

Sustainable Agriculture

Traditional conservation-minded methods combined with modern technology can reduce farmers' dependence on possibly dangerous chemicals. The rewards are both environmental and financial

by John P. Reganold, Robert I. Papendick and James F. Parr

For nearly four decades after World War II, U.S. agriculture was the envy of the world, almost annually setting new records in crop production and labor efficiency. During this period U.S. farms became highly mechanized and specialized, as well as heavily dependent on fossil fuels, borrowed capital and chemical fertilizers and pesticides. Today the same farms are associated with declining soil productivity, deteriorating environmental quality, reduced profitability and threats to human and animal health.

A growing cross section of American society is questioning the environmental, economic and social impacts of conventional agriculture. Consequently, many individuals are seeking alternative practices that would make agriculture more sustainable.

Sustainable agriculture embraces several variants of nonconventional agriculture that are often called organic, alternative, regenerative, ecological or low-input. Just because a farm is organic or alternative does not mean that it is sustainable, however. For a

farm to be sustainable, it must produce adequate amounts of high-quality food, protect its resources and be both environmentally safe and profitable. Instead of depending on purchased materials such as fertilizers, a sustainable farm relies as much as possible on beneficial natural processes and renewable resources drawn from the farm itself.

Sustainable agriculture addresses many serious problems afflicting U.S. and world food production: high energy costs, groundwater contamination, soil erosion, loss of productivity, depletion of fossil resources, low farm incomes and risks to human health and wildlife habitats. It is not so much a specific farming strategy as it is a system-level approach to understanding the complex interactions within agricultural ecologies.

In 1980 the U.S. Department of Agriculture (USDA) estimated between 20,000 and 30,000 farmers—about 1 percent of the nation's total—were practicing nonconventional agriculture, most of which could now be termed sustainable. Today some experts estimate that the figure may have doubled or tripled. Farmers who practice soil conservation and reduce their dependence on fertilizers and

pesticides generally report that their production costs are lower than those of nearby conventional farms. Sometimes the yields from sustainable farms are somewhat lower than those from conventional farms, but they are frequently offset by lower production costs, which leads to equal or greater net returns.

To understand the rationale for sustainable agriculture, one must grasp the critical importance of soil. Soil is not just another instrument of crop production, like pesticides, fertilizers or tractors. Rather it is a complex, living, fragile medium that must be protected and nurtured to ensure its long-term productivity and stability.

Healthy soil is a hospitable world for growth. Air circulates through it freely, and it retains moisture long after a rain. A tablespoon of soil contains millions of grains of sand, silt

JOHN P. REGANOLD, ROBERT I. PAPPENDICK and JAMES F. PARR are soil scientists who have studied agricultural sustainability and organic farming for many years. Reganold teaches introductory soil science and conservation and management at Washington State University and has conducted several studies that compare the effects of conventional and organic farming methods on soil systems. Papendick is head of the land management and water conservation research unit with the USDA Agricultural Research Service in Pullman, Wash. He served as chairman and coordinator of the study *Report and Recommendations on Organic Farming*, published in 1980. Parr is a soil-fertility program leader with the USDA Agricultural Research Service in Beltsville, Md., and an authority on crop-residue management systems for soil and water conservation.

HEALTHY SOIL, essential to agriculture, is a complex, living medium. The loose but coherent structure of good soil holds moisture and invites airflow. Ants (a) and earthworms (b) mix the soil naturally. *Rhizobium* bacteria (c) living in the root nodules of legumes (such as soybeans) create fixed nitrogen, an essential plant nutrient. Other soil microorganisms, including fungi (d), actinomycetes (e) and bacteria (f), decompose organic matter, thereby releasing more nutrients. Microorganisms also produce substances that help soil particles adhere to one another. To remain healthy, soil must be fed organic materials such as various manures and crop residues.





and clay and has a vast expanse of internal surface area to which plant nutrients may cling. That same tablespoon of soil also contains billions of microorganisms, including bacteria, actinomycetes, fungi and algae, most of which are principal decomposers of organic matter. Decomposition results in the formation of humus and the release of many plant nutrients. The microbes also produce sticky substances called polysaccharides that glue soil particles together and help the soil to resist erosion.

