These developments will come from a combination of well-established techniques and agronomic practices as well as new technologies. For example, conventional strain selection and genetic manipulation may be used to produce strains of rhizobia that can compete with soil micro-organisms or that can resist abiotic stresses such as pesticides, drought, and high temperatures. Plant breeding will be used to develop legumes that are better acclimated to soil conditions, have greater photosynthetic activity and less photorespiration, can resist modulation by less effective soil rhizobia in favor of inoculated rhizobia, and can prolong the duration of fixation. Less likely to come to fruition in this century, but of great importance, will be the development of cereals that can fix their own nitrogen in their tissues or root zones.

If funding is adequate, greater nitrogen fixation from legume-bacterial symbiosis will be realized in the next 10 years, and that from the associative fixation of cereal roots will be realized in 15 years. The benefits of these and future improvements will be the reduced use of hydrocarbons for fertilizer production, an increase in the availability of fertilizer worldwide, and less contamination of ground water.

water and Soil-Water-Plant Relations

The distribution of vegetation over the Earth's surface is controlled more by the availability of water than by any other factor (Boersma, 1985). In the United States, agriculture accounts for over 80 percent of the water consumed; about 98 percent of that water is used for irrigation of crops, particularly in the more arid Western States. Several factors complicate the availability of water for irrigation: 1) cities, industry, and farming are in fierce competition for the water available; 2) ground-water sources are gradually being depleted; 3) the costs of pumping and distributing surface water are gradually increasing; and 4) many surface and groundwaters are being contaminated by a variety of pollutants. Thus techniques to conserve adequate supplies of fresh water have become important.

Many important contributions have been made by studying water requirements of crops. Although this information has helped in planning reservoir and canal sizes, the hope for breeding plants with lower requirements for water has not been realized, and no technologies have been advanced that would help realize this goal in the next 15 years. Nearly all improvements in water use efficiency have come from improved irrigation techniques, especially the timely application of the amount of water needed and application in a manner that minimizes evaporation. (At present, nearly all the water taken up by the plant is immediately passed through and evaporated at the leaf surfaces. Only a very small fraction becomes part of the plant's permanent structure.)

Progress in improving the water use efficiency of crops will hinge on gathering the information needed to develop a theoretical framework of the mechanisms that influence uptake, use, and loss of water—in humid regions as well as arid and semiarid regions. Dramatic progress in the development of instrumentation now permits researchers to measure many plant physiological responses in real time. It also allows the recent measurements of plant hormones and

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On e he me han sms of wa e u e effi en y ha e been den fied and a be e unde s and ng of he p an as an n eg a ed who e s ga ned b o echno ogy may he p n he de e opmen of mo e wa e effi en p an s Al eady e en ex pe men s sugges tha ssue u u e may p o de ma e a less us ep b e o wa e s es Fo example alfa fa and e e ne ha e been obtained that tolerate 2 percent sodium chloride, a salt concentration lethal to nonselected cells.

For the near term, however, traditional methods of plant breeding must be relied on, even though there is increasing evidence that for many crops the limits to improvement by this method are being approached. To breakthrough this yield plateau, the breeder must work with the physiologist and biochemist to understand the stress response hierarchy and eventually to control enzymes, membrane characteristics, and mechanisms for communication in the plant.

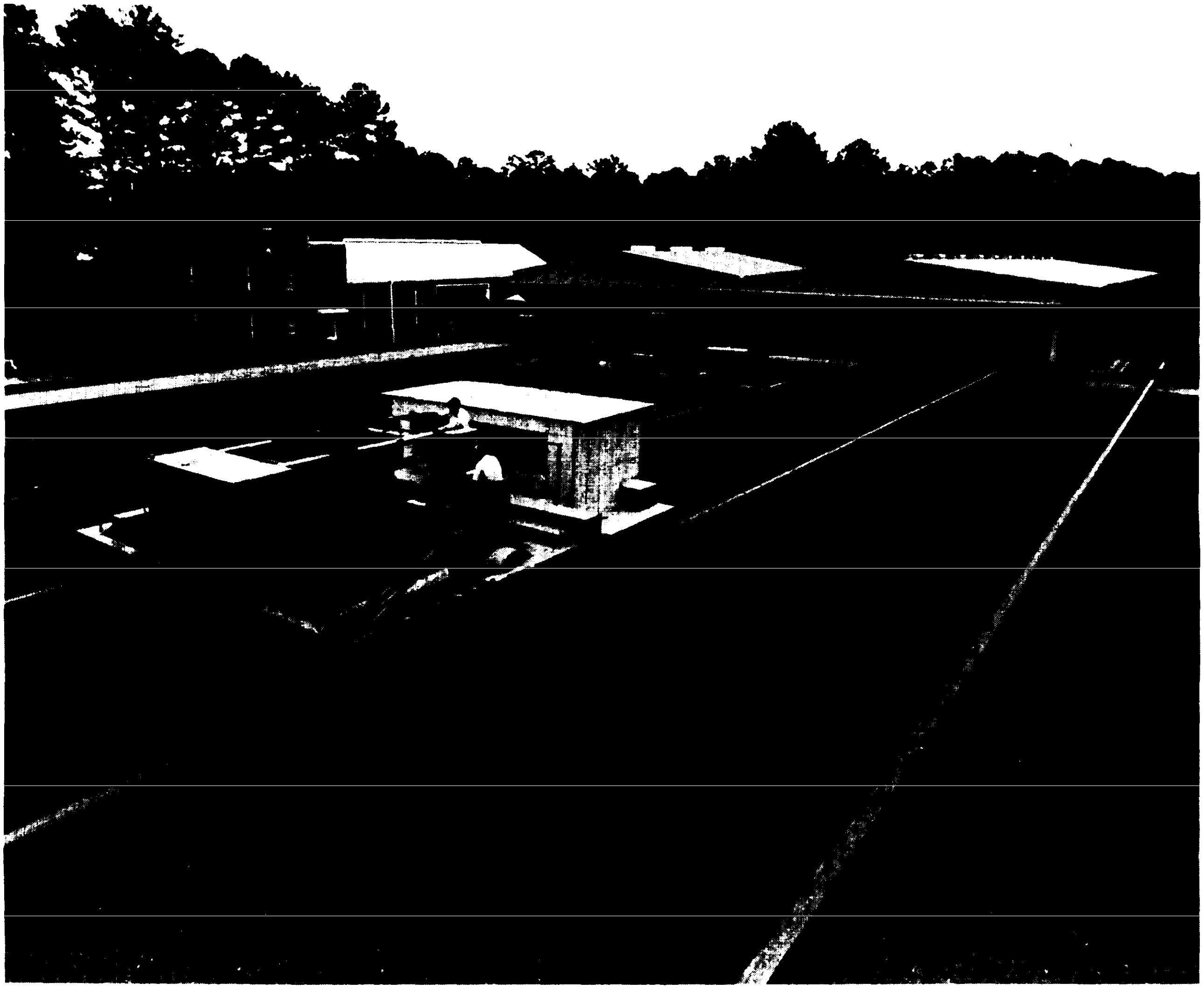
The technologies available for immediate application are those that prevent losses in transport, particularly those for farm distribution of irrigation water. These include drip irrigation, below-ground distribution of water, deficit irrigation, water harvesting, time and frequency of application, and the forecasting of time and frequency of application.[7]