Another essential activity that takes place in the soil is the fixation of nitrogen. Certain bacteria in the soil or in the roots of plants (most notably

legumes) convert atmospheric nitrogen gas into fixed forms of nitrogen that plants and other organisms use to make proteins. The amount of available nitrogen strongly influences soil productivity.

One of the earliest landmarks of the sustainability movement in the U.S. is *Farmers of Forty Centuries: Permanent Agriculture in China, Korea and Japan*, by Franklin King, published in 1911. It documents how farmers in parts of East Asia worked fields for 4,000 years without depleting the fertility of their soil. This text and others of the early 20th century focused on holistic aspects of

agriculture and the complex interactions within farming systems.

Yet around this same time, U.S. agriculture was in the early stages of industrialization. New technologies and scientific methods were developed to help farmers meet the growing demands of expanding urban populations. By substituting mechanical power for horses, for example, farmers could increase their grain acreage by from 20 to 30 percent, because they could plow more ground in less time and did not need to grow fodder.

Many groups and individuals continued to believe that biology and ecology rather than chemistry and technology should govern agriculture. Their efforts helped to give birth to the soil conservation movement of the 1930's, the ongoing organic farming movement and considerable related research. Nevertheless, by the 1950's technological advances had caused a shift in mainstream agriculture, creating a system that relied on agrichemicals, new varieties of crops and labor-saving, energy-intensive farm machinery. This system has come to be known as conventional farming.

As pesticides, inexpensive fertilizers and high-yielding varieties of crops were introduced, it became possible to grow a crop on the same field year after year—a practice called monocropping—without depleting nitrogen reserves in the soil or causing serious pest problems. Farmers began to concentrate their efforts on fewer crops. Government programs promoted monoculture by subsidizing only the production of wheat, corn and a few other major grains. Unfortunately, these practices set the stage for extensive soil erosion and for pollution of water by agrichemicals.

In the U.S. between 1950 and 1985, as a share of total production cost, the cost of interest, capital-related expenses and manufactured farm inputs (such as chemical fertilizers, pesticides and equipment) almost doubled from 22 to 42 percent, while labor and on-farm input expenses declined from 52 to 34 percent. During most of this period, relatively little research on sustainable agriculture was conducted because of lack of funding and public interest.

By the late 1970's, however, concerns were mounting that rapidly rising costs were endangering farmers nationwide. In response, Secretary of Agriculture Robert S. Bergland commissioned a study in 1979 to assess the extent of organic farming in the U.S., as well as the technology behind the farming and its economic and eco-



SOIL EROSION caused by water runoff has cut a deep gully in this field in eastern Washington State. Even a small amount of topsoil erosion can diminish agricultural productivity. Conventional farming methods often increase rates of erosion by depleting the organic matter that helps to preserve soil structure. Sustainable agriculture inhibits erosion by promoting the addition of organic matter to the soil and the growth of cover crops, which prevent soil from blowing or washing away.



GREEN MANURE CROPS, which are plowed under or surface-mulched instead of being harvested for sale, enrich the soil and improve future crop productivity. Legumes, such as sweet

clover (shown being mulched), are very good green manures because they contribute biologically fixed nitrogen to the soil, thus reducing the need for any synthetic nitrogen fertilizers.

logical impact. The study, *Report and Recommendations on Organic Farming*, published in 1980, was based heavily on case studies of 69 organic farms in 23 states.

The USDA report concluded that organic farming is energy-efficient, environmentally sound, productive and stable and tends toward long-term sustainability. Since the report was published, it has stimulated interest, nationally and internationally, in sustainable agriculture. Its recommendations provided the basis for the alternative-agriculture initiative passed by Congress in the Food Security Act of 1985, which calls for research and education on sustainable farming systems.