Land Management

Land is one agricultural resource that cannot be replaced. Thus a variety of methods and technologies have been developed to conserve soil while increasing yields. These land management technologies include conservation tillage, controlled traffic farming, custom-prescribed tillage, multicropping systems, and organic farming.

Conservation tillage is a tillage and planting system that leaves 30 percent of the crop residue on the soil after planting. The use of the various forms of this system has increased at over 13 percent annually from 1972 to 1982. The specific system used depends on local crops, soil type, moisture levels, and pest infestation, among other factors. Most conservation tillage methods eliminate the use of the moldboard plow, using instead chisel plows or heavy disks in conjunction with heavy-duty planting equipment to cut through soil residues. Mulch-till

[7]For more information on this area see the OTA study ***Water-Related Technologies for Sustainable Agriculture in U.S. Arid/Semiarid Lands, 1983.***



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A hough a o n he e ea h age o de e opmen u om p e b d age u ed n ome ag u u a p odu on y em Th ap p oa h o age n eg a e kn w dg o o dynam ma h ne y ma e and op p o du on e onom and en a mak ng a p e p on fo a ou omponen o he age system. The specific machines to be used, as well as the sequence and time of their use, is defined in the prescription.

Multicropping is the practice of planting more than one crop on a field during the same growing season. Such crops can be grown sequentially (double cropping) or simultaneously (intercropping). For example, corn and soybeans can be grown in the same field in strips, reducing soil erosion, using nutrients more efficiently, and increasing crop yield. Currently available machinery and practices are used to perform the field operations needed in multicropping.

Organic farming reduces or eliminates chemical inputs in favor of more "natural," and supposedly safer, inputs. The products from this method are sold to markets willing to pay a premium for the assurance that chemical fertilizers and pesticides have not been used in production. Organic farmers generally prefer to use fewer technological inputs than do conventional farmers, including lower levels of mechanization. They also derive their nitrogen requirements from planting leguminous crops in rotation with nonleguminous crops and sometimes by adding animal manure. If this system were adopted on a large scale in the United States, the need for more mechanization technologies would be reduced, with the exception of the area of waste handling systems for livestock.

No new or unique machinery is needed to further implement conservation tillage, multicropping, or organic farming, However, considerable interdisciplinary research will be needed to implement controlled traffic farming and custom-prescribed tillage commercially. While these concepts have many perceived economic benefits, their true cost-benefit relationships must be evaluated for the wide variety of crops, terrain, soil types, and climate existing across the United States.

Soil Erosion, Productivity, and Tillage

The quantity and quality of harvested crops depend on the amount of land, the suitability of its soil for growing crops, the biology of crops, and the environment (Foster, 1985). Most crops are grown on clean, tilled soil, leaving the soil exposed and unprotected. Severe erosion can result, and over time so much soil is lost that crop yields decrease and some land may be forced from agricultural production. Excessive soil erosion is estimated to occur on about 30 percent of U.S. cropland, but its effects on productivity are thought to have been masked by new technological inputs like hybrids, fertilizers, and chemicals.

Soil erosion is the detachment of soil particles by the erosive effects of rain, surface runoff, and wind. When erosion removes soil more rapidly than it can be formed, soil becomes thinner with less rooting depth for crops. When the topsoil becomes thinner than the tillage depth, subsoil becomes mixed with topsoil during tillage, degrading the soil. Erosion also removes the fine silt, clay, and organic particles most important for good soil quality. The resultant increase in sand content of the soil reduces the soil's productive potential. Sediment from erosion can create off-site problems through deposits inroad ditches, reservoirs, and river channels. Sediment or the chemicals it transports can also pollute off-site air and water.

Four major lines of research on erosion control are proposed: 1) improved conservation farming systems, 2) improved methods for assessing erosion's impacts, 3) evaluation of the potential for restoring productivity to severely eroded soils, and 4) improved understanding of how to use public policy to encourage soil conservation.

Of all factors affecting erosion, crop residue left on the soil surface is most effective in reducing erosion. Research on improved conservation systems will thus emphasize conservation tillage, including reduced tillage, minimum tillage, and no-tillage. These types of conservation tillage differ only in the amount of soil disturbance and in the amount of crop residue left on the soil. When matched to soil conditions, conservation tillage can potentially provide greater economic return and often equal or greater yield than that of conventional tillage. For example, no-tillage works well on well-

Photo credit: U.S. Department of Agriculture, Agricultural Research Service

Crop residue left on the soil surface is an effective way of reducing erosion. Here grain sorghum is growing in barley stubble.

drained, sloping soils but not on cool, poorly drained soils in the Corn Belt. Although conservation tillage has the fewest drawbacks of all erosion control practices, considerable development of the method is still required.

The degree of erosion's impact is a major issue that needs a conclusive answer. The principal tool used to estimate erosion by water is the Universal Soil Loss Equation. The tool for estimating wind erosion is the Wind Erosion Equation. Recent developments in erosion theory and the availability of powerful, portable computers make possible new methods that are more detailed and more accurate for estimating erosion over a varied landscape, erosion from individual storms, and average annual erosion. Remote sensing technology and special image processing equipment will aid in the collection of data. New field studies have been initiated and several mathematical modeling techniques have been developed to evaluate the effect of erosion on crop yield.

If eroded soils can reasonably be reclaimed, the problems of erosion maybe less serious than presently thought. Current research in the Piedmont region shows that conservation tillage and multiple cropping (explained later) can be used to restore productivity. Much research must still be done in this area.

Although several practices are available for controlling erosion, many have drawbacks that hamper adoption by farmers. As a result, various policy alternatives are used and have been suggested to provide incentives to farmers to implement soil conservation. Improving the use of public policy will entail the incorporation of major analytical tools into an integrated package compatible with affordable computer resources. Such tools will include models for climate, erosion, water quality, crop yield, pests, and economics.

The major potential impact of this technology on agriculture will be significantly improved erosion control with little loss, if not gain, in crop yield, improved water quality, improved formability, and increased profit. It is hoped that this technology will provide farming systems with enough positive benefits that erosion control becomes a side benefit.

Multiple cropping

Multiple cropping is the intensive cultivation of more than one cropper year on the same land so as to use land, water, light, and nutrients efficiently (Francis, 1985). Double cropping, or the sequential planting of two crops, such as wheat in the winter and soybeans in the summer, is the only pattern commonly used in the United States. Intercropping, the simultaneous culture of two or more crops in the same field at the same time, is popular with low-resource farmers.

Although widely used in the lesser developed countries by farmers with limited land and resources, multiple cropping systems have not been extensively explored for their applications in this country. Yet, in addition to their efficient use of resources, intensive cropping systems offer several other benefits: vegetative cover through much of the year, which prevents erosion; the need for less fertilizer, owing to the contributions of legumes in these systems; and moderate to high potential yields that are sustainable over time.

Relatively little research attention has been paid to these systems in temperate agricultural regions. If such systems are to be widely adopted in the United States, major new technological advances may be necessary in four areas: breeding crops for intensive planting systems, understanding competition by plant species for growth factors, improving plant nutrition through fertilizers and microbiology, and developing mechanization for multiple cropping.

Crop breeding for multiple cropping systems can lead to the development of crops that can endure the stress conditions found in multiple-species crop combinations. Varieties and hybrids already exist that are well adapted to double cropping and reasonably well suited to relay cropping, the planting of two or more crops with an overlap of the significant part of the life cycle of each crop. Further refinement is needed in developing new hybrids and in further selecting for adaptation. Results could be available in 15 years.

The competition for growth factors by crops that are grown together or sequentially is not well understood. Such competition includes that between two plants of the same species, between two crops of different species, and between crops and weeds. Competition has been studied in grass/legume mixtures for pasture systems, and basic work on crop/weed competition gives insight on species interactions. Some of the results and much of the methodology can be applied to intercropping. Since existing varieties can be used for most preliminary work, results could be available in 6 to 10 years.

Multiple cropping entails a greater input of nutrients or an alternative approach to plant nutrition. Low-resource alternative cropping systems include rotations, minimum-tillage methods, and use of low levels of fertilizers that do not disturb the biological balance in the soil. Research on nitrogen fixation is an active area at present, but a basic understanding of plant nutrition could take 10 to 15 years to develop.

Machines already available can be used for planting and for most other cultural operations. Through modifications of existing tillage, planting, and cultivating equipment, the farmer can accomplish multiple cropping. However, the development of a combine that can harvest two crops simultaneously is necessary for intercropping to have widespread applications. This short-term objective could be achieved within

5 years, using expertise from the commercial sector.

The principal impacts from multiple cropping will be reduced production costs and increased output per year from a given unit of land. The greater sustainability of production and the reduction in energy use would lead to a more stable agricultural sector.

Weed Control

The cost of weeds to agricultural production is one of the most expensive factors in crop production, amounting to more than $20.2 billion annually (McWhorter and Shaw, 1985). Losses caused by weeds include not only direct competition of weeds to reduce crop yields, but also reduced quality of produce; livestock losses; weed control costs; and increased costs of fertilizer, irrigation, harvesting, grain drying, transportation, and storage.

Weeds can be defined as plants growing where they are not wanted. They range from trees and shrubs to grasses and even cultivated crop species. Volunteer corn, for example, is becoming an increasing problem in soybean production as more conservation tillage practices are being adopted.

In modern agriculture, weeds are controlled through integration of crop competition, crop rotation, hand labor, and biological, mechanical, and chemical methods into integrated weed management systems (IWMS). Since 1950, the use of mechanical power for weed control has increased **30** percent, and herbicide use has increased sevenfold. However, manual labor has decreased **40** percent. As a result of modern weed control technology, farming is now less physical and more technological.

Although significant progress has been made in developing new weed control technology, weeds continue to cause severe reductions in yield and quality. Weeds often limit expanded use of conservation tillage and multicropping. New difficult-to-control weed problems develop through ecological shifts and because more established weeds develop increased tolerance to herbicides.

New weed control technologies needed include: ***1)*** improved chemical and biological methods, 2) allelopathic chemicals to bioregulate weeds, 3) crop cultivars with improved tolerance to herbicides and the discovery of the nature of weed resistance to herbicides, and 4) the development of improved IWMS for conservation tillage and for annual multicrop production.

Development of selective herbicides has spearheaded the advances in weed control technology during the last **30** years and will continue to be important in the foreseeable future. Major breakthroughs needed in this area include a nonselective chemical to control vegetation in fallow fields, more selective chemicals for control of broadleaved weeds in dicotyledonous crops (e. g., cotton, soybeans), and a chemical that can be applied postemergence for effective contol of perennial weeds. There is also interest in control of weeds by bioagents, particularly with native pathogens like fungi.

Photo credit: U S Department of Agriculture **Agricultural Research Service**

Seed-killing methyl isothiocyanate kept *crabgrass* seeds *(Digitaria* sanguinalis) in flask on right from germinating. One week after the seeds were placed in flasks the untreated crabgrass seeds in flask on left have germinated, The chemical degrades rapidly in the soil, usually within a few days.

The effectiveness of many herbicides is limited by soil activity; for example, some microbial populations rapidly degrade certain herbicides, limiting the residual effects of the herbicides. Advances in controlled-release technology could aid in this and other problems by reducing volatility and rates of application, reducing herbicide movement through the soil profile, increasing crop selectivity, and reducing environmental exposure. Also helpful is a class of chemical protestant that slows the action of soil micro-organisms, permitting more cost-effective control.