The sustainable agriculture movement received a further boost last September when the Board on Agriculture of the National Research Council released another study, *Alternative Agriculture*. Although controversial, the report is perhaps the most important confirmation of the success of farms that rely on biological resources and their beneficial interactions instead of chemicals. It found that well-managed farms growing diverse crops with little or no chemicals are as productive and often more profitable than conventional farms. It also asserted that "wider adoption of proven alternative systems would result in even greater

economic benefits to farmers and environmental gains for the nation."

Sustainable agriculture does not represent a return to pre-industrial revolution methods; rather it combines traditional conservation-minded farming techniques with modern technologies. Sustainable systems use modern equipment, certified seed, soil and water conservation practices and the latest innovations in feeding and handling livestock. Emphasis is placed on rotating crops, building up soil, diversifying crops and livestock and controlling pests naturally.

Whenever possible, external resources—such as commercially purchased chemicals and fuels—are replaced by resources found on or near the farm. These internal resources include solar or wind energy, biological pest controls and biologically fixed nitrogen and other nutrients released from organic matter or from soil reserves. In some cases external resources may be essential for reaching sustainability. As a result, such farming systems can differ considerably from one another because each tailors its practices to meet specific environmental and economic needs.

A central component of almost all sustainable farming systems is the rotation of crops—a planned succession of various crops growing on one field.

When crops are rotated, the yields are usually from 10 to 15 percent higher than when they grow in monoculture. In most cases monocultures can be perpetuated only by adding large amounts of fertilizer and pesticide. Rotating crops provides better weed and insect control, less disease build-up, more efficient nutrient cycling and other benefits.

A typical seven-season rotation might involve three seasons of planting alfalfa and plowing it back into the soil, followed by four seasons of harvested crops: one of wheat, then one of soybeans, then another of wheat and finally one of oats. The cycle would then start over. The first season of wheat growth would remove some of the nitrogen produced by the alfalfa; the soil's nitrogen reserves would be depleted much less by the soybeans, which are legumes. Oats are grown at the end of the cycle because they have smaller nutrient requirements than wheat.

Regularly adding crop residues, manures and other organic materials to the soil is another central feature of sustainable farming. Organic matter improves soil structure, increases its water-storage capacity, enhances fertility and promotes the tilth, or physical condition, of the soil. The better the tilth, the more easily the soil can be tilled and the easier it is for seed-

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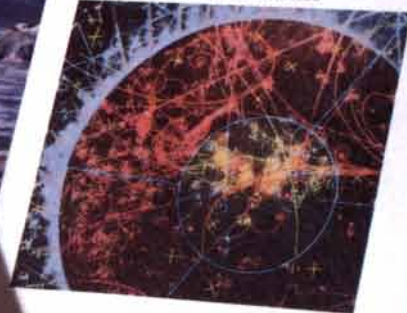
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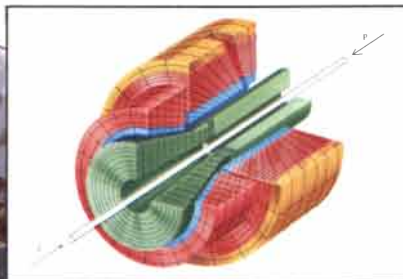
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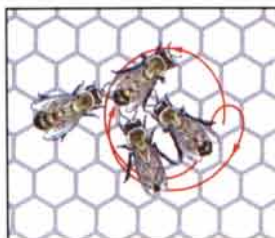
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LADYBUG BEETLES are natural predators of pea aphids (above) and other insect pests. Integrated pest management (IPM) programs now in use on many farms take advantage of natural predator-prey relationships or other biological-control mechanisms to reduce the need for chemical pesticides. Farmers who practice biological control encourage the proliferation of beneficial microbes and insects, such as ladybugs. They also make their fields generally inhospitable to herbivorous pests.

lings to emerge and for roots to extend downward. Water readily infiltrates soils with good tilth, thereby minimizing surface runoff and soil erosion. Organic materials also feed earthworms and soil microbes.