Crops can be protected against the toxicity of certain herbicides through chemical antidotes called safeners, another class of plant protectant. When applied to seeds or soil, these chemicals make an otherwise susceptible plant species tolerant to an herbicide without affecting the weed control aspect of the herbicide.

Plants themselves release secondary chemicals during metabolism that can be toxic to other plants. Such allelopathic chemicals are being studied for their potential use in weed control.

Developments in genetic engineering may allow the availability of herbicide-tolerant crop cultivars in agronomic crops in the next 10 to 15 years. Many weeds have evolved a tolerance to herbicides. The availability of herbicide-tolerant crop cultivars would permit the use of herbicides at higher rates to reduce the evolution of tolerance and would permit the use of herbicides that were previously nonselective.

Finally, research efforts need to be increased to develop more effective IWMS. Basic ecological research is needed to understand weed population dynamics, weed threshold levels, and shifts in weed populations caused by control technology. Research is also needed on how to use rotational tillage to aid in controlling the weeds that develop through several years of conservation tillage. Perennial weeds become particularly troublesome after only 2 or 3 years and have forced many farmers to return to conventional tillage.

Improved weed control technology will result in a slow but steady decrease in production costs and an estimated 10 percent increase in the cost of weed control. Increased use of conservation tillage will necessitate increased herbicide use in the next two decades.

Commercial Fertilizers

The substantial use of commercial fertilizers—about 50 million tons per year—is generally credited with 30 to 50 percent of the cost of U.S. agricultural production (Davis, 1985). Corn and wheat are the most heavily fertilized crops.

Commercial fertilizers supply crops with one or more of the primary plant nutrients (nitrogen, phosphorus, and potassium) in forms usable by crops. Nitrogen and phosphorus are produced in the United States; most (about three-fourths) potassium must be imported from Canada. Nitrogen, phosphate, and potassium intermediates are produced in large plants and then shipped to small plants for combination into final products.

Although expenditures for research and development (R&D) in fertilizer technology are less than 10 percent of that for the entire chemical industry (as a percent of sales), the R&D that exists is aimed at maximizing fertilizer effectiveness, minimizing costs, and protecting the environment.

At present, one-half of the nitrogen applied to the soil is lost to the plants through a variety of inefficiencies, some of which are still not understood. Several new types of nitrogen products under development might improve efficiency of use. They include products with inhibitors to decrease undesirable transformations in the soil (vitrification and urease inhibitors), products coated for controlled release (e.g., the sulfur-coated urea sold for turf and horticultural uses), and acidified products that decrease the volatilization of ammonia (the reaction of urea with mineral acids in the soil). In addition, the use of urea phosphate, urea-nitric phosphate, and sulfur-coated urea may allow closer placement of fertilizer to seed without inhibiting germination. Urea phosphate may also aid in recovering phosphorus, 80 percent of which is unused by the plant and remains fixed in the soil in insoluble forms.

Other research is under way to decrease the energy required to produce, transport, and apply fertilizers. The escalation in oil prices following the oil embargo spurred efforts to design new energy-efficient plants and to retrofit existing plants. In addition, several new urea processes that have been announced will decrease production energy requirements by 25 to 50 percent. New phosphoric acid technology also promises energy savings. To avoid dependence on oil or natural gas (the raw material for ammonia for nitrogen fertilizers), technology for the production of ammonia from coal is in advanced stages of development. Finally, efforts are being made to increase the nutrient content of fertilizers so that the energy expended in transporting and handling will be decreased.

Another area under development is that of phosphate fertilizer production. Because reserves of high-quality phosphate ore are being depleted, researchers are attempting to use lower quality phosphate ore in fertilizers. Their efforts focus on removing the carbonate impurities in such ore and on determining what effect such impurities would have on the efficacy of phosphate fertilizers.

In reduced tillage agriculture, R&D efforts are directed at developing urea-nitric phosphate, urea with urease inhibitors, and urea phosphate and urea sulfate, all of which have the potential to decrease ammonia loss from surface-applied urea. Also, new types of equipment are being designed for precision placement of fertilizer and for simultaneous application of fertilizer with seed.

New developments in the industry evolve rather slowly because of the low level of R&D. Therefore, any new technology that is likely to be introduced by 1990-2000 would have to be under development now. No revolutionary or radically new products or processes appear to be near commercialization.

The future direction of energy prices will probably be the major factor affecting the commercialization of new technology, Because the production of nitrogen, particularly ammonia production, is the most energy-intensive operation for the industry, new nitrogen technology is especially geared to energy prices. The high cost of new facilities is also a deterrent to the adoption of technology. In many situations the industry will prefer to debottleneck or add to existing plants to conserve capital.

Organic Farming

Organic farming uses many conventional farming technologies but avoids, where possible, the use of synthetically compounded fertilizers, pesticides, growth regulators, and animal feed additives (Liebhardt and Harwood, 1985). It relies on crop rotations, crop residues, animal and green manures, legumes, off-farm organic wastes, mechanical cultivations, mineral-bearing rocks, and biological pest control. Organic farmers tend to integrate their farming techniques to a greater extent than conventional farmers do.

In the last 6 to 8 years, several studies have compared organic farming with conventional farming. Although final conclusions must await more rigorous studies and a wider sample of farms, preliminary conclusions show some interesting benefits of organic farming: first, yields per acre are generally equal to or only slightly less than those from conventional farming. Some organic farms have significantly higher-than-average yields. Second, production costs are lower by a high of 30 percent and an average of 12 percent, while energy inputs per unit produced are lower by 50 to 63 percent. Few or no insecticides, fungicides, and herbicides are used. Third, soil erosion is significantly reduced through various cultivation practices. Although organic farming maintains soil quality better and reduces contamination of air, water, soil, and the final food products, much research is needed to determine just why organic practices have this effect and to determine how to maximize the integration of organic practices.

One of the most significant factors in reducing production costs and energy inputs in organic farming is nitrogen self-reliance. Many organic farmers increase nitrogen fixation in their crops by seeding legumes between rows of grain crops during the growing season or after harvest. Research is under way to breed plants that fix nitrogen more efficiently or that fix nitrogen longer in the season. By 1990, research already on-line in this area should be well developed.

For weed control, cover crops are used in rotation; for example, sorghum crops are used to suppress nutsedge. In addition, crop residues are used in conservation tillage to suppress sensitive weed species. Much information about weed control should be available by 1990; however, the technology for wide application of crop rotations will not be available for at least 5 to 10 years.

Organic farms appear to cycle nutrients more efficiently than conventional systems do. One reason is the reduction in erosion that occurs, which allows better soil tillage and better maintenance of productivity. Furthermore, some organic practices enhance the soil's ability to suppress disease, Scientists hope to identify the helpful bacteria and bacterial byproducts involved in disease resistance and to harness them as biocontrol agents.

Biocontrol agents are also used to control insects. One example is the tansy, an insect-repellent plant that shows potential for controlling the Colorado potato beetle. Another example is the use of an antijuvenile hormone, extracted from a common bedding plant, that induces premature metamorphosis in insects, shortening their immature stages and rendering the adult females sterile. In 10 to 20 years, biological pest repellents will probably dominate the market because of their safety for users, consumers, and the environment.

Converting from conventional to organic farming takes about 3 to 5 years, during which yield may initially be reduced. Some of this problem relates to the nitrogen content of the soil and to weed pressure.[8] However, detailed studies of holistic systems are needed to understand better the extremely complex changes in nutrient flow in soil during organic and conventional farming. The potential impact of such studies on U.S. agriculture in the next 10 years could be considerable. If farmers shifted to organic production, farms would be more diverse biologically and economically, and the small farm could remain economically competitive and ensure diverse, competitive food production systems.

Communication and Information Management

Technology for communication and information management helps farm operators collect, process, store, and retrieve information that will enable them to manage their farm so as to minimize costs, maintain and improve product quality, and maximize returns. There are three basic components to such technology: 1) microcomputer-based hardware systems for information processing, storage, and retrieval; 2) high-speed LANs for onfarm communication of digital information; and 3) applications software. The computer allows farm operators to keep track of more detailed information, apply complex problem-solving techniques to this information, and thereby make better, more timely, decisions.

Microcomputers appropriate for onfarm use cover the range of business-class computers. Larger and more complex farm operations will generally benefit from larger, more complicated computer systems. Onfarm computers are likely to be subject to more adverse operating environments than those found in typical nonfarm businesses. Thus some additional equipment and adaptations are needed for onfarm operations (Battelle, 1985).

While LAN technology is rapidly becoming more mature and standardized, onfarm installations are likely to be more expensive per node than the typical business system. Farm nodes are generally much farther apart than nodes of the average office system. Farm installations placed among several separate buildings are also more susceptible to lightning-induced electrical problems. Photoelectric isolators at every node will enable use of copper wiring between nodes. Alternately, use of LANs with fiber optic cabling will eliminate problems from electromagnetic interference.

‘This can be minimized by selecting the correct crops and structuring the production system to avoid nutrient deficiency or weed problems,

Photo **credit: Dr. S.L Spahr, University of Illinois**

Example of microcomputer-based system for onfarm use. This system collects, processes, stores, and retrieves information to control computer feeders and electronic milk flow meters.

Many software packages sold for use on farm computers are general-purpose packages that are identical to those used in other businesses, Spreadsheet programs and database management systems fall into this category. Other packages have only minor modifications and upgrades. The most expensive class of software is generally that written for specialized applications. Few farms are large enough to afford custom programming for their own operations. The range of specialized applications programs that have been developed and are being developed by extension personnel at land grant colleges is quite large, Agricultural software from commercial sources and the land grant institutions is generally task-specific.

Another promising software concept is that of a fully integrated system that would allow the farm operator to simulate the outcome of small and large changes in production practices, The software could generate distributions of prices and weather impacts and simulated biological growth functions, It could produce detailed listings showing expected costs, returns, production schedules, cash flows, and net income streams, working within the constraints of those assets and productive potentials that the operator chooses to consider fixed. Such software would give operators much greater ability to maximize income and flexibility in planning for growth and in responding to changes in the economic and technical environment.

Monitoring and Control Technology

Many processes in plant and animal production may be monitored and controlled by new and emerging electronic technologies. In some cases these devices are designed simply to detect certain conditions and report the information to the farm operator. In other cases, the technology operates essentially autonomously, without operator attention. Devices of this nature are usually programmable, can operate continuously, can be designed to be very sensitive to changes in target variables, and can respond very quickly. These devices, therefore, offer improvements in speed, reliability, flexibility, and accuracy of control, and sometimes reduce

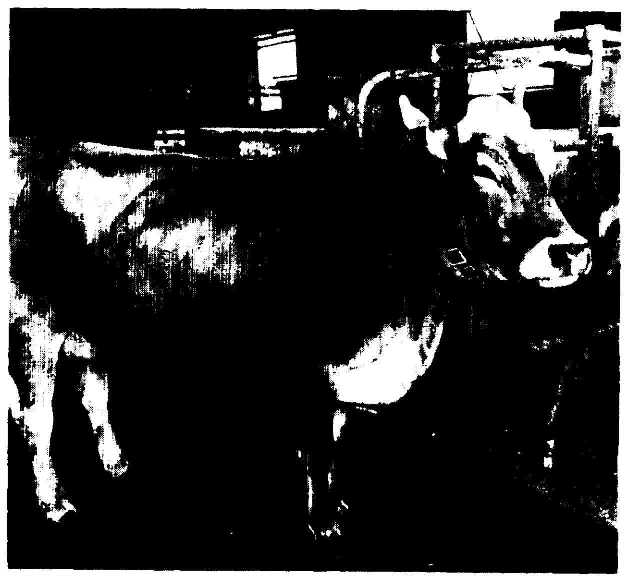

Photo credit: *Dr. S.L. Spahr, University of Illnols*

Electronic animal identification unit around cow's neck with automatic dispensing grain stall in background. Cow goes into stall, is identified electronically, and has grain dispensed to her automatically. Using computer controls, the feed dispensed is individualized to provide each cow a different amount of feed and a different protein percentage based on her nutrient needs labor requirements (Battelle, 1985). Some applications of this technology include irrigation control, pest monitoring and control, and the automatic animal identification and feeding system in livestock operations.