The main sources of plant nutrients in sustainable farming systems are animal and green manures. A green manure crop is a grass or legume that is plowed into the soil or surface-mulched at the end of a growing season to enhance soil productivity and tilth. Green manures help to control weeds, insect pests and soil erosion, while also providing forage for livestock and cover for wildlife.

By raising a diverse assortment of crops and livestock, a farm can buffer itself against economic and biological risks. Diversity results from mixing species and varieties of crops and from systematically integrating crops, trees and livestock. When most of North Dakota experienced a severe drought during the 1988 growing season, for example, many monocropping wheat farmers had no grain to harvest. Farmers with more diversified systems, however, had sales of their livestock to fall back on or were able to harvest their late-seeded crops or drought-tolerant varieties. A biologically diverse farming system is also less susceptible to the economic woes of a flooded market or a fall in prices for a single crop.

Controlling insects, diseases and weeds without chemicals is also a goal of sustainable strategies, and the evidence for its feasibility is encouraging. One broad approach to limiting use of pesticides is commonly called integrated pest management (IPM), which

may involve disease-resistant crop varieties and biological controls (such as natural predators or parasites that keep pest populations below injurious levels). Farmers can also select tillage methods, planting times, crop rotations and plant-residue management practices to optimize the environment for beneficial insects that control pest species or to deprive pests of a habitat. If pesticides are used as a last resort, they are applied when pests are most vulnerable or when any beneficial species and natural predators are least likely to be harmed.

In practice, IPM programs are a mixed bag. They have dramatically reduced use of pesticides on crops such as cotton, sorghum and peanuts. More than 30 million acres (about 8 percent of U.S. farmland) is currently being managed with IPM programs, resulting in annual net benefits of more than \$500 million. On the other hand, IPM programs have also been reduced to "pesticide management" for many crops like corn and soybeans, for which pesticide usage has actually increased significantly.

Biological-control techniques are some of the best ways to control pests without pesticides. They have been used for more than 100 years and have been commercially successful in controlling pests, especially insects, in more than 250 projects around the world. Yet USDA funds for studying them have declined.

Can sustainable farming practices make good on their promise to be ecologically stable, productive and profitable? To compare the effects of sustainable and conven-

tional farming systems on soil productivity, one of us (Reganold), working with Lloyd F. Elliott and Yvonne L. Unger of Washington State University, conducted a study of the soil on two commercial wheat farms. One was an 800-acre sustainable farm that had been managed without synthetic fertilizers and with only limited amounts of pesticides since it was first plowed in 1909. The other was an adjacent 1,300-acre conventional farm, which had first been cultivated in 1908 but had been treated with fertilizers since 1948 and with pesticides since the early 1950's. The sustainable farm used a complex crop rotation system and practiced conservation-oriented methods of tillage, whereas the conventional farm followed a simple two-year rotation. The sustainable farm also grew legumes as a cover crop and green manure.

Because of the differences in farming methods, the soil on the sustainable farm contained significantly more organic matter, nitrogen and biologically available potassium than that on the conventional farm. It had a better capacity for storing nutrients, a higher water content, a larger microorganism population and a greater polysaccharide content. The soil also had better structure and tilth and 16 more centimeters of crop-nourishing topsoil. This topsoil difference was attributed to significantly more soil erosion on the conventional farm.

Average yields of winter wheat per acre between 1982 and 1986 were 8 percent lower on the sustainable farm than on the conventional farm. Nevertheless, the sustainable farm matched the wheat production average for the region—in fact, it yielded almost 13 percent more wheat than another nearby conventional farm with similar soils. Its ability to do so, even after almost 80 years of farming without fertilizer, may result in part from reduced soil erosion and maintenance of soil productivity.

Although conserving soil productivity is important to farmers, most of them usually select an agricultural system on the basis of its short-term profitability. Until recently conventional systems have usually appeared to be more profitable in the short term than sustainable ones. This assessment comes as no surprise, because research and USDA policy over the past four decades have promoted conventional agriculture.