Positive identification of animals is necessary in all facets of management, including recordkeeping, individualized feed control, genetic improvement, and disease control. All animals could be identified soon after birth with a device that would last the life of the animal. The device would be readable with accuracy and speed from 5 to 10 feet for animals in confinement and at much greater distances for animals in feedlots or on pasture. Research on identification systems for animals has been in progress for some years, especially for dairy cows. For example, an electronic device now used on dairy cows is a low-power radio transponder that is worn in the ear or on a neck chain. A feed-dispensing device identifies the animal by its transponder and feeds the animal for maximum efficiency, according to the lactation cycle and the life cycle of that animal. This technology also permits animals in different stages of production to be penned together yet still be fed properly.

The largest potential use of electronic devices in livestock production will be in the area of reproduction and genetic improvement. Estrus in dairy cows can be detected automatically by using sensors that remotely detect small changes in the body temperature of the cows. Such an estrus detection device could prove profitable in several ways:

- Animals could be rebred faster after weaning and could increase the number of litters per year.
- Animals that did not breed could be culled from the herd, saving on feeding and breeding space.
- Time would be saved because breeding would be done faster.
- Embryo transplants would be easier because of better estrus detection.

Environmental control of livestock facilities is another area where monitoring and control

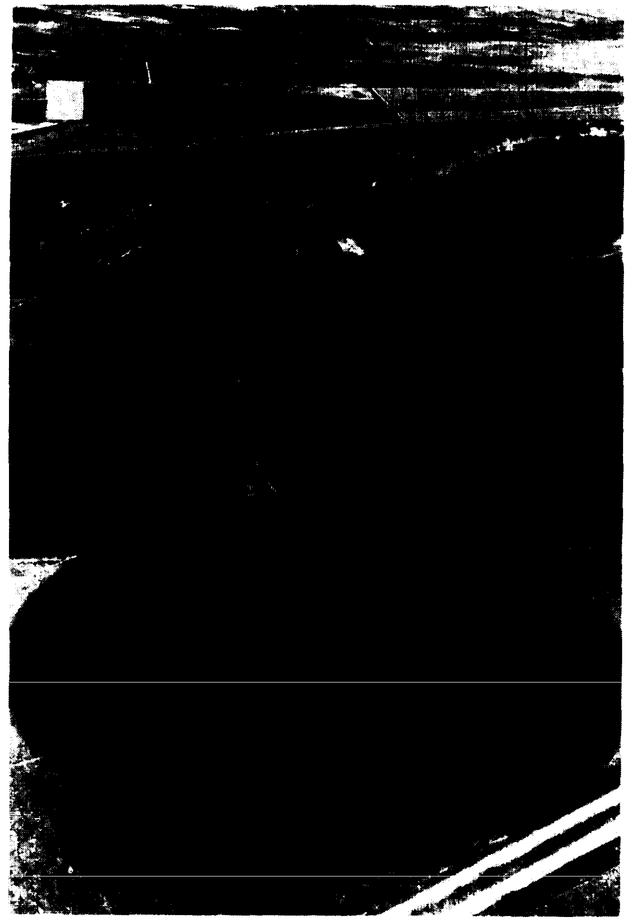

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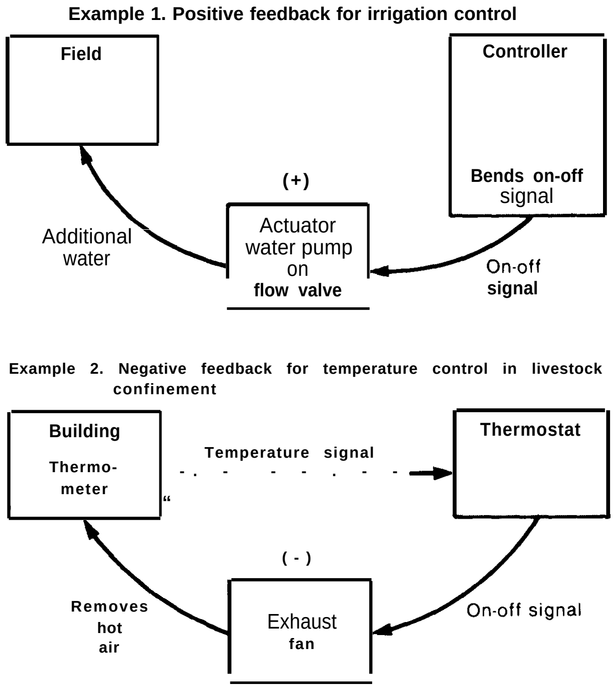
Figure 2-7.—Configuration of Monitoring and Control Technologies in Agriculture



SOURCE. Off Ice of Technology Assessment

evaluated for use on a regional scale by a USDA Animal and Plant Health Inspection Service regional program, Such systems will provide rapid analysis, summarization and access to general crop summaries, observer reports, pesticide and field management information, reports of new or unknown pests, general pest survey information, and specified field locations with pest severities.

Other software systems designed to facilitate directly the implementation of pest management programs are in use and are continually being improved, The Prediction Extension Timing Estimator model (Welch, et al., 1978) is a generalized model for the prediction of arthropod phonological events but is sufficiently flexible to be used for management in many agricultural and nonagricultural systems. For example, it is used as a part of the broader biological monitoring scheduling system developed in Michigan by Gage and others (1982) for a large number of pests on a wide variety of crops (Croft and Knight, 1983).

An irrigation control system is another example of using monitoring and control technology (figure z-z). Since irrigation decisions are complex and require relatively large amounts of information, microcomputer-based irrigation monitoring and control systems are especially useful in areas where soils have variable percolation and retention rates, where rainfall is especially variable, or where the salinity of irrigation water changes unpredictably, In this system, a network of sensors is buried in the irrigated fields, with radio links to the central processor. Additional sensors may include weather station sensors to estimate crop stress and evaporation rates, as well as salinity sensors and runoff sensors. The central processor can then automatically allocate water to each field according to the needs of the crops in each field, subject to considerations of cost, leaching requirements, and availability of water.

Telecommuications

Telecommunications technology provides links for voice communications and the transmission of digital data between farms and other firms and institutions. Through such technology, farms, firms, and institutions can be joined together in a large number of formal and informal networks. These networks enable farmers to have relatively rapid, inexpensive, and reliable access to central databases, centralized software packages, and information on weather, markets, and other subjects of interest. Virtually the same technology will be applied to both animal and plant agriculture. Telecommunications include high speed, low speed, and radio telecommunications, satellite base communications, and remote sensing technology (Battelle, 1985).