Yet the long-term profitability of conventional agriculture seems questionable if the environmental and health costs currently borne by soci-

ety are taken into account. If these indirect costs were factored into the costs of conventional farm production, then sustainable systems would likely prove to be more profitable and more beneficial to society.

One of the best-known studies of the economics of sustainable agriculture was conducted by William Lockeretz, Georgia Shearer and Daniel H. Kohl of Washington University. They compared energy efficiency and crop production costs between numerous pairs of organic and conventional farms in the Midwest. Between 1974 and 1978 the energy consumed to produce a dollar's worth of crop on the organic farms was only about 40 percent as great as on the conventional farms. Although the organic farms had lower crop yields than the conventional farms, their operating costs were lower by about the same cash equivalent. As a result, the net incomes from crop production on the two types of farms were about equal every year except one.

Despite these encouraging results, some farmers who have shifted from conventional to sustainable practices have experienced short-term difficulties. Some of the problems arose because the farmers abruptly stopped applying pesticide and fertilizer to all their fields. Such radical changes can sometimes decrease yields because of severe weed problems, explosive increases in insect pests and diminished soil fertility that lasts a few years.

Researchers at the Rodale Research Center in Kutztown, Pa., have investigated the transition from conventional to sustainable farming and verified that such changes are best implemented with caution. Even a gradual change may involve small decreases in crop yields while the soil establishes a new set of chemical and biological equilibria. Farmers should change only one field at a time to avoid placing whole farms at risk. The transition is also smoother if they regularly add organic matter to the soil in the form of animal or green manures.

What are the forces that inhibit farmers from adopting sustainable methods? One obstacle is the federal farm programs, which generally support prices for only a handful of crops. Corn and other feed grains, wheat, cotton and soybeans receive roughly three fourths of all U.S. crop subsidies and account for approximately two thirds of cropland use. The lack of price supports for other crops effectively discourages farmers from diversifying and rotat-

ing their crops and from planting green manures. Instead it gives them powerful incentive to practice monoculture to achieve maximum yields and profits.

The long-term economic benefits of sustainable agriculture may not be evident to a farmer faced with having to meet payments on annual production loans. Many conventional farmers are greatly in debt, partly because of heavy investments in specialized machinery and other equipment, and their debt constrains the shift to more sustainable methods. To date, society has neither rewarded farmers financially nor given them other incentives for choosing sustainable methods that would benefit the public.

Then, too, there is little information available to farmers on sustainable practices. Government-sponsored research has inadequately explored alternative farming and focused instead on agrichemically based production methods. Agribusinesses also greatly influence research by providing grants to universities to develop chemical-intensive technologies for perpetuating grain monocultures.

Legislative support for change in the U.S. agricultural system is growing, but financial support for sustainable agricultural projects is still only a small part of the total outlay for agriculture. Congress appropriated \$3.9 million in fiscal year 1988 and \$4.45 million in fiscal 1989 to implement

the research and education programs on sustainable farming called for in the Agricultural Productivity Act, one part of the Food Security Act of 1985. Funding in fiscal 1990 has been the same as in the previous year—\$4.45 million—which is only .5 percent of the total USDA research and education budget.

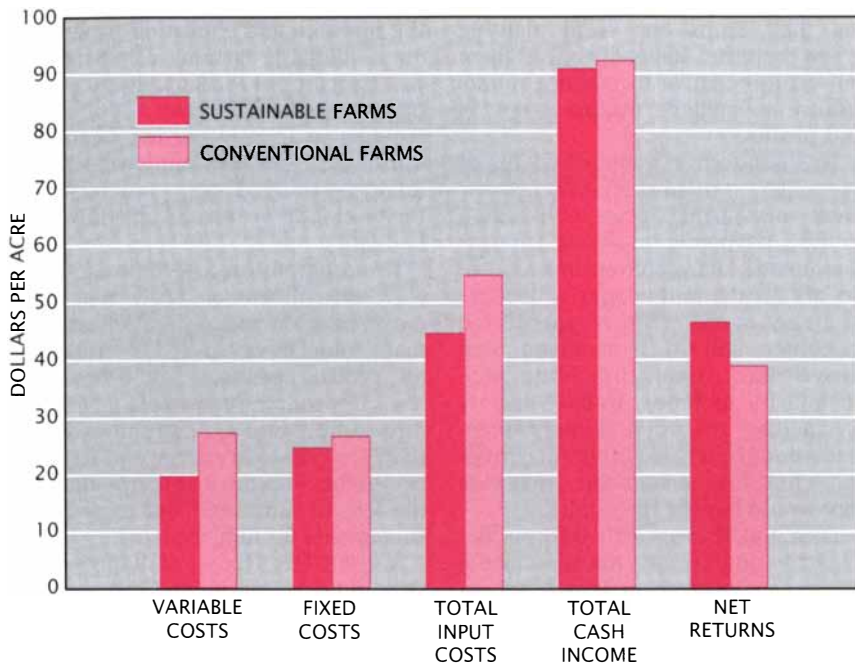
The program for low-input sustainable agriculture, or LISA, that has emerged from this federal effort has many objectives: to reduce reliance on fertilizer, pesticide and other purchased resources to farms; to increase farm profits and agricultural productivity; to conserve energy and natural resources; to reduce soil erosion and the loss of nutrients; and to develop sustainable farming systems.

A 1988 U.S. House of Representatives report, *Low Input Farming Systems: Benefits and Barriers*, recommended that Congress restructure or remove some provisions in farm-support programs, particularly those that encourage greater use of agrichemicals and that impede the adoption of low-input methods. Last year three congressional bills were introduced—two in the Senate and one in the House of Representatives—that would allow farmers to rotate crops and use other alternative methods without losing farm-support funds. All these bills are pending.

Shifting mainstream agriculture toward more sustainable methods will



COMBINATIONS OF CROPS, or of crops and livestock, make farms more sustainable by maintaining soil productivity and by reducing a farm's reliance on a single crop. On the farm shown above, the parallel strips of land have been planted on the contour of the terrain with oats (yellow) or corn or alfalfa (both green). Within each strip, crops rotate on a four-year cycle: corn (a one-year crop) is replaced by oats (another one-year crop), which is then replaced by alfalfa (a two-year crop). Such rotations improve the control of weeds, insects and diseases; they also improve the efficiency of nutrient cycling. Contour strip-cropping greatly reduces soil erosion.



PROFITS from sustainable farms can exceed those of conventional farms, according to Steven L. Kraten, formerly of Washington State University. The cash incomes per acre for the two types of farms were comparable over two years, but because the input costs of sustainable agriculture are lower, its net returns are 22.4 percent higher. Variable costs include those for fuel, machinery maintenance, seed, fertilizer, pesticide and labor. Among the fixed costs are property taxes and interest on loans.

require more than new laws and regulations; it will also require more research and public education. Universities and the USDA are slowly putting more emphasis on sustainable agricultural research. A high research priority is the development of specific cropping systems that produce and consume nitrogen more efficiently. It is essential to learn how much nitrogen is fixed by legumes under various conditions, as well as the optimum means for integrating legumes into crop rotations.

The U.S. should also step up its research efforts on other topics. More must be learned about alternatives to fertilizers and the cycling of nutrients through the agricultural ecosystem. Effective strategies must be developed for controlling pests, weeds and diseases biologically. The strategies may rely on beneficial insects and microorganisms, allelopathic crop combinations (which discourage weed growth), diverse crop mixtures and rotations and genetically resistant crops. More research should also be done on the relative benefits of various cover crops and tillage practices and on integrating livestock into the cropping system.

U.S. farmers now use only a fraction of the thousands of crop spe-

cies in existence. They may benefit by increasing cultivation of alternative crops such as triticale, amaranth, ginseng and lupine, which are grown in other countries. Yet in addition to diversification, germ plasm (seeds, root stocks and pollen) from traditional crops and their wild relatives must be collected and preserved continually.