High-speed or high-bandwidth communications allow the farmer to send and receive much larger amounts of data at lower costs per bit of information. This capability is needed for videotext services, teleconferencing, and, in many cases, satisfactory real-time use of remote computer facilities,

High-speed telecommunications is still undergoing substantial amounts of development. New transmission capabilities or new technologies are needed for bringing high-speed telecommunications to most rural areas, High-bandwidth telecommunications can be provided by technologies that range from conventional high-capacity, coaxial cable, microwave relay systems to fiber optics systems and high-bandwidth direct transmit/broadcast satellite systems. High-bandwidth send-and-receive service for the average farm operation is not likely to be available for some time.

The existing telephone system is capable of handling the demand for slow-speed telecommunications services in many rural areas, The latest generation of microcomputers, modems, and communications software is capable of automatically accessing remote databases and quickly downloading and uploading information at regular intervals without operator attention, Rural areas that install fiber optic telecommunication systems will have enormous information capacity that will easily support very high data rates. In fact, the perennial dream of low-cost, two-way videoconferencing, education, and entertainment may well become a reality in these rural areas by ***1990*** or **2000**,

A number of emerging radio telecommunication technologies will provide improved service in rural areas without the need to rewire the local telephone networks. These technologies can be put into two groups: ground-based, low-power radio repeater systems, such as cellular mobile phone systems; and satellite-based communication systems. In principle, the cellular radio technology being installed in major cities can be expanded to smaller cities, towns, and rural areas at higher power levels for use in voice and data communications. For applications where data transmissions are sufficient and instantaneous communications are not necessary, technology for packet radio messages may provide substantial savings. packet radio systems use ground-based repeater stations to funnel messages with a standard, or "packaged, " format from distributed users to one another or to a point where the messages can be inserted into a national telecommunication network, Messages are entered at each user station, then converted into encoded "packets" complete with addresses and distribution instructions. Each user station then transmits to the local repeater station when the transmission channel is free. This technology may enable cellular radio repeater technology to be extended to especially remote and sparsely populated areas and to areas where the basic telephone system is inadequate and is unlikely to be upgraded.

Satellite-based communication technologies may provide very high-capacity telecommunication channels for rural areas. These systems may be the only feasible high-capacity link for some especially isolated rural areas. Large farms may opt to establish their own ground stations for satellite-based telecommunication, but new generations of communication satellites may have the power to serve many small individual subscribers in remote rural locations.

Almost all commercial satellite communication systems employ satellites in geosynchronous orbit.[9] Alternately, the feasibility y of using low-cost, low-Earth orbit satellites for the collection, storage, and rebroadcasting of message packets has been demonstrated by amateur radio groups. Commercial satellites using this design could enter service by ***1990.***

Remote sensing is a collection of technological systems used to detect, process, and analyze reflected and emitted electromagnetic radiation at a distance. This includes the National Oceanic and Atmospheric Administration weather satellites, land and ocean resource mapping satellites (the Landsat series), airborne camera and electronic sensor systems, and ground-based photogrametric and radiometric sensors. Information from remote sensing technology is used for a wide range of applications. Some examples are weather reporting and forecasting, land use planning, environmental monitoring, crop production estimates, soil mapping, range and forest management, mineral exploration, and watershed management.

Remote sensing technology in the form of weather forecasting has already made a great

'Traveling in orbit around the Equator at the same speed as the Earth rotates, impact on agricultural production. Weather reports and forecasts help farmers decide when to plant and when to harvest, Fruit growers depend on local weather forecasts to help make frost protection decisions.

Farmers can also use remotely sensed information to make other management decisions, Soil moisture levels can be estimated accurately for large northern plains wheat farms that depend on stored soil moisture. Selection of fields for rotation, seeding, and fertilizer rates could then be planned for the available moisture on different parts of the farm to optimize net income.

Remote sensing technologies provide crucial and timely information for the process of estimating global crop production. These crop estimates can have large impacts on price levels and price variability. Estimates of crop production in different countries are an important factor in the administration of commodity and export policies.

Labor-Saving Technology

Labor-saving technologies have made a significant dent in the cost of labor for animal production and, to a lesser extent, for field crops. The change to large-scale confinement operations of livestock and poultry has dramatically reduced labor costs through the automation of feeding, waste disposal, and egg collecting, For field crops, reductions have come from using larger tractors, combines, and tillage equipment.

Opportunities still exist, however, for reducing labor costs, particularly through: ***1)*** mechanization of fruit and vegetable operations, and 2) robotic farming. Researchers and growers are exploring ways to use these technologies with other technologies to change cultivars and cultural practices, rearrange work patterns, develop labor-aid equipment (e. g., conveyors and hoists), improve human relations, and develop labor replacement equipment (Battelle, ***1985).***

Mechanical harvesting is most applicable for fruits and vegetables that are to be processed or dehydrated, because such products will not show the effects of mechanical handling. Most fruits and vegetables targeted for the fresh market must still be harvested by hand.

The most economically important of the process vegetables are the potato and the tomato, both of which are mechanically harvested. The development of mechanized tomato harvesting is a particularly good example of technological success: the concurrent development of a mechanical tomato harvester and anew, high-yield process tomato, shaped for easy mechanical harvesting, gave California a production increase of ***300*** percent with only a 50-percent increase inland. Many other process vegetables are harvested mechanically, and research is still under way to automate the harvesting of cauliflower, lettuce, okra, and asparagus.

Of the fruit crops, citrus crops are the largest in total value. Although oranges would seem to be ideally suited to mechanical harvesting (80 percent of the crop is processed), the “bag and ladder” method of hand picking remains the most economical and widely used method. For mass removal of some crops, mechanical or oscillating-air tree shakers, usually in conjunction with abscission chemicals, are used. (Mechanical shakers are also used to harvest process grapes and process deciduous fruits, such as apples, pears, and peaches,) Technology trends in citrus production point to higher density plantings and the maintenance of trees at a height of 5 meters or less. If high fruit yields result, there is good potential for development of over-the-row equipment for production and harvesting.

The use of robotics in agriculture is likely to be centered on high-value, labor-intensive crops like oranges. Research is also being done on apple harvesters that will use ultrasonic sensors to detect tree trunks and steer around the trees. It is conceivable that by ***1990,*** reductions in cost and increases in the speed of operation will make such robotic technology economically attractive. Robotics may also have applications in animal agriculture—for example, in checking calving and farrowing, identifying estrus, managing feeding, and handling manure.

Future labor replacement in agriculture will likely involve some aspect of electronics technology, much of which will be adapted from offshoots of military and aerospace technology. Such technology will have to be adapted to withstand the variety in agricultural environments and will have to have better cost-benefit ratios for widespread adoption. Many new electronics technologies may affect the quality more than the quantity of labor. People with higher level skills will be needed to operate and maintain the new, more complex equipment.

Engines and Fuels

Continued improvements in engines and fuels can be expected in the energy efficiency, durability, and adaptability of self-propelled farm equipment. These improvements are likely to come from R&D in a number of areas: 1) adiabatic and turbocompound engines, 2) electronic engine controls, and 3) onboard monitoring and control devices (Battelle, 1985).

Expenditures by farms on liquid fuels were $10 billion in 1982. Even modest improvements in energy efficiency in farm production will have a significant impact on the total cost of production in agriculture. However, these technologies will not be adopted unless they also deliver significant increases in productivity to individual farms. Farms are continuing to improve their energy efficiency by converting from gasoline-powered equipment to diesel-powered equipment at a rapid rate. Diesel fuel has more energy per dollar, and diesel engines extract more useful work from each calorie of fuel than do gasoline engines.

All conventional internal combustion engines, including diesel engines, are thermally inefficient because they must dispose of large amounts of heat by means of cooling systems. If engines can be constructed of special ceramics to withstand high operating temperatures, they would not need cooling systems and would be much more efficient. Engines of this type are called adiabatic engines.

Turbochargers are being widely used to increase the performance of gasoline and diesel engines by putting some of the exhaust gas energy to use. Even more work can be extracted from the exhaust gases by means of a device called a turbocompound unit. This device captures exhaust gas energy and applies it directly to the drivetrain of the vehicle instead of using the energy solely to compress intake air, as in the conventional turbocharger. Turbocompound units will be especially useful when installed on adiabatic diesels, owing to the high energy content of the exhaust gases from these engines.

Electronic engine controls are being introduced by some manufacturers in an effort to improve the efficiency of the fuel injection system on diesel engines. As with similar systems developed for automotive applications, this technology automatically works to optimize fuel delivery under changing conditions, based on information from engine sensors, implement sensors, and operator inputs. Minimization of tractor wheel slip by means of onboard monitoring and control technology also improves fuel efficiency. Other applications of this technology to onboard control of field operations is described in the section on monitoring and control technologies.

Considerable research has been conducted on the use of alternate fuels for agricultural applications. Much of this research was motivated by the oil embargo crisis and rapidly rising liquid fuel prices of the 1970s. None of the alternate fuels hold much promise to increase the fuel efficiency of conventional engines, This research has revolved around the use of onfarm production of ethanol for use primarily in gasoline-powered equipment and the onfarm pressing and refining of sunflower oil for use in diesel-powered equipment. Neither fuel is economically competitive with purchased liquid fuels in the absence of substantial subsidies. Moreover, both fuels are more difficult to use than fossil fuels, Ethanol-based fuels tend to absorb moisture and to separate in storage. Vegetable oil-based diesel fuels require special processing, which changes their chemical and physical characteristics, before they can be used reliably in unmodified diesel engines.

Crop Separation, Cleaning, and Processing Technology

New technologies being developed to separate, clean, and process crops offer many benefits in increased yield, quality, and value of crops. There are two major lines of research in this area: ***1)*** improvements in separating and cleaning grain, and 2) in-field or onfarm processing of forages and oilseeds (Battelle, ***1985).***

The mechanization of grain harvesting and separation has been one of the most important factors in reducing the labor cost of grain production. Even small improvements in labor or capital efficiency have significant impacts on grain production because of the large total cost of producing the U.S. cash grain crop.

The basic methods of grain separation used in all combines are mechanical beating, aeration, and screening. While these methods have been continually refined, the same basic techniques have remained unchanged since antiquity.

Grain harvesting productivity has been improved over the past three decades by increasing the size and power of combines. Combines separate grain by beating and rubbing the grain stalk between a stationary surface and a cylinder rotating at high speed. The chaff and other debris are cleaned from the grain by blowing a large amount of air through the grain / chaff mix, The difference in the ability of the two materials to float on the airstream effects their separation.

Constraints on the total size and weight of combine equipment that can be transported over public roads limit the increases in general harvest productivity. Within this constraint, however, continued improvements in microprocessor-based monitoring and control technologies incorporated into grain combines will permit significant increases in capital and labor productivity. New electronic sensors will detect grain loss more accurately, allowing the operator to make adjustments quickly. Moreover, if enough of the internal monitoring and control of the grain separation process can be automated, and if grain losses are minimized, combine operators will be able to devote all of their attention to guiding the combine and can proceed at higher speeds. At present, the rate of travel must be held to 5 to 7 acres per hour so that the combine operator can monitor several functions of the combine.

Improvements in cleaning grain will result in a higher quality of grain and a reduction of dockage at the point of distribution or sale. New technologies will detect contaminants and remove them on the combine or as the grain is transferred into farm storage. Further improvements in grain cleaning will necessitate the use of automated aeration and screening processes.

Another way to increase the value of a crop is to do some of the processing in the field or on the farm. A good example of in-field processing is the extraction of leaf protein juice from alfalfa for use as high-value feed for pigs and poultry and as a food additive for humans. The residue of the process can be used as roughage for livestock.

Onfarm extraction of oil from oilseed crops such as soybeans and sunflowers has technical merit as a way for farms to produce a diesel fuel substitute or extender for tractors, combines, and other equipment. Onfarm production of vegetable oil fuel is more efficient than the conversion of grain to ethanol fuels. Moreover, the oilseed meal and glycerol byproducts from oilseed processing have substantial value as animal feed and chemical feedstocks. However, the principal technology employed uses highly volatile solvents and has a large requirement for capital, prohibiting its practical use on the farm, Moreover, present vegetable oil prices are approximately double the price of diesel fuel.

The adoption of onfarm processing of forages and oilseed is contingent on many domestic and international economic, political, and institutional factors that currently override technical considerations. On the other hand, most technologies to improve combine performance should be achieved by the end of the decade, at costs that will not significantly add to the total costs of today’s combines.

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