Well-managed collections of germ plasm will give plant breeders a broader genetic base for producing new crops with greater resistance to pests, diseases and drought. Today much of the germ plasm that U.S. plant breeders use to improve crops comes from developing countries.

New breeds of crops being developed by biotechnology, such as grains that fix their own nitrogen, may eventually be included in sustainable cropping systems. But neither biotechnology nor any other single technology can fix all the problems addressed by a balanced ecological approach. The success of sustainable agriculture does not hinge on creating supercrops: the system works with crops that are available now.

Better education is as important as further research. Farmers need to know clearly what sustainable agriculture means, and they must see proof of its profitability. The USDA and the Cooperative Extension Service should

provide farmers with information that is up-to-date, accurate, practical and applicable to local farming conditions. Farmers and the public also need to be better educated about the potentially adverse environmental and health consequences of the pollution created by certain agrichemical practices.

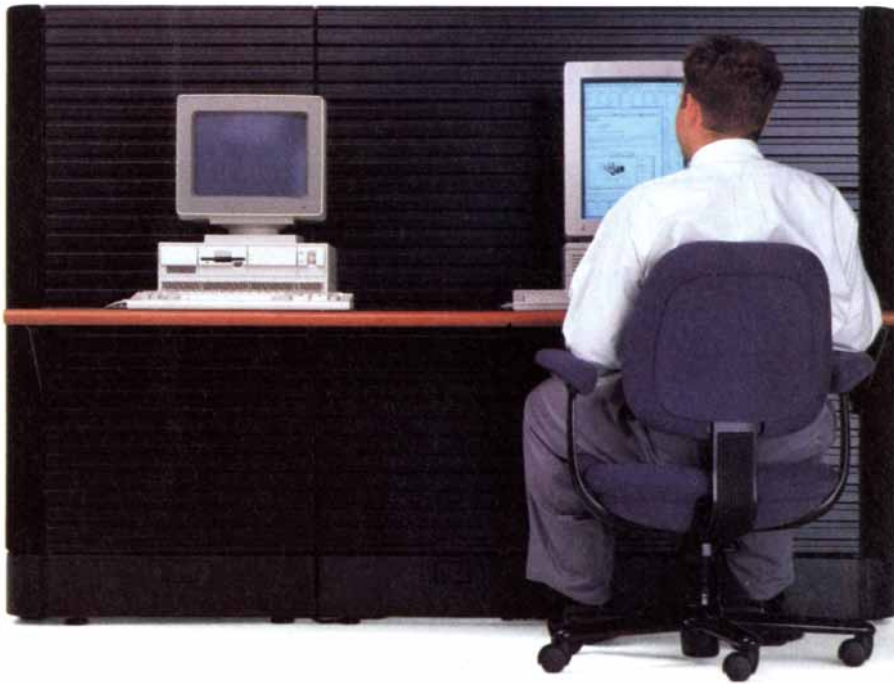
One of the most effective methods for communicating practical information about sustainable agriculture is through farmer-to-farmer networks, such as the Practical Farmers of Iowa. Farmers in this association have agreed to research and demonstrate sustainable techniques on their lands. They meet regularly to share information and compare results. Because such networks have aroused growing interest and proved effective, the land-grant community should try to promote their development.

Some scientists and environmentalists have recommended levying taxes on fertilizers and pesticides to offset the environmental costs of agrichemical use, to fund sustainable agricultural research and to encourage farmers to reduce excessive use of agrichemicals. This approach is precisely how funding for the Leopold Center for Sustainable Agriculture was established by the Iowa State Legislature in 1987 as part of the Iowa Groundwater Protection Act.

Agriculture is a fundamental component of the natural resources on which rests not only the quality of human life but also its very existence. If efforts to create a sustainable agriculture are successful, farmers will profit and society in general will benefit in many ways. More important, the U.S. will protect its natural resources and move closer toward attaining a sustainable society.

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